Influence of Grab Bar Orientation on Balance Recovery Following a Perturbation During Bathtub Exits

by

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A thesis submitted in conformity with the requirements for the degree of Master of Science in Rehabilitation Science

Rehabilitation Sciences Institute
University of Toronto

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Abstract

Grab bars are recommended to assist bathing transfers; however, little evidence on their effectiveness for fall prevention exists. The objective was to explore how grab bar orientation impacts balance recovery during transfers (exit). A low horizontal grab bar, high horizontal grab bar, and vertical grab bar were evaluated. Ten younger adults reached to grasp the grab bar following perturbations (YA RTG) and the remaining younger and older adults used it proactively (YA HIP, OA HIP). Findings showed significantly high downward and resultant loads were applied on the low horizontal grab bar. There were no significant differences in loading between the high horizontal and vertical grab bar, other than in downward forces. Grasping condition, but not age, impacted loading and balance control. The YA HIP group applied significantly higher forces and displayed greater balance control than the YA RTG group. Findings can inform clinical recommendations and standard developments on grab bars.
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Chapter 1
Introduction

Falls are one of the leading causes for fatal injuries, representing a global concern [1]. Older adults over the age of 65 years’ experience the highest number of fatal falls, and there has been a rise in the number of deaths and age-standardized mortality rate over recent years [1, 2]. The number of deaths increases as individual’s age, with persons over the age of 90 experiencing the largest number of fatal injuries [2]. Injuries due to falls are also commonly seen in older adults, with rates of injuries increasing as individuals’ age. A survey analysis on the Canadian Community Health Survey found that, among adults over 65 years of age, the rate of fall-related injuries increased from 49.4 to 58.8 per 1000 population from 2005 to 2013 [3]. This results in a high rate of hospitalization, loss of independence, and reduced quality of life [4].

Many falls occur in the home environment. One of the most commonly identified hazardous areas within the home is the bathroom [5]. Bathing disability increases with age and often results in disability in other activities of daily living (ADLs), higher rates of nursing home admission, and requiring home care services [6, 7, 8]. To address this risky environment, grab bars are often recommended by clinicians. However, these recommendations are not always applied. By allowing users to grasp a supporting aid to facilitate balance control, the presence of grab bar can assist with safety and independence [9]. Although there are standards and codes guiding grab bar installation, there is little empirical evidence towards these recommendations and guidelines. Instead, guidelines are generally based on individual’s perception of comfort, safety, and ease of use, and clinical experience, rather than effectiveness of the grab bar for fall prevention [10, 11]. Specific to this current work, it is unknown how the orientation of the grab bars impact users’ safety and fall recovery effectiveness during bathing transfers [6]. During a bathtub transfer, vertical grab bars are most commonly recommended as per building standards, although it has been suggested that a
horizontal orientation may also support the transfer [12]. More empirical evidence is needed to understand the impact of grab bar orientation on safe bathtub transfers and responses to balance loss.
Chapter 2  
Research Aims & Objectives

The primary goal of this project is to explore how grab bar orientation influences balance recovery reactions following an unpredictable perturbation when exiting a slippery bathtub. To address this question, several specific objectives were investigated.

Study objective 1: To determine the effect of grab bar orientation on measures of balance control and applied grab bar forces during balance loss. Previous research has shown that orientation and placement of handles impacts loading, where participants applied higher forces on horizontal handles [13], but applied less forces on handles located at shoulder level compared to handles located at low heights (e.g. hip level) [14]. Previous research on grab bar use during bathtub transfers has also shown improvements in COP variability while using a vertical grab bar, indicating improvements in balance control [6].

Hypothesis: The grab bar orientation will result in differences in balance control measures. The low horizontal grab bar will result in greater demands on balance control and the largest applied forces to counter the large centre of mass (COM) movement following a balance loss.

Conversely, the high horizontal and vertical grab bars will both provide a mechanical advantage as the user is able to grasp at a higher location, resulting improved balance and lower applied forces in response to a balance loss. There will also be a greater preference for the vertical and high horizontal grab bars since both will provide greater stability for individuals when a balance loss is experienced.
Study objective 2: To determine the effect of age on balance control and applied grab bar forces during balance loss and grab bar use. Older adults have demonstrated poorer balance control compared to younger adults, especially in situations where time to recover is important [9, 15]. Previous findings have also shown a greater dependence on arm reactions with age [9], highlighting the importance of handholds for older adults to recover from a balance loss.

Hypothesis: Older adults will require greater effort to maintain their balance after a perturbation is delivered, thus relying to a greater degree on the grab bar. This will result in higher applied forces when compared to young adults, Older adults will also demonstrate greater challenges to balance, showing larger COM displacement and velocity in response to the balance loss.

The secondary goal of this project is to examine how initial grasping condition impacts balance recovery during a bathtub transfer. Two grasp conditions were experimented in the study: (1) hand-in-place and (2) reach-to-grasp. Although both grasping strategies are commonly used, there is little information regarding how these grasping condition impact balance recovery during a bathtub transfer.

Study objective 3: To examine how initial grasping condition impacts balance control during a bathtub transfer. Hand position impacts the ability to recover. A reactive approach (reach-to-grasp) has been found to be challenging, as it requires appropriate timing and coordination of the limbs. Proactive approach (hand-in-place) can result in improved balance control, as tactile feedback from the surrounding environment can provide cues to make appropriate adjustments in the event of a balance loss [16].
Hypothesis: A greater balance loss will be experienced for participants using a reach-to-grasp response. This will be demonstrated by larger COM displacement and velocity for the reach-to-grasp group (YA RTG) when compared to participants using the grab bar proactively (YA HIP). The reach-to-grasp response will also result in higher forces applied on the grab bar as the participants have less control following the balance loss.
Chapter 3  
Literature Review  

3.1 Epidemiology of falls in bathrooms

A fall is defined as an event where an individual inadvertently comes to rest at a lower level from their initial position [17]. Falls can result in a fatal or non-fatal injury [17]. Although falls occur across all age groups, older adults over the age of 65 suffer the greatest number of fatal falls [1]. The estimated number of falls will increase to 3.3 million in 2036, as the number of aging individuals in Canada is expected to increase [18]. For older adults, falls are the leading cause of injury-related hospitalization [19]. The majority of fall-related injuries result in broken or fractured bones, with hip fractures being a common fall-related injury [18]. Previous analysis on fall-related hospitalizations found up to 95% of hip fractures in Canada were due to a fall [18], with approximately 20% of hip fractures leading to death [20]. There are several psychological and physiological impacts of falls for older adults, such as loss of autonomy, immobilization, and depression [17]. These changes can further impact quality of life and health.

It has been reported that a large number of falls occur within the home, especially in the bathroom [5]. Previous research found that falls within the bathroom were more likely to result in an injury compared to falls that occur in other areas of the home; specifically, older adults with high risk for falls were 2.4 times more likely to experience a fall that can result in an injury within the bathroom compared to injuries in the living room [21]. More than 50% of bathroom falls amongst older adults were related to unsuccessful transfers [11] with difficulty in bathing transfers leading to individuals restricting their bathing activities [11]. Of the high-risk tasks
involved in bathing, the Centre for Disease Control and Prevention reported 9.8% of nonfatal bathroom injuries occurred when getting out of the tub or shower, whereas only 2.2% of nonfatal bathroom injuries occurred when getting into the shower or bathtub [22], highlighting bathtub exit as particularly risky.

There are many factors contributing to the high rates of bathtub injuries, including, but not limited to, the lack of environmental modifications to support safer bathtub transfers (e.g. absence of grab bars). A fear of falling can also lead to anxiety regarding balance ability, making bathing activities difficult. One study showed the fear of falling to be highly prevalent in community-dwelling seniors [23]. Implementing aids such as grab bars can increase one’s independence within their homes, support balance confidence, and assist with bathing activities.

3.2 Grab bars as an assistive technology

Bathing transfers can be risky for older adults as they are required to step over a high obstacle (bathtub rim or apron) and maintain balance when stepping onto and out of a usually wet surface [6]. To combat this high risk, therapists often recommend grab bars to assist with bathing transfers, especially for those who are at risk for falls [6]. However, similar to other bathing aids, grab bars are not used in everyday bathing practice [24]. Reasons for this include: perception that grab bars are not helpful to use or not needed, grab bars are unsafe to use (i.e. are slippery or installed at inappropriate heights), or grab bars are awkward to use during the transfer [11]. Findings show that the ease or comfort of grab bar use is a significant predictor for use [25]. If users find them to be awkward or discomforting to use, they may not engage them during their bathing activities. In cases where grab bars are not present or used, individuals may use
other potentially hazardous surfaces, such as the soap dish or wall to facilitate their transfer [11]. Such compensatory behaviour may place the individual at risk for slips and falls during bathing activities, as these other structures are not meant to aid in transfers or assist with balance recovery. Conversely, having a grab bar at the entry and exit way can facilitate the transfer in to and out of the bathtub, support balance control and prevent injuries [6, 26]. To this end, grab bars have been identified as a high-need device to enable safe and independent bathing among seniors. The lack of grab bars in bathrooms can potentially be an environmental hazard, especially related to transfers and balance [27].

