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# The effect of light touch on balance control during overground walking in healthy young adults

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## Abstract

Balance control is essential for safe walking. Adding haptic input through light touch may improve walking balance; however, evidence is limited. This research investigated the effect of added haptic input through light touch in healthy young adults during challenging walking conditions. Sixteen individuals walked normally, in tandem, and on a compliant, low-lying balance beam with and without light touch on a railing. Three-dimensional kinematic data were captured to compute stride velocity (m/s), relative time spent in double support (%DS), a medial-lateral margin of stability ( $MOS_{ML}$ ) and its variance ( $MOS_{MLCV}$ ), as well as a symmetry index (SI) for the  $MOS_{ML}$ . Muscle activity was evaluated by integrating electromyography signals for the soleus, tibialis anterior, and gluteus medius muscles bilaterally. Adding haptic input decreased stride velocity, increased the %DS, had no effect on the  $MOS_{ML}$  magnitude, decreased the  $MOS_{MLCV}$ , had no effect on the SI, and increased activity of most muscles examined during normal walking. During tandem walking, stride velocity and the  $MOS_{MLCV}$  decreased, while %DS,  $MOS_{ML}$  magnitude, SI, and muscle activity did not change with light touch. When walking on a low-lying, compliant balance beam, light touch had no effect on walking velocity,  $MOS_{ML}$  magnitude, or muscle

activity; however, the %DS increased and the  $MOS_{MLCV}$  and SI decreased when lightly touching a railing while walking on the balance beam. The decreases in the  $MOS_{MLCV}$  with light touch across all walking conditions suggest that adding haptic input through light touch on a railing may improve balance control during walking through reduced variability.

Keywords: Biomedical engineering, Rehabilitation, Neuroscience, Health sciences

## 1. Introduction

Balance control is important for all daily activities—especially for individuals with increased fall risk [1]. As balance control is a modifiable risk factor for falls in older adults [2], interventions aimed at improving balance control may result in a reduction of fall-related injuries with economic, social, and personal benefits [2]. One way to improve balance is through enhanced haptic input via light touch on a stable, external surface external (e.g., railing) [3]. Shear and/or compression forces resulting from touch on an external surface or device are transmitted via mechanoreceptors in the skin and proprioceptors in the joints [3]. This added sensory information gives an individual more information about their position relative to the stable surface as well as their position in the external environment.

Most investigations on the stabilizing effect of haptic input have focused on the relatively static task of quiet standing, whereas walking entails a complex form of balance control with more challenging sensorimotor integration requirements. The use of haptic input to enhance balance during walking is an emerging area of investigation with many gaps in knowledge, including how haptic input affects the more natural task of walking overground and during challenging walking conditions. Research to date on dynamic balance tasks such as standing with a balance perturbation [4], walking on a treadmill [5], or normal walking overground, in healthy [6] individuals or post stroke [7] has demonstrated a beneficial effect of haptic input on balance. The effect of haptic input on young adults' walking performance in challenging overground walking conditions where the base of support is narrowed and/or the kinesthetic input is reduced has not been examined to date.

Dynamic balance control is achieved by maintaining the centre of mass (CoM) inside the current and/or projected base of support. Walking in tandem (heel to toe) decreases the medial-lateral (ML) dimension of the base of support thereby mechanically increasing the balance challenge. Walking on a compliant surface such as sand or snow increases the balance challenge by altering the kinesthetic information used to detect the orientation of the plantar foot surface with the ground [8]. Walking on a compliant surface with a narrow base of support (i.e., on a foam balance beam) further increases the balance challenge through both mechanical and sensory mechanisms.

This research aimed to investigate the effect of added haptic input during normal walking, tandem walking, and walking on a compliant, low-lying balance beam in healthy young adults. We hypothesize that lightly touching a railing while walking would: 1) improve stability for all walking conditions [5, 9] without affecting locomotor progression and 2) reduce muscle activity [10] in the lower extremities. Understanding the effect of light touch during overground walking in a healthy young population will provide the basis for future research to compare to older adults and other populations with known balance challenges.

