Comparing the effect of haptic modalities on walking balance control: Is using one or two arms better?

Alison R. Oates*, Abhishek Kumar, Wyatt Cowell, Aaron Awdhan, Regan Santoro, Joel L. Lanovaz

College of Kinesiology, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

ABSTRACT

Background: Adding haptic input by lightly touching a railing or using haptic anchors may improve walking balance control. Typical use of the railing(s) and haptic anchors requires the use of one and two arms in an extended position, respectively. It is unclear whether it is arm configuration and/or the number of arms used or the addition of sensory input that affects walking balance control.

Research question: This study examined whether using one arm or two arms to add haptic input through light touch on a railing or using the haptic anchors affects walking balance control.

Methods: In this study, young adults (n = 24) walked while using (actual use) or pretending to use (pretend use) the railing(s) and haptic anchors with one or two arms. Inertial-based sensors (Mobility Lab, APDM) were used to measure stride velocity, relative time spent in double support (%DS), and peak normalized medio-lateral trunk velocity (pnMLTV).

Results: Using two arms lead to a decrease in pnMLTV compared to using one arm and pnMLTV was lower in the actual use trials compared to the pretend use trials for the anchors only. Stride velocity and %DS did not change between trials when one or two arms were used or when participants actually or pretended to use the haptic tools. Participants walked slower when using the railing compared to the anchors.

Significance: The importance of considering the number of arms is highlighted in the improved balance control when using two arms with either tool. The augmented sensory input adds to the stabilizing effect of arm configuration for the anchors but not the railings. These results have implications for future research and rehabilitation efforts emphasizing sensorimotor integration to improve walking balance control.

1. Introduction

Injuries are a public health concern and a major cause of hospitalizations in Canada. Falling remains the leading cause of injury-related hospitalizations and 20% to 30% of seniors experience a fall per year (Government of Canada, 2014). Balance control is a modifiable risk factor for falls (Drootin, 2011; Lajoie & Gallagher, 2004; Shubert, 2011); therefore, it is very important to enhance strategies designed to improve the balance of at-risk populations so that falls can be reduced. Balance control during walking can be improved through the addition of sensory input through tools such as light touch of a finger on a railing (Hedayat, Moraes, Lanovaz, & Oates, 2017; Lackner, Rabin, & DiZio, 2000; Oates, Unger, Arnold, Fung, & Lanovaz, 2017) or the use of haptic anchors (Abud et al.,

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2015; Hedayat et al., 2017). Haptic anchors are a pair of small weights on strings that can be dragged on the floor while walking. Both tools provide added cutaneous sensation through contact between the skin and the tool (Rabin, Bortolami, DiZio, & Lackner, 1999). The tension in the strings of the anchors and the compression and shear forces between the finger and the railing, along with the proprioception of the limb(s) using the tool, provides the user with augmented awareness of where their body is in space and where their limb(s) is/are relative to their body (Jeka, 1997). The additional sensory input has been shown to improve control over step parameters and whole body stability during walking (Oates, Hauck, Moraes, & Sibley, 2017).

The railing is most often used to add haptic input with one arm (Arora, Musselman, Lanovaz, & Oates, 2015; Hedayat et al., 2017; Oates et al., 2017; Oates et al., 2017; Rabin et al., 2015) while the anchors typically require two arms (Abud et al., 2015; Freitas, Mauerberg-deCastro, & Moraes, 2013; Hedayat et al., 2017; Mauerberg-DeCastro et al., 2010). Both add sensory information that can augment awareness of where the body is in space; however, the number of arms used may be partly responsible for the changes in walking balance control. A recent comparison between light touch on a railing and the anchors suggests that the arm configuration is important to consider when using the railing and anchors to add haptic input (Hedayat et al., 2017): The beneficial effects of the anchors were due to both the arm configuration and the added sensory input whereas the beneficial effect of the railing was mostly produced by the arm configuration and not the added sensory feedback. It was not clear if the number of arms used to add haptic input contributed to the reported effects since the anchor use required two arms and the light touch on a railing required only one. It is important to understand if the arm position is responsible for any changes in walking stability when using the tools (Marone, Patel, Hurt, & Grabiner, 2014); therefore, walking with the required arm configuration but without added sensory input should be compared to walking with both the required arm configuration and added sensory input.