A grab bar can serve multiple roles in the prevention of falls. The grab bar use has the potential to assist with many age-related deficits during bathing, including impaired balance control, reduced strength and coordination [28]. The use of a grab bar allows the individual to hold on to an external support if balance was lost or if a fall was to occur. Previous findings show that older adults used grab bars more frequently to recover from a balance loss compared to younger adults (~50% versus ~14%) [10]. Although there are studies and resources directed towards grab bar use and installation [10, 25], there is little information to describe effective placement of these grab bars and limited studies that examined grab bar use during realistic bathing transfers, such as inclusion of a wet bathtub surface. More evidence is required to guide recommendations for standards on grab bar installation and design to ensure safety and effective use.
3.3 Grab bar installation: preference, codes and standards

Various standards and codes have provided recommendations on where grab bars should be installed around the bathtub. Select standards and codes are listed in Table 1. One study has directly compared different grab bar placement according to standards and codes, reporting that community-dwelling older adults favoured a vertical grab bar on the side wall as an ideal grab bar configuration to assist with transferring into and out of the bathtub [25]. This configuration is recommended by the Ontario Building Code (OBC) and Canadian Standards Associations (CSA). When there were no grab bars installed at the side faucet wall, older adults consistently rated the transfer low on ease of use, overall helpfulness, safety, and preference [25].

Although horizontal grab bars are not commonly found at the sidewall, the 2015 Architectural Barriers Acts (ABA) Standards and 1989 US Uniform Federal Accessibility Standards (UFAS) recommends a horizontal grab bar be mounted adjacent to the outer edges of the tub, including on the faucet end [29, 30]. Compared to no grab bars at the side wall, previous research found that the UFAS configuration showed significantly improved ratings on helpfulness during bathtub transfer and safety, and higher ratings for ease of use [25]. However, the horizontal grab bar was most preferred on the back wall to assist with sit to stand transfers, while a vertical grab bar was useful at the head or faucet end to assist with bathtub entry and exit [25]. Furthermore, although a horizontal grab bar may be helpful during bathtub entry, Sveistrup and colleagues suggest that a horizontal grab bar would not be helpful when exiting unless it extended past the bathtub rim into the outside area of the bathtub [25]. In contrast, a recent study presented individuals with multiple and simultaneous vertical and horizontal grab bars at various
heights on the side and back wall to assist with bathtub entry and exit. Results showed that younger adults rarely self-selected to grasp the available vertical grab bars (only 7.04% of the time) compared to the horizontal grab bar (92.9% of the time). It has been suggested that one’s hand can slide down on a vertical grab bar [12], which might be a hazard in a balance recovery scenario. Based on these findings, Batista and colleagues have recommended that a horizontal grab bar be placed 102 cm high and outside of the bathtub, which will allow for the variability of grasping locations demonstrated by the study results [12]. The ADA Standards for Accessible Design propose similar installation configurations with some modifications - a lower grab bar height is recommended by ADA, which also does not extend past the bathtub rim (height of 84-91.5 cm (33-36”)). The lower height in the ADA standards likely accounts for accessibility factors, such as allowing for wheelchair users to grasp effectively [12, 31].

| Table 1: Summary of select standards and codes for grab bar installations around bathtubs |
|-----------------------------------------------|-------------------------------------------------|
| **Standard / Code**                          | **Requirements**                                |
| Canadian Standards Association 2018 (CSA B651 bathtubs) [32] | Two grab bars – horizontal on back wall and a vertical on the end of the bathtub. Bars should be at least 1200 mm long and 180-280 above the rim. The vertical grab bar should be installed between 80-1200 mm from the floor area. |
| Ontario Building Code 2015 (Section 3.8.3.13. Showers & Bathtubs) [33] | L-shaped (90 degree) grab bar mounted on the back wall being 900 mm long. Horizontal part is 150-200 mm above and parallel to the bathtub rim and the vertical is 300-450 mm long. A vertical grab bar (760 mm long) mounted at each end of the bathtub, 200 mm above the bathtub rim and 150 mm from the edge of the bathtub. |
| ADA Standards for Accessible Designs 2010 [34] | Two grab bars installed on back wall, one 8-10 inches above the bathtub rim, and another one 33-36 inches from the ground. A 24-inch grab bar would be installed on the control wall end at the front edge of the bathtub. In bathtubs with no permanent tub-seat, a 12-inch grab bar should be installed on the head end wall at the front edge of the bathtub. |
| US Uniform Federal Accessibility Standards (UFAS) 1989 / 2015 Architectural Barriers Acts (ABA) Standards (2015) [29, 30] | Two 61 cm grab bars mounted adjacent to the outer edges of the head and control wall, 33 – 36 inches from the ground, or 48 cm above the bathtub rim. Two additional grab bars (82 cm long) are located 23 cm and 48 cm above the bathtub rim. |
3.4 Physical demands of a bathtub transfer task

3.4.1 Obstacle crossing during bathtub exit

The ability to safely cross an obstacle is an important factor for independence and safe mobility. Crossing a high obstacle, such as the bathtub rim, makes the bathing transfer a risky task for older adults. This is because the task is paired with age-related physiological changes, such as reduced muscle strength in lower extremity muscles, which can affect older adults’ ability to maintain balance [28, 35]. Previous research has found that older adults adapt their gait patterns to accommodate upcoming obstacle crossing tasks compared to young adults, including having shorter crossing step length, slower crossing velocities, and longer toe distance from the obstacle to avoid contact with the obstacle [36, 37]. It has also been suggested that older adults may use a greater percentage of their neuromuscular capacity and strength to safely cross obstacles, as demonstrated by greater muscle activity in their lower extremity muscles compared to younger adults [38]. Similarly, a greater muscle demand with an increase in obstacle height was reported [38]. Given that a bathtub rim can generally present as a high obstacle, it follows that successfully transferring in and out of the bathtub can place a large strain on the neuromuscular system.

3.4.2 Challenges with wet surfaces

Not surprisingly, because of the reduced surface friction associated with the bathroom environment, a systematic review on bathroom design for older adults found that bath mats are a commonly recommended tool to reduce the risk of slip-related falls in bathtubs [39]. An important factor when stepping onto a slippery area is the friction between the foot and the wet
surface. When stepping on a slippery surface, individuals often modify gait to adopt a cautious strategy [40, 41]. This includes reducing the stride length, having a flatter foot angle, and reducing utilized friction when the foot comes in contact with the floor surface [41]. To date, only one study has investigated the amount of friction used during bathtub transfers [41]. Friction was lower in wet conditions compared to dry surfaces during both entry and exiting strategies; however, significant differences between older and younger adults were only observed during bathtub exit [41]. Authors suggest this may be attributed to the idea that both age groups perceive bathtub entry to be more dangerous than exiting, resulting in modifications for both age groups to alter the used friction [41]. In contrast, when exiting the bathtub, older adults may find the task of crossing over the bathtub rim still to be challenging, despite the outside surface potentially (although not always) providing greater friction [41]. Therefore, the friction was still lower for older adults as they exited the bathtub. Nonetheless, there is a chance for a slip to occur when individuals step in and out of a wet bathtub in the absence of bath mats and other aids.

Previous research found that bathmats can also assist with balance control when entering and exiting the bathtub [6]. King and Novak found that the use of bathmats showed improvements in postural control in the medial-lateral direction during bathtub transfers [6]. However, although they showed improvements in balance control, it may not be enough to maintain balance control in the direction of transfer. Findings showed that the presence of a bathmat did not provide significant assistance when transferring in and out of the bathtub in the progression direction, as the challenges with crossing over a high bathtub rim presented a potentially greater threat to balance control than slipping [6]. The presence of grab bars, along with bathmats, may provide additional support in balance control for all directions during transfers.
3.5 Balance control during bathing transfers

Balance control during a movement task is important to prevent falls. Investigating COM and centre of pressure (COP) are common means by which to examine balance control during many functional tasks. For example, crossing over a high obstacle results in large medial-lateral COP displacement, which creates a momentum towards the stance leg [42]. Young adults have demonstrated greater anterior-posterior and medial-lateral COP displacement compared to their older counterparts (up to 138% higher than older adults) when crossing an obstacle [42]. Large COM movement in the sagittal [43] and frontal planes also occurs [44]. The lower limb joints must be coordinated to avoid unwanted obstacle contact with the swing leg; therefore, it must have a large vertical and medial-lateral trajectory to overcome the high obstacle, which alters the COM trajectory [44]. In response to this swing leg, lack of control of COM in the frontal plane, paired with a smaller base of support during single limb stance may challenge lateral stability, resulting in sideway falls [44]. Although no study to date has investigated COM movement during a bathing transfer, the greater COM movement reported in the obstacle crossing literature highlights the potential challenges of bathtub transfers since obstacle crossing is inherent to the task itself [44, 45]. There has been one study to date that explored balance control during a bathing task, measured by COP displacement and velocity. Similar to the findings in the obstacle crossing literature, the authors found that older adults reduced their COP displacement compared to young adults to accommodate the challenges of bathing transfers [6]. However, older adults also demonstrated greater COP variability during the transfer, indicating poor balance control [6]. To assist with balance control, the use of a vertical grab bar resulted in balance improvements as noted by a decrease in COP variability [6]. The use of a horizontal grab bar
installed at the back wall of the bathtub also supported an improvement in balance control compared to no grab bar, although this particular configuration resulted in older adults demonstrating increased COP variability compared to young adults [6]. These findings suggest this to be a risky position for a grab bar to support bathing transfers.