## 2. Materials and methods

### 2.1. Participants

Sixteen healthy young adults (mean age: 25.76 ( $\pm$ 3.52) years, 8 males) consented to participate. Participants were included based on age (18–65 years) and excluded if they reported any conditions that would affect their walking or balance (e.g., spinal cord injury, neuropathy, and musculoskeletal injury). The study protocol received approval from the University of Saskatchewan Human Biomedical Research Ethics Board and all participants provided informed consent before being tested.

### 2.2. Protocol

Participants were asked to walk normally (normal walking: NW) or in tandem (heel to toe tandem walking: TW) for 10 m, and for 5.5 m on a low-lying, compliant foam balance beam (balance beam BB: 4" high x 4" wide, Flaghouse Canada, Ontario, Canada). If an individual was not able to maintain their balance during a TW or BB trial, he/she was asked to continue walking, either in tandem or on the balance beam as appropriate, toward the end of the walkway and these strides were excluded from analysis. In some trials, participants were asked to lightly touch a railing using the index finger of their dominant hand (self-reported). The railing was set at a comfortable height (86 cm, standard building code height) and located along the walking path at a distance that did not affect walking progression and did not require the individual to lean towards or fully extend their arm to touch the railing. Participants were able to practice touching the railing with online feedback given by a researcher to familiarize the level of touch required; however, they did not practice walking and touching the railing. If the level of touch exceeded 1 N during a trial, a researcher asked the participant to try to use lighter touch on the railing in the subsequent trial. All trials were completed in a semi-random order where walking conditions (i.e., NW, TW, or BB) were randomized within a testing period and trials without haptic input were paired with trials with haptic input for that walking condition. Each condition was repeated five times. Participants were asked to walk at their preferred speed while wearing shoes

that they were comfortable walking in that were not sandals and did not have heels. A minimum of two strides in the middle portion of the walkway for each trial were included for analysis in all conditions.

### 2.3. Instrumentation

Three-dimensional kinematic data were captured (Vicon Motion Systems, CO, USA) by placing reflective markers on the feet, lower limbs, pelvis, trunk, upper limbs, and head. Kinematic data were sampled at 100 Hz and low-pass filtered at 8 Hz post collection. Virtual markers on the feet allowed for the calculation of the lateral boundary of each foot during stance phase. A 12-segment whole-body model was mapped to the kinematic data and used to calculate the location of the total body CoM for each frame of data based on published body segment parameters [11].

The railing used to provide haptic feedback was aluminum with a smooth finish and a 20 mm diameter circular profile. The rail was instrumented with two force transducers (Futek Advanced Sensory Technology, Inc., CA, USA; range 0 to 5 N) to measure the level of touch on the railing. The total force output from the rail was calibrated for each participant using a series of four known weights each placed at five locations along the rail. A least squared fit quadratic calibration was used with an average absolute error less than 0.05 N.

Surface electromyography (EMG) was used to measure muscle activity bilaterally in the tibialis anterior (TA), soleus (SOL), and gluteus medius (GM). Pairs of AgCl electrodes were placed over the appropriate muscle bellies and electrode placement was confirmed with voluntary contractions and real-time monitoring of the signal. EMG signals were sampled at 2000 Hz, high-pass filtered at 20 Hz, full-wave rectified, and then low-pass filtered at 100 Hz.

All kinematic, force and EMG data were processed offline using custom routines (Matlab R2006b, Mathworks, Natick, MA, USA).

### 2.4. Analysis

Walking performance was evaluated by the forward gait velocity (m/s) (stride length/stride time for each stride) and the relative time spent in double support (% DS). Examining walking velocity provided insight into the effect of added haptic input on overall walking performance. An increase in the %DS indicated spending more time with both feet on the ground per stride and; therefore, a more cautious gait pattern with enhanced mechanical stability.

