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Effect of Facilitation of Sensation From Plantar Foot-Surface Boundaries on Postural Stabilization in Young and Older Adults

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Background. One of the more pervasive effects of aging is loss of cutaneous sensation, which appears to correlate with impaired postural control and increased risk of falling. This study examined the potential for compensating for the destabilizing effects of reduced cutaneous sensitivity by placing a raised edge underneath the perimeter of the plantar foot surface, so as to facilitate sensation from the stability boundaries of the base of support.

Methods. The main experiment involved 14 healthy older adults (aged 65–73) selected because they were known, from a previous study, to have moderate plantar cutaneous insensitivity. We also report results of an initial experiment involving 7 healthy young adults (aged 23–31). In both experiments, we studied effects of the plantar facilitation on control of rapid stepping reactions evoked by unpredictable postural perturbation, applied via sudden platform movement in forward, backward, and lateral directions. We also studied effects on "feet-in-place" responses evoked by continuous pseudorandom platform motion in mediolateral and anteroposterior directions. Subjects were blindfolded in all tests.

Results. Plantar facilitation reduced the incidence of "extra" limb movements, beyond the initial step, during forward-step reactions in the older adults. There also appeared to be an improved ability to control feet-in-place reactions: young subjects were better able to recover balance without stepping when falling backward (given instructions to "try not to step"), and both young and older subjects reduced the extent to which the center of foot pressure approached the posterior foot boundary during continuous anteroposterior platform motion.

Conclusions. This study provides evidence that mechanical facilitation of sensation from the boundaries of the plantar surface of the foot can improve the efficacy of certain types of stabilizing reactions evoked by unpredictable postural perturbation. The results may be directly transferable to the design of special footwear insoles to reduce instability and risk of falling in older adults.

DIFFICULTY in controlling postural stability appears to be a major contributor to an increased risk of experiencing falls and sustaining related injuries in older adults (1). Although the mechanisms underlying the effect of aging on the postural control system are varied and complex, impaired sensory function is likely to be an important contributing, and potentially remediable, factor (1,2). Age-related loss of cutaneous sensation, in particular, is pervasive (3,4) and appears to correlate with impaired control of postural sway (2,3,5), as well as risk of falling (6). Numerous studies support the important contribution of cutaneous sensation, from the plantar foot surface, in the control of balance (7–15).

It may be possible to develop interventions to improve functional stability in older adults by augmenting sensation from the plantar foot surface. A simple approach is to facilitate sensation mechanically, by means of raised "indentors" within the footwear insole. In previous studies (7,8), such facilitation, implemented by standing on a grid-like array of ball bearings, was found to increase afferent nerve activation and reduce postural sway; "feet-in-place" reactions to postural perturbation also appear to be affected by this type of facilitation (1). Plantar facilitation is likely to be particularly beneficial when stepping to recover balance, by providing information about foot-contact and limb loading; however, effects on these important "compensatory stepping" reactions (16) have not been studied. Previous studies have also been limited in terms of the indentor designs. Rather than using an array of indentors to provide stimulation across the entire foot pad, it may be advantageous to promote sensation specifically from the plantar-surface boundaries. Such sensation could play an important role, within the central nervous system (CNS), in determining the proximity of the body center-of-mass (COM) to the stability boundaries of the base of support (BOS) established by the feet. COM location, relative to the BOS, is thought to be a critical variable that is controlled by the CNS in maintaining upright stance (17).

This study examined potential stabilizing effects due to mechanical facilitation of sensation from the boundaries of the plantar foot surface. The main experiment involved healthy older adults having moderate plantar cutaneous insensitivity. In addition, we report the results of an initial experiment involving healthy young adults. In both experiments, we studied control of rapid stepping reactions evoked by unpredictable postural perturbation, applied by sudden transient platform movement, in forward, backward, and lateral directions. In addition, we measured "feet-in-place" responses evoked by continuous pseudorandom platform motion. Subjects were blindfolded to maximize potential dependence on plantar cutaneous information.

For stepping reactions, it was hypothesized that the facilitation would lead to increased stability following foot contact because of improved ability to sense and control contact of the foot with the ground and subsequent transfer of load to the limb.