### 3.6 Balance recovery strategies for fall prevention

There are different strategies that can be taken to maintain balance. Keeping the COM over the base of support will maintain balance when a perturbation occurs. This can be done by generating muscle torque at the ankles, hips and other joints [9]. However, in many scenarios, individuals are required to, or choose to, change their base of support [9]. This includes making a step or reaching for a support object, such as a grab bar. On wet surfaces where effective stepping reactions may be challenging, grasping responses on a support object may be even more important to support balance recovery reactions.

Proactive handhold use, or using a handhold prior to a balance loss, is a common strategy used to prevent a fall. Tactile feedback afforded by proactive use provides information to the central nervous system regarding where the body is relative to one’s surrounding environment, and what adjustments are required in the event of a balance loss [46]. Previous findings show that proactively using a handhold had improvements in balance control as younger adults were able to sustain higher perturbation magnitudes [47]. However, this may be more challenging for older adults, particularly if a reach-to-grasp response is required. In response to perturbations, it has been previously shown that older adults have a slower neural processing time, with a delay in switching their attention from one motor task to another [9, 48], which may result in a slower
reaction to a balance loss. Older adults are also more likely to take additional steps to regain balance following an unpredicted perturbation [49], may require greater neuromuscular effort than younger adults to generate effective and required lower limb muscle torque [15], and generate the required peak torque at a later period of time [15]. Together, these changes with age can hinder one’s ability to recover effectively in situations where time to recover is important [15]. Importantly, previous work on a moving platform by Maki and colleagues found that older adults reached for a handrail more frequently than younger adults to recover from a balance loss [9, 49], although these arm responses are slower and not as powerful [50]. Since older adults are reliant on arm reactions, it follows that the presence of a grab bar is especially important to support balance recovery following an unexpected slip in a bathtub.

3.7 Using a grab bar to assist with balance loss

3.7.1 Effect of handhold orientation

Grab bars, similar to other handholds, can assist with balance loss, by allowing users to grasp and generate stabilizing forces [51]. If the strength of the grasp response is inadequate, the individual may lose their grip and this can result in an injury [13]. Breakaway strength is defined as the force generated by the hand when holding on to a handhold (i.e. grab bar) before the hand slips off [13]. The hand must resist an external force in order to maintain contact with the grab bar; however, when the force required by the task exceeds the force capacity of the hand, individuals can lose contact of the grab bar and lose balance [13]. When the individual approaches their breakaway strength, the hand may start to slip off the grasped handhold.
The orientation and shape of the handhold can affect the breakaway strength. A study on overhead ladder handholds found that a horizontal handhold had a greater breakaway strength than a vertical handhold [13]. When a handhold is positioned horizontally, load is being applied perpendicularly to the external force. Resistance from the arm muscles along with the grip over the handhold will apply a torque between the hand and the handhold [13]. The active force from the grip, along with the passive force from the friction would prevent the fingers and hands from sliding off the handhold [13]. However, when the handle is aligned vertically, it is oriented parallel to the external force. The grip strength (active force) would create a force to increase friction (passive force) that aims to prevent the hand from sliding down [13]. When holding onto an overhead vertical handhold, friction is the only factor resisting the bodyweight, as the active forces are influencing the friction between the hand and the handhold [13].

Discomfort also plays a role in grasping forces and breakaway strength during ladder use, which can be affected by the handhold orientation. The position of wrist in relation to the ulna can contribute to the discomfort. In the ladder safety literature, when holding onto an overhead vertical handhold, there is an ulnar deviation, or movement of the wrist, which can decrease the grip strength [13]. With a horizontal handhold in a ladder scenario, the wrist is at neutral position. Due to these factors, the horizontal handhold allows for the greatest breakaway strength. Researchers suggest that most individuals can support their body weight with one hand on horizontal handholds, when there are sufficient frictional forces [13]. Although the type of fall from a ladder is comparatively different than that experienced during a bathing transfer – where the direction of the fall, and the ability of the body to support reactions differ – orientation may still affect the use of the grab bar, especially if the hands are wet such as during bathing activities [12].
3.7.2 Effect of handhold height

The ability to apply adequate forces on grab bars is important in preventing falls or fall-related injuries [52]. There are many factors that impact the ability to generate these forces, including initial grasp type (e.g. whether an individual is using the handhold proactively or reactively). It has been reported that applied handrail forces are higher during a reach-to-grasp reaction when compared to a hand-in-place reaction [47]. The orientation and height of the handhold are also important factors, as both will impact the relative position of the upper arm, wrist and hand, which in turn may impact the forces and moments generated on the grab bars [52]. Considering the latter, previous work investigating balance recovery responses with different height handrails found that peak upward forces generally decreased as handrail height increased in the backward fall direction, during both reach-to-grasp and hand-in-place reactions [47]. Similarly, when facing the handrails, downward, upward and resultant forces decreased as handrail height increased in the forward and backward fall directions [47]. This was supported by Maki and colleagues’ work (1984), which showed that volitional forces and moments decreased with increasing handrail height [52]. Furthermore, force capacity during downward pulling also increased with handhold height [53]. Handrail height has also been shown to affect one’s balance control - where improved control was seen with higher handrails [54]. As the moment arm between the ankle and the rail increases with higher handrail heights, users were able to generate greater stabilizing moments to obtain greater COM control [54]. Similarly, trunk angular metrics (e.g. trunk roll angle range, peak roll angular velocity, peak forward pitch angle) improved with increasing handrail height [54]. Conversely, Camernik and colleagues (2019) found no significant differences in the maximum COM displacement when using a handle.
located at the hip level, shoulder level or over the head [14]; the differences in findings likely due to the type of perturbation delivered and grasp response required. Given these differences in study findings, further research is required to understand how higher handholds would improve COM control while stepping over an obstacle or out of a wet surface.

3.8 Summary

The ability to successfully step in and out of a bathtub can be challenging. This can be due to the external demands of the task paired with aging changes that may limit physical capacities and balance control. Bathroom aids, such as grab bars, provide a commonly used tool to assist with bathtub transfers although there is little evidence on how various installation recommendations, including the orientation of the grab bar, impacts balance control when stepping out of a bathtub. Similarly, there is little evidence on how the occurrence of a slip may impact the effectiveness of grab bar use during bathtub exit. By studying the use of horizontal and vertical grab bars in simulated bathing environments, a better understanding of balance control and the impact of grab bar orientations in response to a balance loss during a bathtub transfer can be obtained.
Chapter 4
Methods

4.1 Study population

Healthy younger adults (18-35 years of age) and healthy older adults (65 years and older) participated in the study. Participants were recruited from the community through recruitment flyers/newspaper ads. Participants were screened to ensure that they met the inclusion criteria. Prior to beginning the study, all participants provided informed consent. The study was approved by the hospital and university research ethics board.

4.2 Inclusion and exclusion criteria

To be eligible in the study, all participants were community-dwelling and self-reported to have normal or corrected-to-normal vision. They were able to grasp the grab bar independently with no assistance during the protocol. Individuals with hand or upper-extremity pathologies were excluded, as this may have limited their ability to use the grab bar. Individuals were also excluded if they had any mobility, orthopedic, or neurological conditions (i.e. stroke, lower limb pathologies), used any aids to support their mobility, suffered recent injuries or concussions, and/or presented with any other relevant conditions that may have affected their balance. All participants had to be able to understand and communicate in English as all the study instructions, including study documents such as the informed consent, were presented in English. Participants were screened through a phone interview and during their initial contact to ensure they met the inclusion criteria.
4.3 Sample size calculation

There are limited studies on balance control and lower limb effort related to bathtub transfers. However, sample size was calculated using G*Power3, an online statistical analysis program, where type I error (alpha error probability) was set at 0.05, and power level (1-β) set at 0.80. Effect size was determined based on previous research on centre of pressure variability during bathtub exit task, and was set at 0.3 [6]. Based on this calculation, a total sample size of 30 (10 participants per group) was estimated.

4.4 Experimental environment

The study took place in the General Purpose Lab at the Challenging Environment Assessment Laboratory (CEAL) at Toronto Rehabilitation Institute. The General Purpose Lab is a 5.55m x 5.15m space, which sits on top of a 6-degree of freedom motion simulator base and is capable of producing translational and rotational motion to evoke perturbations (Figure 1).

Within the General Purpose Lab, a custom-built handhold apparatus was secured, which permitted the installation of both vertically- and horizontally-orientated grab bars. All grab bars were equipped with tri-axial load cells.
(AMTI, Watertown, MA) on each end, allowing for the determination of applied forces during grab bar use, in response to a balance loss. Two customized bathtubs were placed adjacent to the horizontal and vertical grab bars (Figure 2 and Figure 3). White non-reflective sheets were placed behind the grab bars to reduce contrast between the apparatus and the grab bars. To prevent injuries, the bathtubs were modified so that all edges of the bathtub were removed and replaced with soft foam, and a foam block was used to replicate the bathtub’s rim. The height of the foam block was 41cm to coincide with commercially available bathtub heights. Finally, independent force plates (AMTI, Watertown, MA) were installed on the surface outside and under the bathtub. Participants wore a harness, equipped with a load cell to measure harness reliance. Load cell and force plate data were collected at a recording frequency of 1000Hz.