The objectives of this study were to 1) investigate whether the number of arms used to add haptic input with the railing or anchors affects walking; 2) examine whether arm configuration required to add haptic input alone or the combination of arm configuration plus added sensory input with one or two arms affects walking when using the railing or the anchors; and, 3) compare the effect on walking when using the railing and anchors with one or two arms. We hypothesized that using two arms with either haptic tool will improve walking balance control but that the added sensory input gained from actually using the anchors will further improve walking balance control (Hedayat et al., 2017). In addition, we hypothesized that the added sensory input would have a greater impact on balance control when using the anchors compared to using the railing (Hedayat et al., 2017).

2. Methods

Twenty-four young healthy adults (27.8 ± 6.33 years, 11 female, 137.9 ± 21 kg, 174.3 ± 7.6 cm) volunteered for this walking study after advertisement and word of mouth recruitment. Exclusion criteria included any impairment that may have affected balance and/or walking or the ability to perceive sensory feedback such as diabetic neuropathy, multiple sclerosis, acute musculoskeletal injury etc. This study was reviewed and approved by the institutional ethical review board. All participants provided informed consent.

Participant height with shoes on (m), weight (kg), leg length (greater trochanter to the floor (m)), dominant hand (self-reported), and age were recorded. Walking data were collected using Mobility Lab (APDM, Oregon, U.S.A.) which consists of six inertial-based sensors placed on the wrists, ankles, lower trunk, and sternum (Fig. 1). Participants were asked to walk normally along an 8 m walkway at a self-selected speed while lightly touching a railing on one side; touching a railing on both sides; dragging an anchor with one hand; or dragging an anchor in each hand. To examine the effect of arm position without added sensory input, participants were asked to perform trials where they held their arm(s) and finger(s) similar to when actually using the tools without either contacting the railing or holding the anchors. The trials when participants touched/used the tools were termed the "actual use" trials and the trials when participants held their arms in position but did not actually use the tools were called "pretend use" trials. A difference between the actual and pretend use trials suggests that the added sensory input from actual use of the railing/anchors was used in the control of walking. Alternatively, if there is no difference between the actual and pretend use trials, then it is merely the arm configuration leading to a change in balance control (Hedayat et al., 2017). Trials were organized into two blocks to accommodate the set-up of the railings. Each walking condition was completed four times for a total of 32 trials (Table 1). Trial order was randomized within a block and the starting block (i.e., railing(s) or anchor(s)) was counterbalanced across participants so that half of the participants started with the railing conditions and the other half started with the anchor conditions.

The railings were placed along each side of the walkway and set to a standard height of 89 cm matching local building codes. This height was chosen to make the use of the railing more ecologically valid. One railing included force sensors (Futek Advanced Sensory Technology, Inc., CA, USA; range 0 to 5 N) that were used to ensure "light" touch (< 1N) with the index finger was maintained. If the vertical force exceeded 1 N during a trial, that trial was repeated. The second railing was set to the same height as the other and the width between the two railings was adjusted according to each participant's preference and to keep the arm angle similar for both arms (two arm condition) and for the one arm condition. The anchors were constructed of 125 g beanbags attached to a 3 mm thick nylon twine strings approximately 1.5 m long (Hedayat et al., 2017). To maintain consistency between conditions, participants were asked to hold the anchors at a length and arm position they felt was comfortable.

Prior to starting each block, participants practiced walking with the haptic tool being used. After the participant completed the first block of trials they took a short five minute break to rest and to allow the researchers time to prepare for the next block.