This improvement, we predicted, would manifest as a reduced tendency to execute "extra" stabilizing reactions (i.e., taking additional steps or moving the arms). Increased information about BOS stability boundaries, due to the facilitation, was expected to improve ability to maintain the COM over the BOS and thereby improve ability to resist stepping. For continuous perturbation, we predicted that this effect would manifest as increased "stability margins", that is, reduced excursion of the center of foot pressure (COP) toward the BOS boundaries (18).

MATERIALS AND METHODS

Subjects

The initial study involved 7 healthy young adults (2 men and 5 women; average age 26, range 23–31; average weight 72 kg, range 48–88 kg; average height 168 cm, range 147–182 cm). The main experiment involved 14 older adult subjects (8 men and 6 women; average age 69, range 65–73; average weight 73 kg, range 48–94 kg; average height 163 cm, range 150–177 cm). Inclusion criteria were: right-side dominance; able to stand one minute and walk 10 m without assistance; able to understand English instructions; living independently. Volunteers were excluded if they reported any of these conditions: diabetes; neurological or sensory disorders; recurrent dizziness or unsteadiness; use of medications that may affect balance; joint replacement or fusion; medical conditions interfering significantly with daily activities; or functional limitations on use of the limbs. Each subject provided written informed consent to comply with ethics approval granted by the institutional review board.

All older adult subjects had participated in a previous postural-perturbation study within the preceding 6 months; 6 of the 7 young adults had no prior exposure to balance testing. The 14 older adult subjects were selected from a pool of 35 previous volunteers on the basis of plantar sensitivity measures collected during the previous study. Our objective was to recruit subjects with measurable, but not complete, loss of sensation. Vibration-detection thresholds (100 Hz) in the selected subjects were 9–86 μm (median = 24) at the fifth metatarsal head and 10–100 μm (median = 39) at the heel. Corresponding ranges reported for healthy young adults (similar measurement conditions) are 2.5 ± 2.5 μm (mean ± *SD*) and 7.5 ± 9 μm (19).

Facilitation of Sensation From Plantar-Surface Boundaries

To facilitate sensation, a length of flexible polyethylene tubing (3 mm outer diameter, 1 mm inner diameter) was adhered to the plantar foot surface, using double-sided tape (see Figure 1 for details of the tubing placement used in each experiment). Pilot tests, in which blindfolded subjects were asked to map out the location of tubing segments (placed, randomly, at different locations under the foot), demonstrated that subjects were well able to perceive the facilitation. Pilot tests in which volunteers moved about while wearing the tubing for several hours showed no problems with discomfort or loosening of adhesion to the skin. In addition, during balance testing, all subjects reported that they could perceive the facilitation, without discomfort, and there was negligible loosening of the adhesion.

Postural Perturbation Tests

Postural reactions were evoked by horizontal translation of a computer-controlled, movable platform (20). Subjects stood at the center of the platform, with each foot on a forceplate (a third forceplate was behind the subject), in a standardized position [14-degree angle between medial foot margins, spacing between heel centers = 11% of body height (21)]. The large (2 × 2 m), flat surface of the platform allowed unobstructed space for subjects to step. Safety handrails were mounted around the perimeter of the platform. In addition, older subjects wore a safety harness (designed to prevent impact with the floor, without otherwise restricting movement or providing proprioceptive feedback).

Stepping reactions were evoked by sudden transient platform motion, either forward, backward, left or right; "feet-in-place" reactions were elicited by continuous (pseudorandom) anteroposterior (ap) or mediolateral (ml) platform motion (see Figure 2 for details). To reduce potential for predictive adaptation, perturbation direction, magnitude, and timing (30–45 s between trials) were varied in an unpredictable manner. In all trials, subjects wore a blindfold and held a lightweight, 40-cm rod (transversely, behind the buttocks) to deter arm movement. Subjects were instructed to close their eyes, hold their head as if looking straight ahead, and try not to move their arms. During continuous-perturbation tests, they listened to "white noise" through headphones (to mask auditory cues from the platform) and were asked to count aloud backward by threes (to control attentional variation).

Protocol

The initial experiment (young adults) included 96 transient- and 8 continuous-perturbation trials (see Table 1 for details). The main experiment (older adults) was shortened to allow for the reduced endurance of older subjects: 40 transient- and 16 continuous-perturbation trials. In addition, the range of perturbation magnitudes was reduced to allow for age-related reduction in stability. Subjects were always instructed to try not to step in continuous-perturbation trials; however, instructions for transient-perturbation trials differed for the two experiments: young subjects were instructed to try not to step (to assess efficacy of "feet-in-place" reactions), whereas older adults were given no explicit instructions regarding foot movement (to simulate "natural" behavior). In both experiments, half the trials were performed with plantar facilitation and half were performed without, and order of testing was balanced across subjects.