Stability was assessed in the ML plane using the average magnitude of the margin of stability ( $MOS_{ML}$ ) and its variability during a stride ( $MOS_{MLCV}$ ). The  $MOS_{ML}$  magnitude, averaged across each stride, was calculated by finding the distance

between the extrapolated CoM position [12] and the closest lateral edge of the base of support determined by the foot markers. Stride-to-stride variability of the  $MOS_{ML}$  was assessed using the coefficient of variation ( $SD/mean = MOS_{ML}CV$ ). A larger  $MOS_{ML}$  magnitude value [13] and smaller  $MOS_{ML}CV$  [14] indicated improved stability. A symmetry index (SI) of the MOS was also calculated to examine differences in the  $MOS_{ML}$  between the touch and no-touch side of the body using the following equation:  $SI = 1 - ((MOS_{MLTOUCH} - MOS_{MLNOTOUCH}) / (MOS_{MLTOUCH} + MOS_{MLNOTOUCH}))$ . A value closer to one suggested greater symmetry where a value less than one suggested a larger  $MOS_{ML}$  on the touch side.

Muscle activity was evaluated by integrating the signals for each muscle over a stride. Muscles were categorized according to the side closest to the railing (touch side) or farthest away from the railing during light touch trials. A reduction in the amount of muscle activity with light touch suggested improved control of walking [10]. Integrated EMG values were normalized to walking velocity to account for any changes in muscle activity that may occur with changes in walking velocity [15].

Data were examined for normality using a Shapiro-Wilk test and by examining the skewness and kurtosis values relative to the standard error. If data were not normally distributed, data that were more than three standard deviations outside of the mean were removed to normalize the data. Pearson's correlation analysis was used to determine if the  $MOS_{ML}$  was correlated to stride velocity for each walking style. Two-tailed paired t-tests were used to compare the no touch and touch conditions within each walking style (NW, TW, BB;  $\alpha = .05$ ). Effect sizes were calculated using Cohen's d [16] with a correction for dependence between means [17] with  $d = .2$  (small),  $d = .5$  (medium), and  $d = .8$  (large).