Walking performance was evaluated using stride velocity and the relative amount of time spent in double support (%DS). A decrease in stride velocity and an increase in the relative amount of time spent in double support suggests a more cautious gait (Oates et al., 2017). To control for any effect of leg length, stride velocity was normalized to participant leg length (nSV) (Hof, 1996). As a decline in medio-lateral stability is shown to be a major risk factor for falls (Maki, 1997; Schrager, Kelly, Price, Ferrucci, & Shumway-
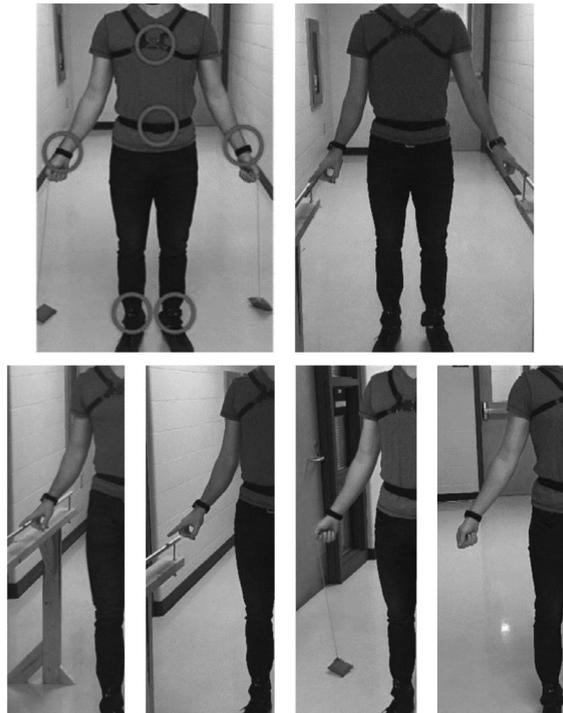
Fig. 1. Experimental setup of the inertial sensors (circled in top left image) and walking conditions. Top row (left to right): Two arm actual use of anchors, two arm actual use of railings. Bottom row (left to right): One arm actual use of railing, one arm pretend use of railing, one arm actual use of anchor, one arm pretend use of anchor.

Table 1
Outline of walking conditions within each block. Each condition included four trials. There was one block for the railing and one block for the anchors.

Condition		Railing	Anchors
One arm	Actual use	4	4
	Pretend use	4	4
Two arms	Actual use	4	4
	Pretend use	4	4
Total number of trials		16	16

Cook, 2008), peak mediolateral trunk velocity was used to examine walking balance control where a decrease suggests improved balance control (Hedayat et al., 2017; Schrager et al., 2008). To account for any effects of walking velocity (Lee, Verghese, Holtzer, Mahoney, & Oh-Park, 2014), the peak mediolateral trunk velocity was normalized to the normalized stride velocity (npMLTV).

Data were checked for normality using the Shapiro-Wilks test and any outliers were removed before analyses. Sphericity was also checked using Mauchly's Test of Sphericity (with no violations present) before performing any statistical analysis. To examine the impact of number of arms and arm configuration with or without added sensory input from contact with the haptic tool (actual use and pretend use, respectively), two-way RMANOVAs (number of arms × actual/pretend use) were run for the railing and anchors separately. To directly compare actual use of the railing and the anchors and the impact of number of arms, a two-way RMANOVA (railing/anchor × number of arms) was used. Within-subject main effects were further examined using univariate tests and pairwise comparisons with a Bonferroni correction (Cramer et al., 2016). Significance was set at $\alpha = 0.001$ to accommodate the multiple comparisons and avoid any type 1 errors. All analyses were completed using SPSS v23 (IBM Corp. Released 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp) and partial eta squared (η_p^2) values are also reported as measures of effect size (Richardson, 2011) relative to Cohen's small (0.2), medium (0.5), and large (0.8) effect size criteria (Cohen, 1988; Richardson, 2011).