To simulate a realistic bathtub environment, the bathtub surface was wetted with a standard soapy water solution. One litre of diluted sodium lauryl sulfate (SLS) (2 grams) was used to produce the water solution, and was based on the British Standard Institution slip resistant test standard (BS EN 13845). Both bathtubs were cleaned with soap removal solution and water after each participant’s data collection to ensure consistency in slipperiness between participants.
Figure 2: Experimental environment inside the lab. Two bathtubs are placed adjacent to each grab bar orientation (horizontal and vertical grab bar). Force plates are placed underneath and immediately outside the bathtub. Load cells are installed on both ends of the grab bars. The bathtub rims are comprised of foam blocks. Vinyl tiles and bath mats were placed outside the bathtub and a slippery solution (water and sodium lauryl sulfate) was used in the bathtubs to simulate realistic bathing conditions.
Figure 3: (Left) The horizontal grab bar is shown, which is height adjustable. The horizontal grab bar was aligned to the bathtub rim, and extended inside the bathtub. A piece of foam was placed on the portion of the horizontal grab bar that extended outside of the bathtub to restrict the available grasping location, as shown in the figure above. (Right) The vertical grab bar is shown, which was aligned with the bathtub rim.

Four video cameras (Point Greys Research) were mounted within the laboratory space to capture participants’ activities throughout the study protocol. These captures were used to identify global strategies for exiting a bathtub. Finally, twelve motion capture cameras (Motion Analysis Inc., Santa Clara, CA) were mounted throughout the laboratory, which captured three-dimensional kinematic data at a recording frequency of 250Hz.

4.5 Participant instrumentation

Participants were equipped with reflective motion capture markers to track whole-body movement during the protocol. Rigid clusters of markers were secured on the shank, thigh, foot,
pelvis and upper thoracic region. Individual markers were placed on the back spine (C7), jugular notch, acromion, upper arm, forearm, lateral elbows, medial and lateral wrists, 2\textsuperscript{nd} and 5\textsuperscript{th} metacarpals, anterior and posterior of the thighs and shanks, lateral knees, and feet (lateral ankles, 1\textsuperscript{st} and 5\textsuperscript{th} metatarsal; middle of the foot; heel). Additional markers were placed on the medial elbows, medial knees, hips (ASIS, PSIS, greater trochanter), and medial ankles to identify segment endpoints in a static, standing position. All markers were secured to the participant with hypoallergenic medical tape and elasticized straps to ensure that the markers did not move during the protocol. The additional markers were removed during the protocol.

Participants were secured in the overhead harness to protect them if a fall was to occur. The harness was positioned above the participant, and was continuously tracking the participant throughout the protocol. The harness stopped moving once the participant dropped 0.15m from the starting position, or if the velocity exceeded 0.6m/s. When the harness was engaged (exceeded the given displacement and velocity), there was additional tension in the line to protect the participant from an injury.

Knee guards and elbow guards were placed on the participants, to further protect the participant from potential contact with the handhold apparatus, bathtub, or the ground. Finally, all participants wore a helmet throughout the protocol to ensure safety in the event the participants head were to come into contact with the handhold apparatus following a perturbation.
4.6 Perturbation parameters

Perturbations were delivered by moving the entire laboratory space in the opposite direction of the intended participants’ movement. For this study, perturbations were delivered to initiate a lateral slip. Based on pilot testing, lateral perturbations seemed to have greater effect on balance during bathtub exit. Previous research also showed that age-related differences are more evident in the lateral direction and therefore, perturbations were initiated to evoke a balance disturbance in the lateral direction [55]. The perturbation was triggered by laser sensors, which were attached above and slightly forward of the bathtub rim. The sensor had a range of the full bathtub, which provided enough span to allow participants to cross the bathtub with any leg. The perturbation was triggered when the leading leg was in the mid-swing phase while exiting the bathtub. The perturbation parameters included in the study were: peak acceleration: 2m/s²; peak velocity: 0.4 m/s; peak displacement: 0.08 m. These perturbation parameters were determined based on previous literature [10] and pilot testing, and were generally sufficient to evoke a balance loss.

4.7 Grasping conditions

Two grasping conditions were included in this study. Participants either proactively used the handrail throughout the duration of the bathtub exit (hand-in-place) or performed a reach-to-grasp reaction. Ten younger adults were instructed to reach and grasp for the available grab bar when they experienced a perturbation. The remaining ten younger adults were instructed to proactively use the available grab bar (hand-in-place condition) prior to experiencing the perturbation. All older adults exited the bathtub using a hand-in-place strategy only.
4.8 Grab bar conditions

Individuals exited the bathtub under three different grab bar conditions: (1) a low horizontal grab bar, 86.4 cm above the ground, (2) a high horizontal grab bar at 102 cm above the ground, and (3) a vertical grab bar directly above the bathtub rim. The horizontal grab bar heights were measured from the floor to the top of the grab bar. The heights included for the horizontal grab bar corresponded to the CSA Standards on grab bars and are based on previous findings from Batista and colleagues [12]. The graspable length of the horizontal grab bar was 51 cm, mounted inside the bathtub and terminating at the bathtub rim. The remainder of the grab bar was restricted with a foam block to discourage participants from grasping the area outside the bathtub (see Figure 3). The vertical grab bar was installed in accordance with the CSA Standards on grab bars [32] and the Ontario Building Code [33]. The lower bound height of the vertical grab bar was 35 cm above the bathtub rim, with a graspable length of 85 cm. All grab bars were 1.5 inches in diameter, made from a metal material coated with white paint. The order of grab bar conditions tested was randomized across participants.

4.9 Protocol

Data was collected in one session lasting approximately three hours. Participants reviewed and signed the informed consent form prior to starting the study. Several demographic questionnaires were then completed, which included questions related to medical history, physical activity levels, type of bathtubs/showers used at home, and general grab bar use. Additional demographic data, including weight and height were also collected at the beginning of the testing session. In addition to demographic data, several clinical tests were completed,
including grip strength and the Activities-Specific Balance Confidence (ABC) scale [56]. Grip strength was determined using a hand-held dynamometer, completing a total of three trials on each hand. The grip strength measure was used as an overall measure of strength [57]. The ABC scale is a 16-question scale, evaluating one’s confidence in maintaining their balance during various functional activities.

Following the completion of questionnaires and clinical assessments, participants were instrumented with motion capture reflective markers (see section 4.5 for instrumentation details) and began the bathtub exit protocol. Participants were asked to perform several bathtub transfers using self-selected strategies. This included using whichever foot to lead with and how they preferred to exit (e.g. laterally facing the grab bar or using two hands). Prior to exiting, participants were instructed to take a few steps in place while inside the bathtub. This was to discourage pre-planning of the task and act as a distraction task. Between each trial, participants dried their feet with the available bathmat and towels.

Ten younger adults completed reach-to-grasp reactions (YA RTG), where they would initially exit the bathtub without using the grab bar. Following a perturbation, the participants were told to reach for the available grab bar to assist with recovery. An additional ten younger adults (YA HIP) and all the older adults (OA HIP) completed hand-in-place trials, where they used the available grab bar proactively throughout the bathtub transfer. All older adults were given a “practice trial” where a perturbation was delivered to them, while they stood still holding onto the grab bar. This was to familiarize them with the type of perturbation they may receive, but to also reduce any fear that they had regarding the perturbation. If the older adults were comfortable with the perturbation, they continued the protocol. Participants exited the bathtub
several times prior to experiencing the perturbation. Participants only received one perturbation trial while using each grab bar condition (total of 3 trials). Trials were repeated if there were any issues with the data acquisition systems. Trials with no perturbations were included to avoid pre-planning and anticipation. One researcher was always present in the General Purpose Lab to ensure that the participant was comfortable with the protocol and was safe throughout the testing. Participants were given several scheduled rest periods during the protocol, or when required. Following the protocol, a post-test questionnaire, developed by the researchers, was administered. This questionnaire examined how likely participants were to use each grab bar conditions when exiting a bathtub.

4.10 Data processing

For the purpose of this thesis, only the exit trials that had a perturbation delivered were analyzed. Motion capture data were filtered using a low-pass Butterworth filter with a cut-off frequency of 6Hz. From the raw motion capture data, a 12 segment, link segment model was developed to estimate COM kinematics. To process the load cell data, inertial artifacts in the force signals due to the movement of the platform during perturbations were first removed by subtracting load cell data collected during “blank perturbations” (i.e. when there was no grab bar contact). This was filtered using a second-order, Butterworth filter, with a cut-off frequency of 10Hz. Force data from the grab bar were then filtered with a second-order, Butterworth filter, using a cut-off frequency of 20Hz [47]. The harness load cell data was filtered using a second-order, Butterworth filter, with a cut-off frequency of 8Hz [58]. Using the analog signal from the motion capture data, the data was realigned to sync motion capture and force data. To determine perturbation onset, a 45 ms offset (average based on previous data) was removed from the
measured perturbation onset. All kinematic data were processed using Visual 3D, whereas the kinetic data were processed and filtered using MATLAB.

4.11 Data analysis

All exit trials that had a perturbation delivered were included in the analysis, regardless of whether a slip or substantial balance loss was experienced. To identify the extent to which the balance loss resulted in any assistance by the harness, the vertical load of the harness load cell was examined. A harness load greater than 8% bodyweight was classified as harness-assisted recovery, where the balance recovery was supported by the harness to some degree [58]. This classification was used in a previous study that determined harness-assisted recovery in young adults who walked barefoot on a slippery vinyl sheet. Harness reliance over 30% was classified as a fall [59]. Any trial that exceeded a harness loading of 30%, or identified as a “fall”, was excluded from the biomechanical analysis, although included in the overall description of the performance related to the various grab bar conditions.

For all data analysis, the data were extracted between two time points during a single transfer phase. The phase of interest represented the most challenging phase of the bathtub transfer as individuals were exiting while responding to a perturbation:

1) Perturbation onset: identified based on platform acceleration [60] (see section 4.10 for details on determining perturbation onset).