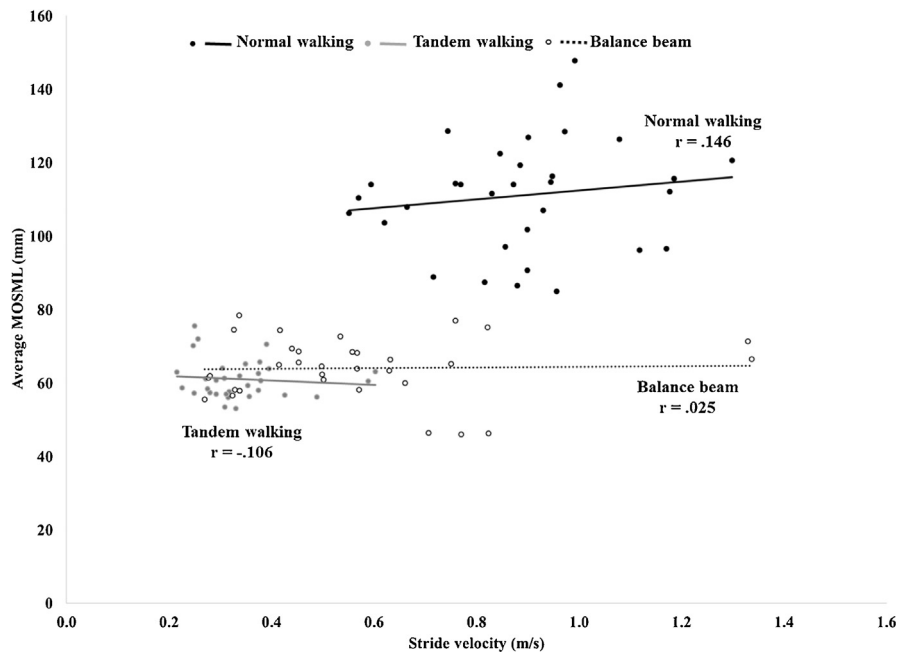
### 3. Results

The average level of force applied to the railing was below 1 N for all walking conditions (NW = .51 N, TW = .66 N, BB = .52 N). Table 1 includes means (+/- 95% CI) for stride velocity, %DS,  $MOS_{ML}$ ,  $MOS_{ML}CV$ , and SI for all walking conditions. During normal walking, adding haptic input with light touch on a railing decreased stride velocity ( $p = .001$ ,  $d = 1.061$ ), increased the %DS ( $p = .004$ ,  $d = .850$ ), had no effect on the  $MOS_{ML}$  magnitude ( $p = .578$ ), and decreased the variability of the  $MOS_{ML}$  ( $p = .012$ ,  $d = .764$ ). There was no effect of light touch for the SI ( $p = .117$ ) and  $MOS_{ML}$  and stride velocity were not significantly correlated (Fig. 1:  $p = .426$ ,  $r = .146$ ) during normal walking. During NW, muscle activity significantly increased during the touch conditions in all muscles except for the TA on the touch side (Touch side: TA  $p = .108$ ; SOL  $p = .002$ ,  $d = .986$ ; GM  $p = .003$ ,  $d = 1.057$ . Non-touch side: TA  $p = .005$ ,  $d = .827$ ; SOL  $p = .002$ ,  $d = .971$ ; GM  $p = .044$ ,  $d = .578$ ).

**Table 1.** Average (with lower and upper 95% Confidence Interval (CI) values) for kinematic variables.

	Normal walking		Tandem walking		Balance beam	
	No Touch	Touch	No Touch	Touch	No Touch	Touch
<b>Gait velocity (m/s)</b>	.94 (.84–1.03)	.84* (.74-.93)	.35 (.30-.40)	.33* (.28-.38)	.58 (.44-.72)	.56 (.41-.70)
<b>%DS (%)</b>	33.9 (31.7–36.2)	35.8* (33.5–38.2)	43.8 (41.1–46.6)	44.7 (41.2–48.2)	39.8 (36.0–43.7)	42.6* (40.0–45.1)
<b>MOS<sub>ML</sub> (mm)</b>	111.1 (102.6–119.7)	110.3 (102.7–117.9)	60.4 (57.7–63.1)	61.9 (58.9–64.9)	62.7 (57.8–67.5)	65.6 (69.7–61.5)
<b>MOS<sub>ML</sub>CV (%)</b>	21.4 (19.4–23.3)	19.5* (18.1–20.9)	17.0 (14.3–19.7)	14.2* (11.6–16.8)	21.3 (17.0–25.7)	16.1* (12.3–19.9)
<b>SI</b>	1.03 (.97–1.10)	.99 (.95–1.03)	1.0 (.98–1.15)	.98 (.93–1.02)	1.08 (.97–1.2)	.92* (.85-.99)

%DS = percentage of time spent in double support. MOS = margin of stability. ML = mediolateral. CV = coefficient of variation. SI = symmetry index. \* = significantly different from No Touch condition (within walking condition).



**Fig. 1.** Scatterplot showing the average  $MOS_{ML}$  and stride velocity data along with the associated Pearson correlation analyses for the normal walking (Normal walking), tandem walking (Tandem walking), and walking on a low-lying, compliant balance beam (Balance beam) conditions.

Lightly touching a railing during tandem walking decreased stride velocity ( $p = .046$ ,  $d = .551$ ), had no effect on %DS ( $p = .376$ ) or the magnitude of the  $MOS_{ML}$  ( $p = .187$ ), and decreased the variability of the  $MOS_{ML}$  ( $p = .022$ ,  $d = .655$ ). Lightly touching the railing did not affect the SI ( $p = .051$ ) and  $MOS_{ML}$  was not significantly correlated with stride velocity (Fig. 1:  $p = .564$ ,  $r = -.106$ ) during tandem walking. There were no significant changes in any of the muscle activities with light touch during tandem walking.