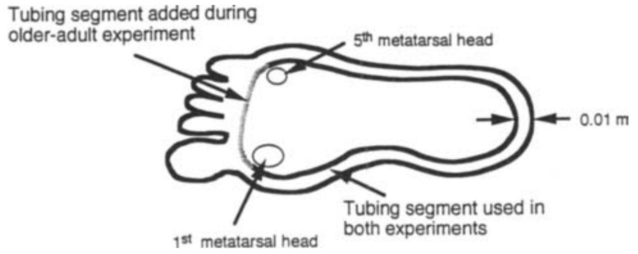
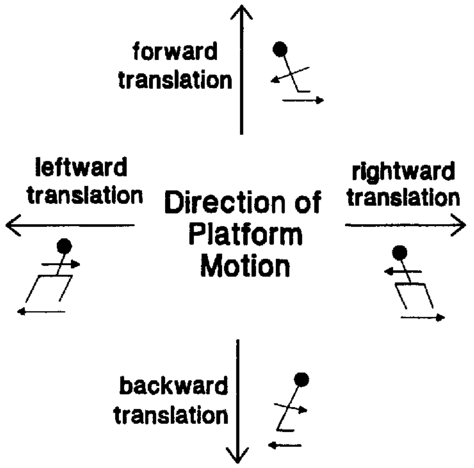


Figure 1. Facilitation of sensation from the plantar-surface boundary. The placement of the tubing, used to facilitate sensation, is shown relative to the boundary of the plantar foot surface. Note that the anterior section of tubing (placed transversely across the foot, midway between the calloused region over the metatarsal heads and the skin crease at the base of the toes) was not included in the initial experiment, but was added to the main experiment to determine if any additional benefits would accrue.



Transient translations	accel (m/s^2)	vel (m/s)	displ (m)
Forward:			
medium magnitude	1.3	0.40	0.12
high magnitude	2.0	0.60	0.18
Lateral and backward:			
medium magnitude	2.0	0.60	0.18
high magnitude	3.0	0.90	0.27

Continuous translations	accel (m/s^2)	vel (m/s)	displ (m)
Anteroposterior:			
medium magnitude	0.05	0.02	0.08
high magnitude	0.10	0.04	0.15
high+ magnitude	0.15	0.06	0.23
Mediolateral:			
medium magnitude	0.10	0.04	0.15
high magnitude	0.20	0.08	0.30

Figure 2. Perturbation characteristics. The directions of platform motion that were used in the balance tests, and the corresponding patterns of body motion, are indicated schematically. The acceleration, velocity, and displacement corresponding to the transient platform motion are listed in the upper panel (the transient waveform was 600 ms in duration, comprising a 300-ms square-wave pulse of acceleration followed immediately by a 300-ms deceleration pulse). The root-mean-square acceleration, root-mean-square velocity, and peak-to-peak displacement corresponding to the continuous pseudorandom platform motion are listed in the lower panel (the continuous waveform was 96 s in duration and comprised a sum of 15 sinusoids ranging in frequency from 0.13 to 5.0 Hz).

Table 1. Details of the Experimental Protocols

Trial Block	Facilitation in Group 1 [Group 2]*	Perturbation Waveform	Perturbation Directions†	Perturbation Magnitudes†	Number of Replicates	Total No. Trials per Trial Block‡
Initial Experiment (young adults)						
1, 4	No [Yes]	Transient	4 (L,R,F,B)	2 (med, high)	3	24
		Continuous	2 (ml,ap)	1 (high/high+)	1	2
2, 3	Yes [No]	Transient	4 (L,R,F,B)	2 (med, high)	3	24
		Continuous	2 (ml,ap)	1 (high/high+)	1	2
Main Experiment (older adults)						
1	No [Yes]	Transient	4 (L,R,F,B)	1 (med)	5	20
2	Yes [No]	Transient	4 (L,R,F,B)	1 (med)	5	20
3	No [Yes]	Continuous	2 (ml,ap)	2 (med, high)	2	8
4	Yes [No]	Continuous	2 (ml,ap)	2 (med, high)	2	8

*For each experiment, subjects were divided into two groups, according to the order in which facilitation and nonfacilitation trials were administered; facilitation conditions for both groups are listed (group 2 in brackets).