2) End of balance recovery: identified as the point in time when the participant has used the grab bar to recover from the balance loss and their trailing limb starts to lift off the
bathtub ground to complete the transfer. At this point, participants would have established a new base of support after their leading limb has made contact with the outside surface. The “end of balance recovery” time point was visually inspected and manually identified using Visual 3D (C-Motion Inc., Germantown, MD).

4.11.1 Postural control variables

To understand balance control in response to the perturbation (and degree of balance loss) during bathtub exit and the effect of the different grab bar orientations, the following variables were determined:

- Peak COM displacement: Crossing over an obstacle requires a large trajectory of the foot, altering the COM trajectory. The limited base of support during a single leg stance requires accurate control of the COM, and large disturbances to the COM can result in a balance loss.
- Peak COM velocity: The magnitude and direction of one’s COM velocity is important in determining the ability to maintain balance [54]. However, age-related changes impact factors controlling balance [61], which can impact peak COM velocity. The degree of balance loss may also impact COM velocity.

All variables were calculated from perturbation onset to the end of the recovery phase, and calculated in the direction of progression (i.e. forward direction), perpendicular to the direction of progression (i.e. lateral or away from the grab bar wall and medial or toward the grab bar wall), and in the downward (vertical) direction.
4.11.2 Force application

Forces applied to the grab bar were determined in response to a balance response. Peak anterior-posterior, medio-lateral, vertical and resultant forces were identified and analyzed from perturbation onset. In the reach-to-grasp condition, the initial spike in grab bar forces was removed from analysis. This initial peak likely represents the initial hand contact with the grab bar, and not the applied forces required during balance recovery. Grab bar forces were recorded in Newtons (N) and normalized based on participant’s body weight (%BW) enabling comparisons between participants.

4.12 Statistical Analysis

Descriptive statistics (means and standard deviations) were calculated for all variables. A one-way ANVOA was used to determine any significance in the demographic variables (i.e. weight, height, grip strength) between the three groups (young adults proactive grab bar use, young adults reach-to-grasp, and older adults). A 3x3 repeated measures ANOVA was performed to determine the effect of grab bar orientation and group on all biomechanical variables of interest. Although comparisons between the younger adults using a reach to grasp (YA-RTG) approach and older adults using a hand in place (OA-HIP) approach were made, these were not considered. Only group comparisons between (1) younger adults using reach to grasp and younger adults using hand in place approach, and (2) the younger and older adults using a hand in place approach were considered in this study. Mauchly’s test of sphericity was performed to confirm that the assumption of sphericity was not violated. In the event that the Mauchly’s test was violated, the Greenhouse Geisser correction was used if the estimate of
sphericity ($\varepsilon$) was less than 0.75, and Huynh-Feldt corrected values were used if the estimate of sphericity ($\varepsilon$) was higher than 0.75. Following the identification of a significant main effect in groups, a post-hoc comparison with Bonferroni’s adjustment was performed to account for multiple comparisons. In the event of a significant interaction (grab bar orientation*group), a repeated measures ANOVA test was performed within individual groups to determine the significant pairwise comparisons. All statistical analyses were conducted using SPSS (IBM, Armonk, NY). A significance level of $p<0.05$ was considered for all analyses.
Chapter 5
Results

5.1 Participant demographics

Data from 20 younger adults and 10 older adults’ were included in the analysis. Three groups were included in the study: (1) young adults using the grab bar reactively following the perturbation (i.e. the participants were instructed to reach and grasp the grab bar when they experienced a perturbation; YA RTG), (2) young adults using a the grab bar proactively (or “Hand-in-place”) as they exited the bathtub (YA HIP), and (3) older adults using the grab bar proactively as they exited the bathtub (OA HIP). Participant demographics are presented in Table 2. There were no significant differences in height (p=0.202), weight (p=0.770) or grip strength (p=0.322) between the groups.

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Younger adults (Reactive grasp) n=10</th>
<th>Younger adults (Hand-in-place) n=10</th>
<th>Older Adults (Hand-in-place) n=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.7 (2.2)</td>
<td>24.6 (4.2)</td>
<td>67.8 (2.8)</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>3/7</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.5 (9.0)</td>
<td>173.2 (11.8)</td>
<td>165.5 (8.2)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73.5 (14.2)</td>
<td>73.1 (15.7)</td>
<td>69.3 (12.8)</td>
</tr>
<tr>
<td>Hand Dominance (R/L)</td>
<td>9/1</td>
<td>9/1</td>
<td>9/1</td>
</tr>
<tr>
<td>Grip Strength of the Right Hand (kg)</td>
<td>35.3 (13.7)</td>
<td>39.0 (16.2)</td>
<td>29.8 (9.6)</td>
</tr>
<tr>
<td>ABC Score (/100%)</td>
<td>95.4 (2.4)</td>
<td>96.1 (2.9)</td>
<td>94.8 (4.4)</td>
</tr>
</tbody>
</table>
5.2 Global exit strategy

Participants exited the bathtub using a self-selected strategy. In most cases, everyone exited facing forward, using a one-handed approach (either reactively or proactively). However, for 6 participants, the grab bar was used with both hands: One older adult used two hands for all three grab bar orientation conditions, and another older adult used two hands on the high horizontal grab bar condition only. Two younger adults also grabbed the grab bar using two hands on their first perturbation trial, one being with the high horizontal grab bar and the other participant using it on the vertical grab bar. Participants generally exited the bathtub using the foot further away from the grab bar. However, in very few cases (13 trials), participants used the foot closest to the grab bar.

5.3 Harness Reliance

A harness reliance of over 30% body weight (BW) was used to classify a fall, based on previous literature [59]. Using this definition, no falls were experienced throughout the protocol. The maximum harness reliance observed was 17.37 %BW (by a younger adult, using the high horizontal grab bar in a reach-to-grasp condition). This was classified as “harness-assisted recovery” (i.e. between 8 %BW and 30 %BW of harness reliance), whereas between 0 %BW and 8 %BW harness reliance was deemed “minimal harness reliance, or self-recovery” [58]. A summary of harness reliance is provided in Table 3. In most cases, participants were able to recover balance following the perturbation without relying on the harness for assistance. However, in a few cases, the harness was observed to support balance recovery to some extent. Although only 8 trials resulted in harness-assisted recovery, 7 of those recoveries occurred when
using the horizontal grab bars; amongst those trials, 4 of the trials identified as harness reliance were experienced when using the low horizontal grab bar.

Table 3: Total number of trials with varying degrees of harness reliance

<table>
<thead>
<tr>
<th>Harness reliance (%BW)</th>
<th>Total number of trials (out of 90 trials or 3 trials/participant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 %BW to 8 %BW (self-recovery)</td>
<td>82</td>
</tr>
<tr>
<td>8 %BW to 30 %BW (harness-assisted recovery)</td>
<td>8</td>
</tr>
<tr>
<td>30+ %BW (fall)</td>
<td>0</td>
</tr>
</tbody>
</table>

Although limited harness loads were observed, repeated measures ANOVA revealed a significant main effect of group on harness loading (%BW; Figure 4 (p=0.001). Post-hoc analysis revealed that there were significant differences between the two younger adult groups, where those using a reach to grasp approach (YA RTG) had a significantly higher harness reliance (greater harness loading) than those using a hand-in-place approach (YA HIP) (p=0.004). There was no significant difference between the YA HIP and OA HIP (p=1.00). Grab bar orientation did not significantly impact harness loading (p=0.607) and there was no interaction effect between grab bar orientation and groups (p=0.83).
Figure 4: Harness loading (% BW) across the different groups. Standard deviations are presented in the figures
* indicates significant effect of group

5.4 Grab bar force profiles and peak grab bar forces

Figure 5 below provides a schematic representation of the directions of applied forces analyzed in this study.

Figure 5: Direction of grab bar loading in all directions. In all cases, Fy (+) represents upward forces, Fy (-) represents downward force, Fx (+) represents backward force (i.e. opposite to the direction of progression), Fx (-) represents forward force (i.e. the direction of progression), Fz (+) represents towards the wall (i.e. medial) and Fz (-) represents away from the wall (i.e. lateral).
For all grab bar orientations, high forces were generally noted in the lateral direction. This was likely due to the nature of the perturbation causing a lateral balance loss, where participants applied high forces in the lateral direction or away from the grab bar wall. Similarly, there were generally high forces applied in the downward direction to counter the falling motion (with the exception of the vertical grab bar). Example grab bar force profiles for one participant from each group (using the high horizontal grab bar) are presented in Figure 6.

![Figure 6: Example force profile over time, across all three Cartesian axes and resultant force for (a) YA RTG, (b) YA HIP and (c) OA HIP. The blue line represents forces applied in the anterior-posterior direction, with positive value indicating backward forces (i.e.](image-url)
The red line represents the vertical forces, with positive value indicating forces applied in the upward direction. The green line represents the medial-lateral forces, with positive values indicating forces applied towards the grab bar wall (medial). The purple line represents the resultant force. The orange highlighted box represents the area of interest for analyses, from perturbation onset to end of recovery (i.e. balance recovery).