3. Results

For the railing trials, there was a significant effect of number of arms ($F(3,16) = 34.269$, $p < .001$, $\eta_p^2 = 0.865$) but not for actual/pretend use ($F(3,16) = 0.394$, $p = .759$, $\eta_p^2 = 0.069$) and no interaction between number of arms and actual/pretend use ($F(3,16) = 2.03$, $p = .150$, $\eta_p^2 = 0.276$). There was a significant decrease in pnMLTV ($p < .001$) when using two arms (Fig. 2)
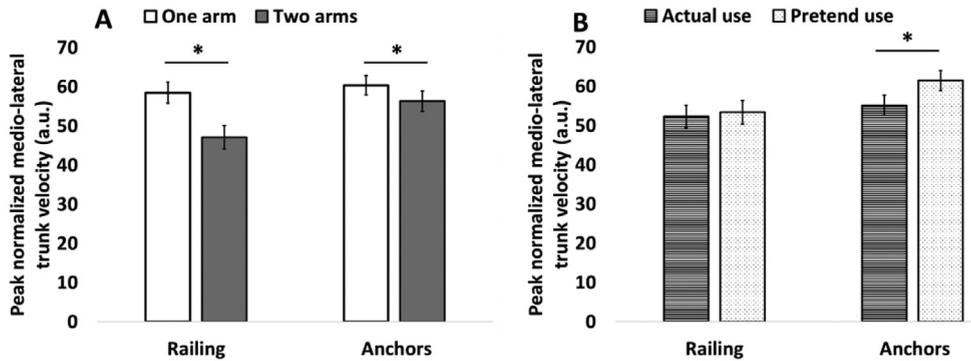
Fig. 2. Peak normalized ML trunk velocity values (mean ± SE) within the railings and anchors conditions comparing one and two arm use (A) and actual and pretend use (B) *denotes significant difference ($p < 0.01$).

compared to one and no differences between one or two arms for stride velocity ($p = .519$) nor %DS ($p = .732$).

Within the anchors conditions, there was a main effect for both number of arms used ($F(3,17) = 7.299$, $p = .002$, $\eta_p^2 = 0.563$) and actual/pretend use ($F(3,17) = 11.480$, $p < .001$, $\eta_p^2 = 0.670$) but no significant interaction ($F(3,17) = 2.941$, $p = .063$, $\eta_p^2 = 0.342$). For the number of arms used, there was a significant decrease in pnMLTV when using two arms compared to one ($p < .001$; Fig. 2) but no difference between number of arms for stride velocity ($p = .353$) nor %DS ($p = .628$). For the actual/ pretend use conditions, pnMLTV was significantly decreased when actually using the anchors compared to pretending to use the anchors ($p < .001$; Fig. 2). There were no significant differences between pretend and actual use for stride velocity ($p = .897$) nor % DS ($p = .637$) when using the anchors.

When the anchors and railings were compared directly, there was a significant main effect of tool ($F(3,17) = 8.877$, $p = .001$, $\eta_p^2 = 0.610$) and number of arms used ($F(3,17) = 29.775$, $p < .001$, $\eta_p^2 = 0.840$), but no interaction between tools and number of arms ($F(3,17) = 3.327$, $p = .045$, $\eta_p^2 = 0.370$) (Table 2). There was a significant decrease in stride velocity when using the railing compared to when using the anchors ($p < .001$) but no difference between tools for %DS ($p = .031$) nor pnMLTV ($p = .015$). There was a significantly lower pnMLTV when using the two arms compared to one arm ($p < .001$) and no differences between number of arms for %DS ($p = .723$) nor stride velocity ($p = .830$).

4. Discussion

The purpose of this study was to investigate the effects of adding haptic input with railing(s) and anchors(s) using one or two arms, the effect of arm configuration to walking when adding haptic input, and to compare the use of the railing to the anchors with one or two arms. Our results support most of our hypotheses with medium to strong effect sizes: Balance control was improved with the use of two arms for both the railing and anchors. The addition of sensory input in combination with the required arm config- uration led to greater balance control when using the anchors; however, the lack of difference between pretend and actual use trials for the railing trials confirms that it is the arm configuration which is helping to reduce trunk sway with the railings and not the additional sensory input. Our final hypothesis suggesting the anchors would provide have a greater effect than the railing was not supported: The only difference between using the anchors and the railings was a slower stride velocity when using the railing(s).