†Within each block, replicates of perturbations were presented in "rounds." In the initial experiment, each round of transient perturbations comprised 8 trials (4 directions × 2 magnitudes, in random order); the 2 continuous perturbations (1 in each direction, in random order) were administered at the end of the trial block. In the main experiment, each round of transient perturbations comprised 4 trials (1 in each direction, in random order); each round of continuous perturbations also comprised 4 trials (2 directions × 2 magnitudes, in random order). Abbreviations: L = left, R = right, F = forward, B = backward, ap = anteroposterior, ml = mediolateral, med = medium. See Figure 2 for definition of perturbation magnitudes (note: "high+" magnitude was used for ap continuous perturbations in initial experiment).

‡In addition to the trials listed, a short series of "familiarization trials" was performed prior to the start of the experiment. Total time spent standing on the platform was approximately 3.5 hours for young adults and 1.5 hours for older adults. Subjects were seated for 10–15 minutes during each change in facilitation condition.

Measurements and Analysis

Four high-resolution video cameras were used to record postural behavior (stepping and arm movements). Step location was determined (±1 cm) by resolving the position of a marker on the foot relative to a grid on the platform, using an overhead camera view. The forceplate signals were used to determine step timing (foot-off and foot-contact), COM motion during the step (via double integration of shear forces), rate of limb loading (after foot contact) and, for continuous-perturbation tests, COP displacement.

For each continuous-perturbation trial, we characterized the degree to which the COP approached the anterior and posterior BOS boundaries (ap perturbations) or the lateral BOS boundaries (ml perturbations) by determining the forward, backward, or lateral COP displacement level that was exceeded for less than 1% of the trial (99th percentile). For transient-perturbation trials, the primary variables of interest were the frequency of stepping reactions and, within the stepping reactions, the frequency of "extra" steps and/or arm movements (of sufficient magnitude to involve releasing the rod) beyond the initial stepping reaction. For lateral-perturbation responses that involved a sequence of "side-steps," the first two steps were considered to constitute the initial reaction [the initial medially directed step, which provides little stabilization in itself, appears to be a preparation for executing a laterally directed step with the contralateral leg (20)].

Repeated-measures analysis of covariance (ANCOVA) was used to test the hypothesis that facilitation would lead to reduced COP excursion during continuous-perturbation tests (trial number was included as a covariate, to control for order effects due to "learning" or fatigue). For transient-perturbation trials, the Fisher Exact Test was performed to test hypotheses that facilitation would (a) improve ability to resist stepping, and (b) decrease the proportion of stepping responses that involved "extra" limb movements. Secondary analyses, involving repeated-measures ANCOVA, were performed to explore possible relationships between the need for additional reactions and the characteristics of the initial step (timing, step length, COM motion, rate of limb loading). For all ANCOVAs, order-of-testing was included as a between-subjects factor, and the data were log- or rank-transformed prior to analysis, where necessary, to achieve normality and homoscedasticity of residuals.

RESULTS

Stepping Reactions Evoked by Transient Perturbation

In the absence of instructions to resist stepping (main experiment), stepping was a very common reaction: the older-adult subjects stepped in 90% (251/280) of facilitated trials and 86% (240/280) of nonfacilitated trials. As hypothesized, the facilitation appeared to improve control of the stepping reactions. Without facilitation, 46% (111/240) of the initial stepping reactions were accompanied by "extra" reactions (additional steps or arm movements), whereas this proportion was reduced to 38% (95/251) when facilitation was provided ($p = .036$). The frequency of arm movement was reduced from 8% to 3% (18/240 vs 8/251; $p = .026$); the frequency of additional steps was reduced from 44% to 37% (106/240 vs 94/251; $p = .077$).

The effect of facilitation was most pronounced for forward steps: 44% of facilitated forward-step reactions involved "extra" limb movement versus 60% of nonfacilitated reactions (31/70 vs 42/70; $p = .045$; Figure 3). Considering only extra steps (i.e., excluding arm reactions), the difference was 44% versus 59% (31/70 vs 41/70; $p = .064$). Although similar trends also appeared to occur in backward and lateral stepping reactions, these were not statistically significant (*p*s > .24).