5.4.1 Effect of grab bar orientation and group on peak grab bar forces

A significant main effect of grab bar orientation or interaction effect of group x grab bar orientation was found for all directions of applied forces during balance recovery, except for forces in the forward direction (p≥0.176) and medial direction (or towards the grab bar wall; p≥0.238). A significant interaction effect showed that the peak force applied away from the wall was greater in the high horizontal grab bar orientation compared to the low horizontal grab bar orientation for the YA HIP group (p=0.006). In the backward direction, a significant interaction effect also showed that the YA HIP applied higher backward forces on the high horizontal grab bar (p=0.037) and vertical grab bar (p=0.035) compared to the low horizontal grab bar. However, in the downward direction, the vertical grab bar showed the lowest forces compared to the other conditions (p<0.001) for all groups. Conversely, the low horizontal grab bar showed the highest forces, which were significantly so when compared to the vertical and high horizontal grab bar in the downward direction (p≤0.023), and the vertical grab bar only for the resultant force (p=0.012) for all groups.

In the vertical direction, not all participants generated upward forces. In the YA RTG group, only 2 participants applied upward forces across all grab bar conditions. For the hand-in-place conditions, only 1 YA HIP and 4 OA HIP participants applied upward forces on the
vertical grab bar. However, some degree of upward force was generally applied on both the low and high horizontal grab bars (with the exception of a few participants in each horizontal condition). Because of these findings, there was a limited participant sample when considering upward vertical forces thus limiting ability to conduct statistical comparisons. Qualitatively, of those participants that did exert an upward force, this only represented an average between 1 and 9 %BW across all groups for the vertical grab bar, and an average between 3 and 16 %BW for the horizontal grab bar conditions across each group.

Similar to the effect of grab bar orientation, a main effect of group was also found for the peak forces applied in the forward (p=0.023) and lateral (away from the wall) (p<0.001) directions, and for the resultant forces (p=0.001) during balance recovery; forces directed towards the wall, downward, or backward were not significantly different across groups (p≥0.246). As previously noted, statistical comparison between groups could not be performed for the upward forces due to the limited sample size. For the forward, lateral and resultant forces, pairwise comparisons between groups revealed greater peak force for YA HIP when compared to YA RTG (p<0.019); no significant pairwise effects were found across any force direction for YA HIP compared to OA HIP (p>0.121). Figure 7 summarizes the mean peak forces for the loading directions where significance was determined. The mean peak forces for all directions are summarized in Appendix A.
Figure 7: Mean peak grab bar forces applied during balance recovery for the (a) forward, (b) backward, (c) downward, (d) lateral, and (e) resultant force across all three grab bar orientations and groups. Standard deviations are presented in the figures. Sample size for each group is also indicated on the graphs.
‡ indicates significant main effect of grab bar orientation.
* indicates significant main effect of groups.
≠ indicates significant interaction effect between grab bar and groups.
5.5 Balance control during bathtub exit

As participants exited the bathtub, which required stepping down to a lower height, the corresponding movement was generally characterized by a large forward and downward COM displacement and velocity. The COM (displacement and velocity) was also directed away from the wall (or laterally) during the balance recovery, as the perturbation was delivered in the same direction for all grab bar conditions. An example COM profile highlighting the general movement pattern (experienced for all grab bar conditions and groups during the bathtub exit) is presented in Figure 8. Data is presented from one younger participant using the horizontally oriented grab bar).

Figure 8: Example COM displacement and velocity profiles over time in each axis using a horizontal grab bar. All profile traces are from one participant using the high horizontal grab bar as an example of the COM displacement and velocity during balance recovery. (a) COM displacement (left) and velocity (right) in the medial-lateral direction, where positive
values represent COM directed away from the wall (lateral), (b) COM displacement (left) and velocity (right) in the forward-backward direction, where positive values represent the COM directed backward, and (c) COM displacement (left) and velocity (right) in the vertical direction, where positive values indicate upward COM movement. The rectangle region highlights the time from perturbation onset to the end of recovery (i.e. balance recovery).

5.5.1 Effect of grab bar orientation and group on measures of COM displacement and velocity

As illustrated in Figure 8, COM displacement and velocity primarily occurred in the forward, lateral (i.e. away from the wall), and downward directions. The analysis presented in the results was therefore limited to these directions of interest. However, a detailed summary for all directions of movement can be found in Appendices B & C.

5.5.2 Peak COM displacement during balance recovery when exiting the bathtub

During balance recovery, grab bar orientation significantly affected peak COM displacement in the forward direction only, where forward COM displacement was highest when using the vertical grab bar compared to when using the high and low horizontal grab bars \((p \leq 0.009)\). Grab bar orientation did not significantly impact peak COM displacement in the lateral (away from the grab bar wall) or downward directions \((p \geq 0.078)\), nor was any interaction effect with group detected for any of the directions of interest when considering peak COM displacement \((p \geq 0.054)\). When considering the main effect of group, COM displacement was significantly greater for the YA RTG compared to the YA HIP group for both the lateral and
downward directions (p≤0.007); no significant main group effect was found for peak COM displacement in the forward direction (p=0.440). Data are summarized in Figure 9.

Figure 9: Mean peak COM displacement (m) during bathtub exit in the (a) forward, (b) lateral (away from the wall) and (c) downward direction across all grab bar orientations and groups. Standard deviations are presented in the figures. † † indicates significant effect of grab bar orientation. * indicates significant effect of groups.
5.5.3 Peak COM velocity during balance recovery when exiting the bathtub

The peak COM velocity in the forward direction (axis of progression) differed across grab bar orientation (p=0.003) and group (p=0.001). Pairwise comparisons revealed that using the vertical grab bar resulted in significantly higher forward COM velocity compared to using the low horizontal grab bar (p=0.004). Similar to COM displacement, significant differences in the forward COM velocity was only observed between the two younger groups, where the YA HIP group had a significantly higher forward COM velocity than the YA RTG group (p=0.001); however, there was no significant differences between the YA HIP and the OA HIP (p=0.149). There was no significant interaction effect between the groups and the different grab bar orientations (p=0.256).

Although lateral perturbations were delivered, the peak COM velocity in the lateral direction did not significantly differ between the different grab orientations (p=0.602) or between groups (p=0.098). There was also no interaction effect between grab bar orientation and group (p=0.294) in the lateral direction. However, as participants exited out of the bathtub, the COM velocity in the downward direction significantly differed between the groups (p<0.001). A post-hoc analysis revealed significant differences between the two younger adult groups, where the YA RTG group had a significantly higher downward COM velocity than YA HIP group (p<0.001). There was also an interaction effect observed between grab bar orientation and group, where the YA RTG group had a significantly higher downward COM velocity when using the
low horizontal grab bar compared to the vertical grab bar (p=0.019). Figure 10 summarizes the peak COM velocity data.

Figure 10: Mean peak COM velocity (m/s) during balance recovery in the (a) forward, (b) lateral (away from the wall) and (c) downward directions, across all grab bar orientations and groups. Standard deviations are presented in the figures.
* indicates significant effect of group.
‡ indicates significant effect of grab bar orientation.
≠ indicates significant interaction effect between grab bar and groups.
5.6 Grab bar preferences

Following the testing session, participants were asked to rate how likely they were to use grab bar orientation to assist with bathtub exit on a scale from 0 to 10, with 0 representing “not likely to use” and 10 representing “extremely likely to use”. In general, the low horizontal grab bar was rated the lowest in terms of likelihood to use, whereas the vertical grab bar and the high horizontal grab bar were rated to a similar degree by all groups. A summary of the findings are presented in Table 4.

Table 4: Ratings (Mean (SD)) on the likelihood for using the different orientated grab bars across each group.

<table>
<thead>
<tr>
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<th>High Horizontal Grab bar</th>
<th>Low Horizontal grab bar</th>
<th>Vertical grab bar</th>
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<td>6.9 (2.7)</td>
</tr>
<tr>
<td>OA HIP</td>
<td>8.7 (1.7)</td>
<td>7.5 (3.1)</td>
<td>9.1 (1.4)</td>
</tr>
</tbody>
</table>
Chapter 6
Discussion

This is the first study to explore the influence of grab bar orientation on balance recovery following a perturbation when exiting the bathtub. The main findings showed that grab bar orientation influenced grab bar loading, as higher forces were generally applied on the low horizontal grab bar without any differences in measures of balance. This suggests that users had to generate higher forces to maintain their balance with the low horizontal grab bar. All groups rated that they were more likely to use the high horizontal and vertical grab bar, over the low horizontal grab bar, further supporting this placement orientation as the least favorable among those evaluated. No effects of age for both loading forces and COM measures were found. However, hand condition significantly impacted balance recovery, as the YA RTG group had poorer balance control and applied less force on the grab bar compared to the YA HIP group, highlighting the benefit of using a grab bar proactively to assist with bathtub exit.

6.1 Influence of grab bar orientation on grab bar loading and balance control

Although there are various recommendations for grab bar installation, there is limited research on how grab bar parameters impact balance control while transferring out of a bathtub. Many of these installation recommendations are based on individuals’ perception of comfort, safety and ease of use [11]. Findings from this present study show that grab bar placement impacts performance when balance recovery is required and biomechanical measures of task performance have the potential to assist current clinical recommendations.
The findings from the current work demonstrated that the low horizontal grab bar resulted in high grab bar loading. In the more challenging reach-to-grasp scenario, the low horizontal grab bar also resulted in additional demand to balance control. Users applied high downward forces when using the low horizontal grab bar, and applied higher resultant forces to effectively respond to the perturbation. Similar to our findings, Komisar and colleagues also found that the applied handrail forces decreased with increasing handrail height [47]. As suggested by the authors, the increase in the moment arm with a higher grab bar allows users to generate greater stabilizing moments for a given applied force, which was also reflected in the participants’ ability to withstand higher perturbation magnitudes [47]. This further suggests why the vertical grab bar and the high horizontal grab bar were generally similar in terms of loading – since both permitted a higher grasping location, reduced grab bar loading in most directions could be applied to support the balance recovery.