When walking on a low-lying, compliant balance beam, lightly touching a railing had no effect on walking velocity ( $p = .133$ ), increased the %DS values ( $p = .034$ ,  $d = .693$ ), had no effect on the  $MOS_{ML}$  magnitude ( $p = .105$ ), and decreased the variability of the  $MOS_{ML}$  ( $p = .017$ ,  $d = .683$ ). The SI was significantly lower during light touch trials during balance beam walking ( $p = .004$ ,  $d = .940$ ). There was no significant correlation between  $MOS_{ML}$  and stride velocity (Fig. 1:  $p = .894$ ,  $r = .025$ ). There were no significant changes in any of the muscle activities with light touch when walking on the balance beam.

#### 4. Discussion

This study investigated the effect of adding haptic input in the form of light touch on a railing during different and challenging walking conditions in young healthy adults. The results support previous research examining the effect of added haptic

input during normal walking [6, 9] and present new information about the effect of light touch during walking on the more challenging walking conditions of tandem walking and walking on a compliant, low-lying balance beam in young, healthy adults. Lightly touching a fixed railing may improve balance control as seen in the reduced variability of the margin of stability in all walking conditions.

During normal walking, adding light touch decreased forward velocity. The decrease in stride velocity suggests that adding haptic input may not just add sensory information but also attentional demands that might interfere with walking performance [14, 18, 19]. Notably, the average stride velocity for participants in this study was slower than previously reported results for healthy young adults [6, 14]; however, the stride velocity for this study was similar to other research studies conducted in the same research environment. While increases in the relative time spent in double support leads to a mechanically more stable gait, it also suggests a more cautious gait [20] perhaps due to the increased attentional demands assumedly required to maintain light contact with the railing. The reduction in  $MOS_{ML}$  variability aligns with previous research [5] and suggests an improvement in balance control. While the magnitude of reduction in  $MOS_{ML}$  variability in this study was small, it is similar to the magnitude of the difference in step width variability between older adults identified as fallers and non-fallers [21] suggesting that adding haptic input may indeed have meaningful improvements to walking stability.

When the ML base of support was reduced and the balance challenge was increased during tandem walking, adding haptic input through light touch reduced walking velocity which, as suggested above, may be due to the additional attentional demands of light contact on the railing [14, 18, 19]. Unlike normal walking, the time spent in double support did not change but there was still a positive effect on stability seen through a decrease in the variability of the margin of stability. Previous research investigating the effect of added haptic input on stability during tandem walking in older adults also found an improvement in stability as seen by a decrease in variability of the ML trunk acceleration [9]. The effect sizes for all significant effects in tandem walking are limited; however, and may indicate the need for further research to determine if adding haptic input can indeed improve stability during tandem walking.

When walking on a compliant, low-lying balance beam, not only was the ML base of support reduced in size (mechanical challenge) but important sensory information about the body's orientation with respect to a support surface was impaired (sensory challenge) [8]. Similar to normal walking, light touch on a railing did not change the  $MOS_{ML}$ , increased the relative amount of time spent in double support, and decreased the variability of the margin of stability. Different from normal walking, stride velocity did not change and the  $MOS_{ML}$  was smaller on the side closest to the railing (decreased SI value). We hypothesize that the



added haptic input may have replaced the sensory input impaired by the compliant surface and facilitated walking performance beyond simple narrow-based (i.e., tandem) walking. The task of adding haptic input during balance beam walking may have had the same attentional demands as outlined above but the beneficial effect of replacing important sensory information about body orientation may have overridden any detrimental velocity-related effect on the added attentional demands. Notably, walking velocity during the balance beam condition was faster than tandem walking which reflects observations of individuals visibly walking faster and is likely due to increased step length as individuals did not consistently walk heel-to-toe on the balance beam. The change in the symmetry index indicates that individuals created a larger MOS on the opposite side of the railing compared to the no touch trials. Participants may have shifted towards the railing to ensure contact with the railing was maintained during this difficult walking task.