This research demonstrates the importance of considering arm configuration when adding sensory input during walking: The pnMLTV decreased when using two arms compared to one arm for both the railing and anchors with medium to strong effect sizes. A possible mechanical explanation may be the increased frontal plane total body moment of inertia with both arms out to the sides, increasing the resistance to trunk sway. Another possible cause for the differences between the one and two arms conditions could be the symmetry of the body. The symmetry present when both arms were used may have improved control of the trunk and decreased pnMLTV. For the railing(s), there was no added reduction seen in pnMLTV when actually touching the railing compared to the pretend use trials suggesting the benefits to improved balance control when using the railings are mostly caused by the arm

Table 2

Means (SE) values for main outcome variables for the railing and anchor use for the one and two arms conditions.

Outcome variable	Condition	Railing	Anchors
Stride velocity (a.u.)	One arm	0.447 (0.03)[*]	0.461 (0.03)[*]
	Two arms	0.443 (0.03)[*]	0.463 (0.02)[*]
Relative time in double support (%)	One arm	23.1 (5.0)	22.1 (4.2)
	Two arms	23.2 (4.8)	21.8 (4.6)
Peak normalized medio-lateral trunk velocity (a.u.)	One arm	57.2 (12.1)	58.4 (11.9)
	Two arms	43.5 (13.2)	52.0 (11.5)

[*] = significant difference between railing and anchor ($p < .001$)

configuration required to lightly touch the railing(s). The significant reduction in pnMLTV when actually using the anchors compared to pretending to use them supports previous research (Hedayat et al., 2017) and suggests that the benefits of the anchors to controlling trunk movement and; therefore, walking balance control are due to both arm configuration and the added sensory input.

The decrease in stride velocity when using the railings compared to the anchors suggests that lightly touching a railing may have an adverse effect on walking. It could be that the task of maintaining light contact on a relatively small surface during walking required significantly more attentional resources and; therefore, had a negative effect on walking performance compared to simply holding and dragging the anchors (Al-Yahya et al., 2011; Awdhan, Bone, Lanovaz, Moraes, & Oates, 2019).

It is important to consider some limitations to this study. The sample population was mostly university students (< 30 years of age). As balance decreases with age (Choy, Brauer, & Nitz, 2003; Du Pasquier et al., 2003), this limits the generalizability of the findings to older adults. Another consideration is differences in postural configuration between the two tools. The railings required consistent and limiting arm configurations between participants while the anchors allowed for some variation of arm configurations. Even though participants were asked to be consistent with their arm configuration when using the anchors, variability in arm placement between trials for each participant may have influenced results. In addition, use of the railing(s) required the precise location of the finger(s) on a narrow surface with a prescribed level of force (1 N) whereas the anchors required the user to simply hold and drag the anchor(s) along. There may be additional attentional requirements for using the railings to add haptic input compared to using the anchors thereby impacting walking balance control (Awdhan et al., 2019). Adding haptic input using two railings created an environment that restricted the lateral movement of the participant. While two railings were necessary to add haptic input at each limb and the railings needed to be within arm's reach of the participant, the physical constraints of the environment may have impacted the behavior during the conditions with two railings present.

This study shows that the benefit to balance control using anchor-based haptic feedback is due, in part, to the sensory input provided by the anchors whereas the benefits from using light touch on one or more railings likely comes from postural configuration alone. When using either tool during walking, using two arms to add haptic input increases balance control through reduced trunk movement compared to using one arm. Future research should investigate the potential for including added haptic input in the form of the railing and/or anchors as part of a rehabilitation program designed to improve walking balance control.

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Declaration of Competing Interest

The authors have no competing interests to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.humov.2019.102495.

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