In addition to the higher grab bar loading required when using the low horizontal grab bar, for those participants that used a reach to grasp approach, COM control was also impacted. There was a higher COM velocity in the downward direction observed within this group while using the low horizontal grab bar. This is particularly risky given the change of height between underfoot surfaces that is navigated when exiting the bathtub, where the downward velocity becomes important to control. In the event of a balance loss during exit, by reducing COM velocity in the downward direction, the high horizontal grab bar or vertical grab bar may improve balance recovery or reduce the severity of a balance loss.

It should be noted that the high horizontal grab bar and the vertical grab bar showed comparable results for most measures of interest, with more effective recovery compared to
using the low horizontal grab bar. However, when examining the loading profiles in the downward direction, the difference between all grab bar orientations was apparent. Users applied significantly less downward forces on the vertical grab bar in comparison to the high and low horizontal grab bars. The lower applied load in the vertical direction with a vertical grab bar may be beneficial in several scenarios: (1) if users were to reach close to their maximum capacity in generating forces and (2) in the presence of impairment where strength is affected, or (3) in the case of wet hands. If users applied forces close to their maximum force generating capacity, then it would be beneficial to have a grab bar which demanded lower forces without impacting balance. In other activities of daily living, greater fall risk has been reported when individual’s approach their maximum muscular capacities [62]. Similarly, it would also be beneficial in the presence of impairment, where capacities to generate high forces to maintain one’s balance may also be compromised. Future studies incorporating muscular utilization ratios would provide a better understanding of the impact of higher applied forces on task demands for persons with and without impairment. Finally, it has been suggested that the hand can slide down the vertical grab bar during bathing, which can increase the chances of fall-related injuries [12]. Since the vertical loads are minimal with a vertical grab bar, the impact on balance recovery with wet hands/wet surfaces may not be as severe highlighting the potential benefit of the vertical grab bar.

Despite the lower applied forces, the vertical grab bar resulted in reduced control in the forward direction as indicated by higher forward COM velocity and displacement. These findings could be explained by the difference in the users’ hand and wrist position with the different grab bar orientations. Although not captured with the current biomechanical model, a horizontal grab bar primarily permits ulnar and radial deviation of the wrist as individuals exit the tub. When using a vertical grab, the wrist will primarily flex and extend which could allow
the hand to rotate about the axis of the grab bar. In very recent work, Mannella and colleagues found greater wrist angular displacement during flexion and extension compared to radial and ulnar deviation when a perturbation was delivered during grasping in a neutral wrist position [63]. The greater movement of the wrist may contribute to a greater forward COM displacement and velocity observed in our findings when using the vertical grab bar. This is also important to consider, since the grab bars tested in this study were of a smooth, non-textured finish. If greater wrist movement is occurring with the vertical grab bar leading to reduced control in the forward direction, this suggests high friction or textured grab bars could assist with improving balance recovery. Future studies should examine rotational forces, kinematics of the wrist, and how the findings would differ when the hand is also wet.

6.2 Influence of grasping condition (Reach-to-grasp vs. Hand-in-place)

Using the grab bar proactively can provide several benefits during a balance recovery reaction. The tactile information from the surrounding environment provides information to the central nervous system so that appropriate adjustments can be made to upcoming challenges, such as a balance loss [16]. In the absence of this tactile information, there is a greater challenge as the body has to coordinate all the limbs to control the COM, so that a fall can be prevented. Proactive grasping also removes the challenges of having to reach accurately for a grab bar in a timely manner. In a reach-to-grasp response, speed of reaching the grab bar is an important feature that determines the success of recovering from a balance loss. This can be challenging for older adults especially, as previous findings have shown that they are slower to initiate and
execute a reach-to-grasp response [64]. Previous research also showed that proactively using a handrail has shown to reduce energy cost and muscle activity in stroke survivors, compared to no contact and light touch of the handrail [65]. By designing handholds that allows users to grab on proactively, it can reduce the incidences of falls and fall-related injuries.

Our data revealed that initial hand position significantly impacts both grab bar loading and balance control, with the greatest challenge seen in the young adult group who were required to reach and grasp for the grab bar following the perturbation. Considering applied forces, proactive grab bar use permitted the YA HIP group to rely to a greater extent on the grab bar, thus applying higher forces. This may be particularly beneficial given the nature of the task demands, which include stepping down to a lower height with slippery underfoot surfaces. Due to the demand of a reach to grasp response, the YA RTG group may not have been able to effectively generate high forces as the other group, placing them at higher risk of falls in response to a balance loss; results which have been shown in other perturbation studies involving handrail grasping [47]. In fact, those that used the harness to a greater extent were participants in the YA RTG group. The lower applied forces are important in this case, given the additional challenges to balance control that were also detected. The YA RTG group had higher COM displacement and velocity than the YA HIP group in the lateral and vertical direction. As shown by these results, the magnitude of a balance loss can be reduced while proactively using a grab bar, which in turn may reduce the incidence and severity of a fall. This is supported by previous research that has shown proactive handhold use resulted in sustaining higher perturbation magnitudes while maintaining their balance [47].
As suggested above, the ability to rely on the grab bar by the YA HIP group enabled users to stabilize their COM in the event of a large balance loss. Conversely, lower applied forces by the YA RTG group resulted in poor balance control, as shown by high COM movement in response to a perturbation during the transfer. Although we expected the YA RTG group to have poorer balance control, we also hypothesized this group would apply higher forces to counterbalance this balance loss. The current findings showed the opposite. The YA HIP group was able to rely on the grab bar more by applying higher forces, while the YA RTG group may have made other adjustments to respond to the challenge of the task.

6.3 Effect of age on balance control during bathtub transfers

In order to examine the potential effect of age on balance control, both younger and older adults completed the protocol using a hand-in-place approach. Findings showed no significant difference between age groups in grab bar loading or COM measures included in this study. Although a difference with age was hypothesized, this finding may not be surprising as the older adult group only completed the task using the grab bar proactively – a strategy which provided the greatest degree of confidence in performance and may have also permitted greatest balance control when compared to the alternative, reach-to-grasp condition [9]. Future work should include older adult participants completing the balance recovery task using a reach-to-grasp approach to more comprehensively understand the effect of age and assistive device use on effective recovery. Despite the similarities in grab bar loading and COM displacement and velocity, the older adults had less grip strength compared to the younger adults, with an average
of 29.8 kg and 39.0 kg respectively. Despite this observation, grip strength was not significantly different between the groups, which may be due to the limited sample size. In other activities of daily living, it has been shown that even healthy older adults utilize a greater proportion of their muscular capacity to complete the task [38]; if grip strength is taken to represent overall strength [57, 66], the same could apply here given the lower strength noted (although not statistically significant) in the older adults included in this study. Future work should also consider additional measures such as the muscular demands during the bathing transfer task, to understand the effect of assistive device use on other aspects of performance and physical demands.

6.4 Limitations & Future steps

There are several limitations of this study that should be acknowledged. First, only three grab bar conditions were considered in the current study, all intended to assist with bathtub exit only. These conditions were chosen to align with current recommendations [32, 33] and previous research [12, 47]. However, other heights, orientations (e.g. angled grab bar) and assistive devices are commonly used to assist with bathtub transfers. This work should be expanded to consider (a) a more comprehensive evaluation of the effect of other assistive device use on the bathtub transfer, and (b) the effect of the various clinical recommendations for grab bar placement on other bathing tasks. Further, when specifically investigating the horizontal grab bar placed at the bathtub exit, the height of the grab bar was chosen to align with previous research and existing standards [12, 31, 47]. Scaling the horizontal grab bars to individual height would provide further input on how grab bar height impacts COM control and forces generated on the grab bar, and should be considered in future research.
The fear of falling has been shown to limit performance in many activities of daily living [67]. In this study, it was evident that anxiety or fearfulness impacted the chosen exit strategy of the older adult group as the majority of the older adults did not feel comfortable completing a reach to grasp recovery. Thus, the protocol was restricted so that all the older adults used a hand-in-place approach only. In other balance recovery tasks, age-related declines in handhold loading has been shown when completing a reach to grasp approach [52], and the same could be applied to grab bar use during a bathing exit task. Future studies should consider looking at the older adults’ ability to recover effectively with different grab bar orientations using the more demanding reach-to-grasp strategy. This is particularly important since not all older adults will choose to utilize a grab bar proactively, even if it is available to them [25].

Although the bathtub was wetted with a soapy solution, the hands were not wet nor were the grab bars. Since we were not able to consistently wet the hands throughout each trial, it was not included in this study. During bathing activities, having wet hands would affect the ability to grasp the grab bar effectively. The hands can slip off the grab bar, or it may affect the ability to successfully grasp the grab bar in a reach to grasp approach. This would potentially affect the forces generated on the grab bar and the individuals’ balance control. Future studies should consider how wet hands would impact grab bar use during bathtub transfers.

The rotational moments generated between the hand and the grab bars were not measured, which would provide further insight on the ability to grasp the grab bar. Especially in a balance recovery scenario, the hand can rotate along the grab bar, impacting one’s ability to generate appropriate forces and control COM. Future work should consider exploring these
rotational moments. This would serve as an important benchmark for the further exploration of other grab bar surfaces such as textured or high friction surfaces.