The facilitation appeared to improve control of forward-step reactions in 10 of 14 subjects. After adjusting for order effects (mean reduction in frequency of multiple-step reactions = 46%, trial-block 2 vs 1), the facilitation-related reduction in frequency of multiple-step reactions ranged from 6% to 86% in these 10 subjects (median=20%). Of the remaining four subjects, one showed the opposite trend (increase of 26%), two always took "extra" steps in forward-step trials (regardless of facilitation condition), and one never took "extra" steps in these trials.

Effects of the facilitation appeared to be related to control of events occurring after foot contact. For the 10 subjects who showed evidence of facilitation-related increase in stability during forward-step reactions, the characteristics of the initial step, up to the time of foot contact, were remarkably similar in comparing multiple-step reactions (nonfacilitated trials) versus single-step reactions (facilitated trials) (*p*s > .19; Figures 4A–4D). After foot contact, however, the maximum rate of swing-leg loading was reduced by 23% during facilitation trials ($p = .027$; Figure 4E).

In the initial young-adult study, effects of facilitation were restricted to backward stepping reactions evoked by medium-magnitude perturbations. For these responses, facilitation improved ability of the young adults to resist stepping (as instructed): stepping occurred in 19% (8/42) of facilitated trials versus 38% (16/42) of nonfacilitated trials ($p = .045$). No effect on frequency of stepping was seen for other directions (*p*s > .76), nor for large perturbations (the large perturbations forced subjects to step in over 85% of trials, with or without facilitation). The frequency of "extra" reactions was low in the young subjects regardless of facilitation condition (15% of stepping responses vs 17%, facilitated vs nonfacilitated; $p = .35$).

Feet-in-Place Responses to Continuous Perturbation

Results from the main experiment support the hypothesis that facilitation would decrease COP excursion; however, this effect was seen only in the backward direction ($p = .003$; *p*s > .13 for forward and lateral directions). The effect on backward COP excursion appeared to occur primarily at the "high" perturbations (Figure 5). For these responses, the average size of the facilitation effect (percentage decrease in backward COP excursion) was about 10%, and there was a mean reduction in backward COP excursion in 9 of 14 subjects (mean reductions, adjusted for order of testing, ranged from 3%–13% of BOS length, median = 6%). Of the remaining five subjects, one showed negligible change and the others showed an increase, rather than decrease, in backward COP excursion (1.5%–6% of BOS length).

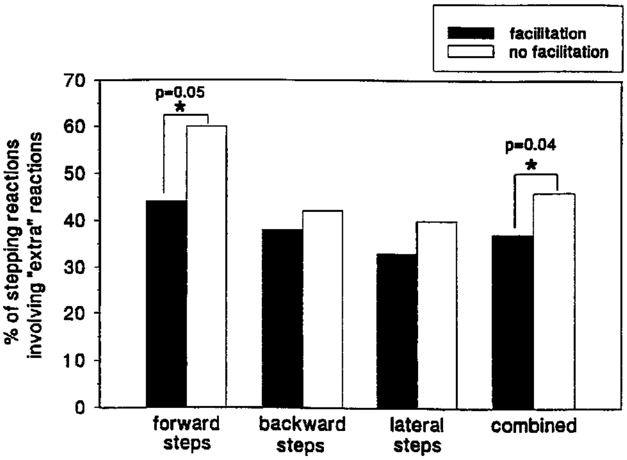


Figure 3. Summary of results from the transient-perturbation trials (older adults). The percentage of stepping responses in which "extra" limb reactions (additional steps and/or arm movements) were executed is shown for each direction of stepping (initial step): forward, backward, and lateral. In addition, the percentage is shown for all directions combined. The percentages were calculated across all 14 older-adult subjects. Statistically significant differences, due to facilitation, are indicated on the graph (Fisher Exact Test; $p < .05$).