Adding haptic input through light touch on a railing did not affect the  $MOS_{ML}$  in any of the walking conditions. It is unclear why the magnitude of the  $MOS_{ML}$  did not change with haptic input but it may be due to the balance conditions utilized in this study. The  $MOS_{ML}$  was calculated using the lateral edges of the base of support. Both the tandem and balance beam conditions constrained the ability to modify the lateral boundaries limiting the absolute range of stable  $MOS_{ML}$  values; therefore, the  $MOS_{ML}$  could only be effectively modified by changing the COM motion. Notably, the  $MOS_{ML}$  was not correlated to stride velocity in any of the walking conditions suggesting the  $MOS_{ML}$  is controlled independently of walking speed.

We hypothesized that adding haptic input would lead to a decrease in muscle activation as a result of improved control [10]. During normal walking, muscle activation in most muscles increased with light touch, despite a slower walking velocity, suggesting a different control strategy during this condition. The increased muscle activity may have led to a more consistent  $MOS_{ML}$  as discussed above. The increased muscle activity during normal walking may also be due to the change in the attentional demands as proposed above [22] but research investigating the effect of an added task on muscle activity during walking has shown mixed results [23, 24, 25]. Previous studies investigating the effect of added haptic input have also found mixed results for changes in muscle activity [7, 10, 26, 27]; however, those studies were completed using treadmill walking [10, 26, 27], and/or with individuals who have had a stroke [7, 27]. The absence of a significant difference in muscle activity with added touch for the tandem and balance beam conditions could be due to increased muscular requirements for the more difficult walking tasks. These more challenging conditions may have increased the muscular requirements towards maximal levels thereby limiting the opportunity for any changes related to added sensory input.

## 4.1. Limitations

This study presents unique results investigating the effect of added haptic input during challenging walking conditions; however, there are some limitations which should be considered. First, all walking conditions were performed with full vision. Previous research suggests that adding haptic input in young healthy adults may have a greater impact on balance when vision is removed [5, 28]. Investigating the effect of added haptic input without vision may have produced different results showing a stronger effect, especially for tandem walking. Next, holding one arm extended to lightly touch the railing may have had an impact on stability regardless of the additional sensory input [29, 30]. Also, the attentional demand of adding haptic input through light touch on a rail has not been determined. If there is added attentional demand, future research should investigate ways to either decrease the attentional demand and/or train individuals to reduce attentional demands. There was also no measure in this study about how participants felt about using the railing in terms of comfort, their perception of their balance, and if they would use light touch to improve balance control outside of the laboratory setting. This qualitative information could be used to inform future research design. The balance beam used was slightly raised off the floor. Walking with a narrow base of support on a raised surface may have had added challenges compared to walking in tandem on a level floor; however, the height was required to provide the compliant surface and was intentionally low to limit any height effects. Finally, stride velocity was calculated using strides from the middle of the walkway: It is possible that those strides included fragments of acceleration/deceleration from the start/end of the walkway thereby explaining the low values for a young healthy population.

## 5. Conclusions

Adding haptic input through light touch on a railing seems to improve balance control through a reduction in the variability of the  $MOS_{ML}$ . These results suggest that adding haptic input through light touch on a railing may improve balance, particularly when balance is challenged through mechanical and sensory restrictions. More research is needed to understand the attentional demands associated with adding haptic input, and users' perspective on adding haptic input during walking.

## Declarations

### Author contribution statement

Alison Oates, Joel Lanovaz: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Janelle Unger: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Cathy Arnold, Joyce Fung: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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### **Competing interest statement**

The authors declare no conflict of interest.

### **Additional information**

No additional information is available for this paper.

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