Finally, in this study, the perturbation magnitude aligned with past research to provide a disturbance to one’s balance during bathtub exit, but was not sufficient to cause a fall for any participants. Generating vertical forces may be particularly important if the COM were to fall in response to more severe perturbations. In this scenario, grab bar orientation may become more important. Future work should consider exploring grab bar use with larger perturbations, to see how grab bar orientation
Chapter 7
Conclusion

This study is the first to provide insight on the effect of grab bar orientation on balance control and applied forces following a perturbation. Grab bar orientation significantly impacted grab bar loading, where the low horizontal grab bar resulted in high downward and resultant forces. In the challenging reach-to-grasp condition, the low horizontal grab bar also resulted in high downward COM velocity suggesting greater demands were required to recover balance. Conversely, the high horizontal and vertical grab bar resulted in lower forces compared to the low horizontal grab bar in the downward direction; the vertical grab bar also resulted in lower resultant forces. With the exception of the forward COM displacement and downward forces, the grab bar conditions did not result in differences in balance control between the high horizontal and vertical grab bars indicating these grab bars support balance when a perturbation occurs under the conditions evaluated in this study. Hand position had a significant impact on loading and balance control where the reach to grasp group applied less forces on the grab bar, but demonstrated higher balance disturbance. For those proactively using the grab bar, they were able to rely on the grab bar and generally applied high forces, which in turn led to better COM control. However, the younger adult group using a hand-in-place approach applied lower forces on the low horizontal grab in the backward and lateral direction, which may suggest that the low horizontal grab bar is too low to generate high forces in these directions when proactively using a grab bar. Nonetheless, the overall improvement in balance control emphasizes that grab bars should be placed to support proactive use while transferring out of the bathtub. The results of this study provide an important reference for clinical decision making when recommending grab bars to assist with bathtub transfers and can serve to inform future standard development.
References


[64] K. Cheng, S. McKay, E. King and B. Maki, "Does aging impair the capacity to use stored visuospatial information or online visual control to guide reach-to-grasp reactions evoked by unpredictable balance perturbation?," *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, vol. 11, no. 1238-1245, p. 67, 2012.


Appendix

Appendix A: Peak forces (%BW) applied during balance recovery, for each axis and the resultant force across all three grab bar orientations and groups. Mean values and standard deviations are provided, along with the ranges. Significance value for group, grab bar and group x grab bar are provided. In cases where there were missing participants, sample size is also included.

<table>
<thead>
<tr>
<th>Force comp</th>
<th>Reach to grasp (YA RTG)</th>
<th>Hand in place – Younger adults (YA HIP)</th>
<th>Hand in place – Older adults (OA HIP)</th>
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<tbody>
<tr>
<td></td>
<td>H</td>
<td>L</td>
<td>V</td>
</tr>
<tr>
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<td>Vertical Up</td>
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<td>3.38 (4.28)</td>
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H, High horizontal grab bar; L, Low horizontal grab bar; V, Vertical grab bar
YA RTG, Young adult group reach-to-grasp condition; YA HIP, Young adult group hand-in-place condition, OA HIP, Older adult group hand-in-place condition
*p<0.05 significant effect of group (only between YA RTG and YA HIP)
†p<0.05 significant effect of grab bar (across all grab bars orientations)
‡p<0.05 significant effect of grab bar (only between LOW horizontal and VERTICAL grab bar)
≠p<0.05 significant interaction effect between HIGH and LOW horizontal grab bar
±p<0.05 significant interaction effect between LOW horizontal and VERTICAL grab bar

H 0.001 0.138 0.027
L 0.246 0.795 0.238
V 0.023 0.176 0.618

64
Appendix B: Centre of mass displacement (m) in all directions across all grab bar orientations and groups. Mean values and standard deviations are provided, along with the ranges. Significance value for group, grab bar and group x grab bar are provided.

<table>
<thead>
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<th>Direction</th>
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<th>Hand in place – Younger adults (YA HIP)</th>
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<th>pGrab Bar</th>
<th>pGroup × Grab Bar</th>
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<td>Mean (SD)</td>
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<td>0.00 0.01 0.00</td>
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<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>0.17 (0.03) 0.19 (0.04) 0.17 (0.02)</td>
<td>0.15 (0.03) 0.14 (0.03) 0.13 (0.02)</td>
<td>0.13 (0.02) 0.15 (0.03) 0.14 (0.02)</td>
<td>0.001*</td>
<td>0.078</td>
<td>0.054</td>
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<td>0.12 – 0.12 – 0.13 –</td>
<td>0.11 – 0.10 – 0.11 –</td>
<td>0.11 – 0.10 – 0.10 –</td>
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<td>0.22 0.18 0.17</td>
<td>0.15 0.20 0.17</td>
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</table>

H, High horizontal grab bar; L, Low horizontal grab bar, V, Vertical grab bar
YA RTG, Young adult group reach-to-grasp condition; YA HIP, Young adult group hand-in-place condition, OA HIP, Older adult group hand-in-place condition
* p<0.05 significant effect of group (only between YA RTG and YA HIP)
† p<0.05 significant effect of grab bar (only between LOW horizontal and VERTICAL grab bar)
× p<0.05 significant effect of grab bar (between HIGH horizontal and VERTICAL grab bar)
Appendix C: Centre of mass velocity (m/s) in all directions across all grab bar orientations and groups. Mean values and standard deviations are provided, along with the ranges. Significance value for group, grab bar and group x grab bar are provided.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Reach to grasp – Younger adults (YA RTG)</th>
<th>Hand in place – Younger adults (YA HIP)</th>
<th>Hand in place – Older adults (OA HIP)</th>
<th>pGroup</th>
<th>pGrab Bar</th>
<th>pGroup x Grab Bar</th>
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<tbody>
<tr>
<td></td>
<td>H L V</td>
<td>H L V</td>
<td>H L V</td>
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<tr>
<td></td>
<td>0.44 ± 0.09 (0.09)</td>
<td>0.55 ± 0.11 (0.07)</td>
<td>0.50 ± 0.08 (0.07)</td>
<td>0.001*</td>
<td>0.003†</td>
<td>0.256</td>
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<td></td>
<td>Range 0.32 – 0.56</td>
<td>Range 0.34 – 0.68</td>
<td>Range 0.34 – 0.41</td>
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<tr>
<td>Backward</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>0.00 ± 0.00 (0.00)</td>
<td>0.00 ± 0.00 (0.00)</td>
<td>0.00 ± 0.00 (0.00)</td>
<td>0.073</td>
<td>0.180</td>
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<td>Range 0.00 – 0.00</td>
<td>Range 0.00 – 0.00</td>
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<tr>
<td>Away from the wall</td>
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<td>Mean (SD)</td>
<td>Mean (SD)</td>
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<tr>
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<td>0.40 ± 0.11 (0.07)</td>
<td>0.30 ± 0.07 (0.07)</td>
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<td>0.602</td>
<td>0.294</td>
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<td>Range 0.28 – 0.43</td>
<td>Range 0.20 – 0.35</td>
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<tr>
<td>Towards the wall</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.10 ± 0.06 (0.08)</td>
<td>0.21 ± 0.15 (0.13)</td>
<td>0.27 ± 0.13 (0.15)</td>
<td>0.006</td>
<td>0.566</td>
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<td>Range 0.04 – 0.14</td>
<td>Range 0.07 – 0.12</td>
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<tr>
<td>Vertical (Up)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
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<td></td>
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<tr>
<td></td>
<td>0.15 ± 0.06 (0.07)</td>
<td>0.10 ± 0.09 (0.06)</td>
<td>0.09 ± 0.05 (0.07)</td>
<td>0.001*</td>
<td>0.899</td>
<td>0.259</td>
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<td>Range 0.15 – 0.26</td>
<td>Range 0.01 – 0.04</td>
<td>Range 0.00 – 0.00</td>
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<tr>
<td>Vertical (Down)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
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<tr>
<td></td>
<td>0.60 ± 0.17 (0.17)</td>
<td>0.42 ± 0.13 (0.09)</td>
<td>0.38 ± 0.11 (0.08)</td>
<td>&lt;0.001</td>
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<td>Range 0.60 – 0.76</td>
<td>Range 0.42 – 0.57</td>
<td>Range 0.53 – 0.60</td>
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<td>0.014</td>
</tr>
</tbody>
</table>

H, High horizontal grab bar; L, Low horizontal grab bar; V, Vertical grab bar
YA RTG, Young adult group reach-to-grasp condition; YA HIP, Young adult group hand-in-place condition; OA HIP, Older adult group hand-in-place condition
* p<0.05 significant effect of group (only between YA RTG and YA HIP)
† p<0.05 significant effect of grab bar (only between LOW horizontal and VERTICAL grab bar)
± p<0.05 significant interaction effect between LOW horizontal and VERTICAL grab bar
Appendix D: Grasp Location for each group when using the horizontal grab bar (TOP) and vertical grab bar (BOTTOM). For the horizontal grab bar, the reported location is defined relative to the bathtub rim in the anterior-posterior direction, with positive values representing a grasp location inside the bathtub. For the vertical grab bar, the grasp location is defined as the hand location vertically above the bathtub rim (with positive values representing a grasp location above the bathtub rim). The vertical height of the high and low grab bars are presented on the vertical grab bar grasp location graph (BOTTOM) for reference. Mean values and standard deviation are provided.