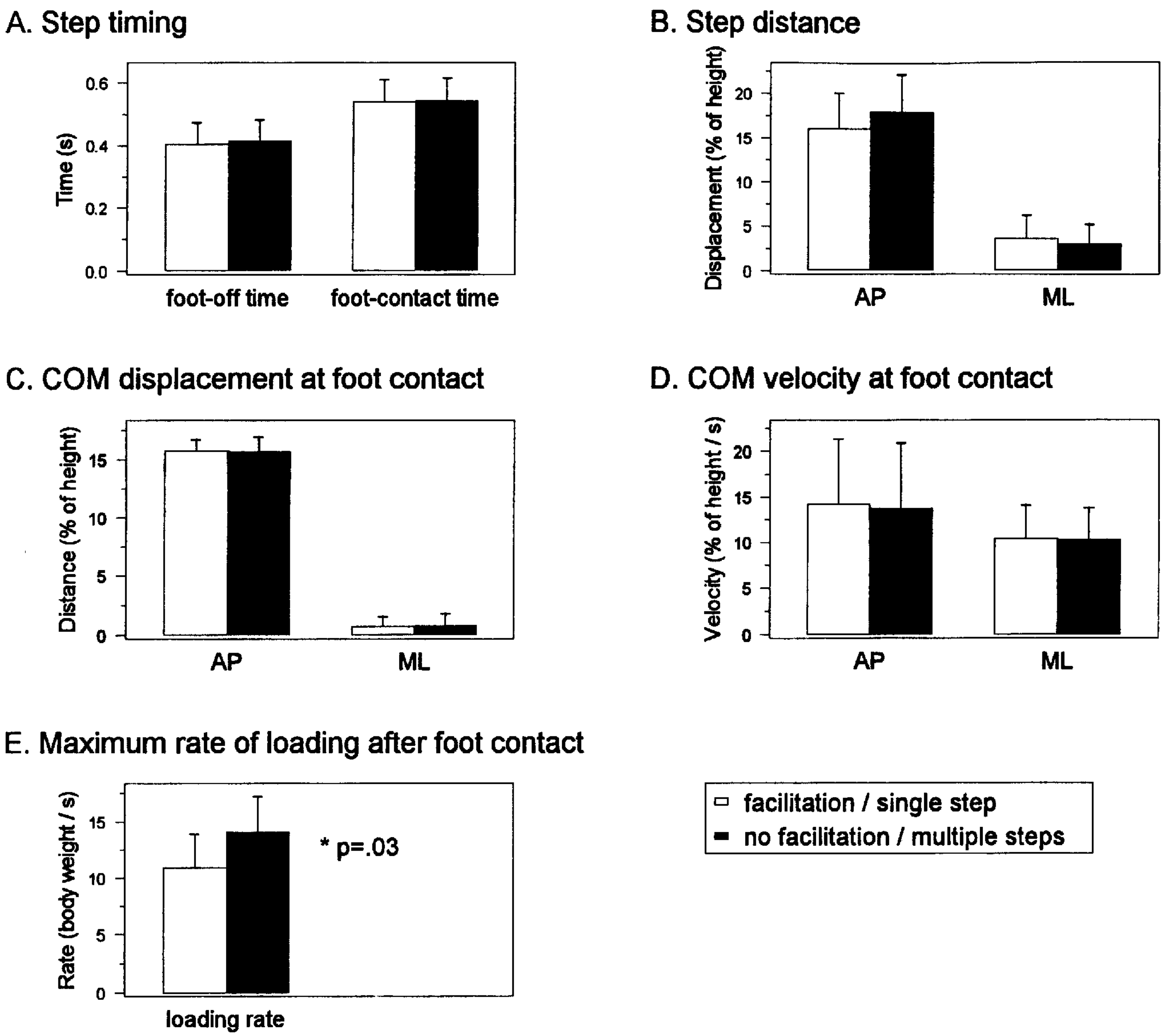


Figure 4. Characteristics of the initial step, for forward-step reactions (older adults): **A** step timing, **B** step distance, **C** COM displacement at time of foot-contact, **D** COM velocity at time of foot contact, and **E** maximum rate of swing-load loading, following foot contact (within the first 100 ms). Foot-off was defined to occur when forceplate loading dropped below 1% of body weight, and foot-contact was defined in an analogous manner; timing is defined relative to onset of platform acceleration (0.1 m/s^2). All spatial measures represent movement with respect to the platform; positive values correspond to movement in the forward direction (ap measures) or toward the swing-leg side (ml measures). Means and standard deviations are shown for facilitation trials where subjects recovered balance by means of a single step (n = 29; unfilled bars) versus nonfacilitated trials where subjects took one or more additional steps (n = 24; filled bars). The data were derived from the subjects who exhibited both patterns of response and who appeared to exhibit a "facilitation effect," i.e., a reduction in frequency of multiple-step reactions (adjusted for order of testing) during facilitated trials. Only one comparison was statistically significant (ANCOVA; $F[1,6] > 5.99, p < .05$): rate of loading after foot-contact (panel **E**).

Similar trends were seen in the young adults. Facilitation led to a decrease in backward COP excursion: mean values for the closest approach of the COP to the posterior BOS boundary (99th percentile estimate) were 23.0% versus 21.7% of BOS length, for facilitation versus nonfacilitation trials, respectively (p = .013). There was no change, due to facilitation, in forward or lateral COP excursion (p's > .79).

DISCUSSION

The results provide evidence that mechanical facilitation of sensation from the boundaries of the plantar foot surface can improve the efficacy of certain types of postural reactions evoked by unpredictable perturbation. The observed reduction in frequency of "extra" steps and arm reactions, beyond the initial step, during forward-step reactions in older adults is consistent with the hypothesis that facilitation would improve ability to control compensatory stepping. There also appeared to be an improved ability to control "feet-in-place" reactions: young subjects were better able to avoid stepping, when instructed to do so, in responding to transient instability in the backward direc-

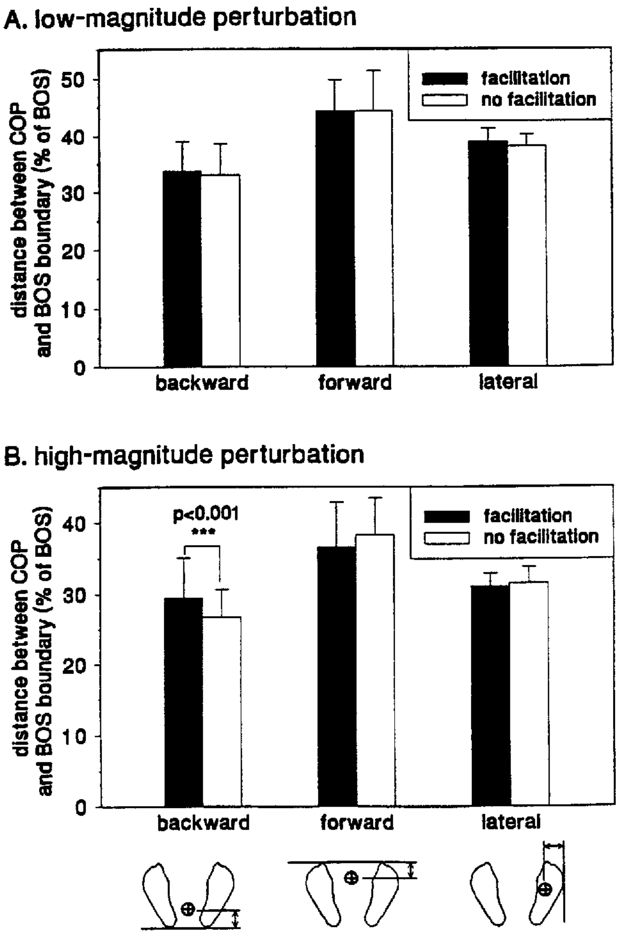


Figure 5. Summary of results from the continuous-perturbation trials (older adults). The degree to which the COP approached the boundaries of the BOS (99th-percentile estimates; see text for details) is shown in each of the forward, backward, and lateral directions for the "low" and "high" perturbation magnitudes. The forward and backward values were derived from trials involving ap perturbation; the lateral values were derived from trials involving ml perturbation. Each bar represents the mean value calculated across all 14 older-adult subjects; the flag is the standard deviation. The COP values were measured relative to the relevant BOS boundary; hence, smaller values indicate a closer approach to the BOS boundary. To negate variation due to differences in body size, the COP values are expressed as a percentage of the BOS length (for forward and backward COP) or maximum BOS width (for lateral COP). Statistically significant differences, due to facilitation, are indicated on the graph (ANCOVA; separate analyses of low- and high-magnitude trials; $F[1,12] > 4.75, p < .05$).

tion; both young and older subjects reduced the extent to which the COP approached the back of the foot during continuous perturbation. The effects on "feet-in-place" reactions are consistent with the hypothesis that boundary facilitation would provide the CNS with increased information about the BOS stability limits.

The functional implications of the observed facilitation effects, in terms of improving ability to move about safely during daily activities, remain to be determined. It also remains to be determined whether these effects, observed under blindfolded conditions, persist when vision is present. Our findings may, nonetheless, be relevant to "real-life" situations where visual information is compromised as a result of visual impairment, poor environmental lighting, or visual-spatial tasks that interfere with the ability of the CNS to use visual information for postural stabilization (22). The modest magnitude of the observed facilitation effects might lead one to predict a relatively minor effect on functional mobility; however, it can be noted that similarly modest differences have been shown to be predictive of falling risk. For example, in comparing "fallers" and "nonfallers," the average difference in root-mean-square COP displacement during pseudorandom platform motion was about 10% (23). A similar magnitude of effect, due to facilitation, was seen in the current pseudorandom tests. Although similar fall-related norms are not yet available for stepping data, a previous study comparing healthy young (aged 22–28 yr) and older (aged 65–81 yr) adults found, for forward-step reactions, an age-related increase of 19% in the frequency of multiple-step reactions (24). This is comparable to the facilitation-related change of 15% for forward-step reactions observed in the present study.

In interpreting the findings regarding multiple-step reactions, it should be noted that certain patterns of multiple stepping may represent a preplanned strategy. For example, a series of short, rapid steps could serve to permit more frequent correction of errors in the response, compared to a single large step (25). This, however, is unlikely to explain the observed effect of facilitation on forward-step reactions. The first step of the multiple forward-step reaction, occurring during nonfacilitated trials, was in fact very similar to the steps occurring during facilitated single-step reactions. Conversely, the tendency for higher rates of limb loading to occur *after* foot contact, in nonfacilitated trials, is suggestive of a difficulty in controlling the landing that may tie in with a need for further stabilizing action. The reduction in loading rate during facilitated trials could reflect improved ability to sense and control the foot contact and subsequent weight transfer.

A directional specificity of the facilitation effect was observed. In continuous-perturbation trials, facilitation limited COP excursion toward the back of the foot but had no effect on COP excursion in anterior or lateral directions. In transient-perturbation trials, the effect on ability to resist stepping was limited to backward-step reactions, whereas the effect on frequency of "extra" reactions was largely limited to forward-step reactions. These findings appear to complement results of studies in which plantar cutaneous sensation was attenuated rather than facilitated. In juxtaposition to our findings that facilitation *reduces* posterior COP excursion and frequency of forward multiple-step reactions, hypothermic anesthesia of the foot sole has been found to *increase* these same variables (13,14).

A possible explanation for the differing influences of cutaneous sensation, depending on the direction and type of reaction, relates to the availability of information from proprioceptive receptors in the joints and muscles of the toes. For feet-in-place reactions, these receptors may provide a sensitive indicator of forward and lateral COM movement, whereas ability to control COM motion (and resist stepping) in the backward direction may be more dependent on the cutaneous mechanoreceptors. For stepping reactions, contact tends to occur near the forefoot when stepping backward or sideways; hence, toe proprioception is potentially available to aid in detecting and controlling the landing. Forward steps, which tend to involve contact near the heel, may be more reliant on cutaneous cues. Additional efforts to facilitate sensation in the anterior region of the foot (i.e., adding a tubing segment anterior to the metatarsal heads; Figure 1) did not appear to provide any benefit in controlling forward/lateral COM motion or backward/lateral steps.

In summary, the present results add to the growing body of evidence that supports the important role of the plantar cutaneous mechanoreceptors in the control of specific aspects of postural stabilization. The finding that the facilitation affected the responses of healthy young adults, as well as older subjects, highlights the potent influence of these receptors. The results also have important practical implications with regard to development of novel footwear designs to reduce risk of falling in older adults. (As a matter of fact, the authors have filed a patent application for footwear design concepts based, in part, on the results of this study.) Further work is needed to assess the generalizability of the findings to a wider range of test conditions and subject characteristics. It will be particularly important to determine whether benefits persist after prolonged exposure to the facilitating device. Ultimately, favorable results may justify a randomized trial to examine more directly the feasibility of incorporating mechanical facilitation in footwear as a means of reducing falling risk.

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