Standing Balance Stability and the Effects of Light Touch in Adults With Profound Loss of Vision—An Exploratory Study

Aachal Kotecha,[1] Andrew Royston Webster,[1,2] Genevieve Wright,[2] Michel Michaelides,[1,2] and Gary Stuart Rubin[1]

[1]NIHR Biomedical Research Centre for Ophthalmology, UCL Institute of Ophthalmology and Moorfields Eye Hospital NHS Foundation Trust, London, United Kingdom
[2]UCL Institute of Ophthalmology, University College London, London, United Kingdom

Correspondence: Aachal Kotecha, Department of Visual Neuroscience, Rubin Lab, Institute of Ophthalmology, 11-43 Bath Street, London EC1V 9EL, UK; Aachal.Kotecha@moorfields.nhs.uk.

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Purpose. We evaluated the postural stability of adults with inherited profound vision loss and examined the effects of touch on their balance control.

Methods. A total of 11 severely-sight impaired patients (mean [SD] age, 51.6 [5.3] years) and 11 control subjects (mean age, 49.7 [5.3] years) participated. Postural stability was measured using a force-balance platform eyes open/closed on a firm/foam surface under 3 test conditions: no touch, light touch, and unrestricted touch (UT), where "touch" involved placing their index finger on a rigid table. Average magnitude of center of foot pressure displacement was calculated. A somatosensory ratio (SR) was used to evaluate the somatosensory contribution to balance. A repeated measures ANOVA was used to investigate the effects of touch on standing balance.

Results. Patients had a significantly increased SR compared to control subjects (mean [SD] SR controls = 1.2 [0.2], patients = 1.9 [0.5]; $P < 0.01$). There was a significant effect of touch, vision, and surface on balance control ("touch" $F = 68.1$, $P < 0.01$; "vision" $F = 20.1$, $P < 0.01$; "surface" $F = 200.8$, $P < 0.01$). Light touch attenuated sway in patients and controls. The effects were greater in controls when their vision was removed, and greater in patients when their somatosensory system was disrupted. Light touch was as effective as UT in attenuating sway.

Conclusions. The results of this exploratory study suggest that patients with severe sight impairment show an increased somatosensory contribution to balance control compared to their normally sighted counterparts. Light touch significantly reduces sway amplitude in severely sight impaired adults when standing on the foam surface, that is, when the somatosensory system is perturbed.

Keywords: vision, standing balance, light touch, Romberg quotient

Maintaining upright standing balance is a complex task requiring the processing and integration of sensory inputs from the vestibular, somatosensory, and visual systems to generate motor control of the eyes and body muscles.[1] A lack of reliable information from one of these sensory systems leads to postural instability, which may lead to an increased falls risk.[2–4]

While usually information from the plantar mechanoreceptors and ankle proprioception is used in the maintenance of upright balance, there is evidence that tactile information gained from the upper extremities also can facilitate balance control even when the force of touch is too small to give biomechanical support.[5–8] This "light touch" phenomenon is thought to be a result of the increase in somatosensory information being delivered to the central nervous system (CNS) via the fingertips, allowing for a feedback mechanism by which cues of body motion and orientation are detected, triggering corrective postural control mechanisms as necessary. The beneficial effects of light fingertip touch on balance stability are apparent in healthy individuals when other sensory inputs to balance are removed,[9,10] and is more apparent in older persons,[7,11] as it is thought to compensate for the a natural age-related decline in sensory function, central processing, and motor control.[12]

The impact of light fingertip touch in those with impairments in one or more of the processes involved in balance control (afferent sensory input, central processing, efferent motor control) has also been studied. Fingertip touch has been shown to improve the standing balance of patients with peripheral diabetic foot neuropathy[13] and bilateral vestibular loss,[14] as well as in Parkinson's disease, multiple sclerosis, and hemiparesis following a stroke.[15–17]

However, there is little evidence whether light fingertip touch improves the standing balance stability in those with severe sight impairment.

It has been shown that if a healthy individual is put in an environment where there is conflicting information from the sensory inputs to balance control, the CNS reweights the relative contributions and use of these sensory inputs to maintain postural stability.[18–21] This sensory reweighting is essential for normal balance control, as the body must be able to adapt rapidly to a constantly changing environment to remain upright.

It has been suggested that this sensory reweighting mechanism could be exploited and used in rehabilitation to improve balance in those with long-term pathologies that result in unreliable sensory information. For example, work suggests that training individuals with vestibular disease to rely more on somatosensory feedback has been shown to improve their balance control.[22,23] Some have proposed that individuals with profound vision loss may make more use of their vestibular and somatosensory systems to achieve balance control compared to those with no visual impairment,[24,25] although this has been disputed by others who suggest that the postural control afforded by the visual system cannot be replaced by other senses.[26,27] However, in a previous study, we found that patients with acquired irreversible peripheral visual loss from glaucoma showed an increased somatosensory contribution to balance control, which was thought to represent an adaptation to their peripheral vision loss.[28] Similar observations have been made by other studies of older individuals with acquired loss of either central or peripheral vision.[29,30] This suggests that there may be a long-term adaptation to unreliable visual information, whereby the CNS makes better use of the remaining sensory modalities to maintain upright balance.

Evidence suggests that individuals with profound vision loss have an increased tactile "acuity",[31,32] and recent work has shown that "blind" individuals more rapidly implement tactile information to stabilize balance compared to sighted individuals.[33] If those with profound sight loss make better use of somatosensory information to achieve balance control compared to their normally-sighted counterparts, it is possible that light fingertip touch will improve balance control in these individuals.

The purpose of this exploratory study was to evaluate the standing stability of adults with inherited profound vision loss and examine the effects of light fingertip touch on their balance control. We had two research questions: (1) Do those with profound vision loss exhibit a greater reliance on their somatosensory system to maintain balance, compared to control subjects, and does this increase as the visual contribution to balance decreases? (2) Are the beneficial effects of light fingertip touch in stabilizing balance greater in those with profound vision loss, compared to those with "normal" vision?

METHODS

Local ethics committee approval and informed consent according to the tenets of the Declaration of Helsinki was obtained before study participation. Patients were recruited from the Genetics clinics at Moorfields Eye Hospital, London, United Kingdom. Control volunteers were recruited by approaching spouses and relatives of patients, and staff members of UCL Institute of Ophthalmology. As it has been shown previously that there is an age-related decline in balance control,[34] and that the relative contributions of the sensory systems to balance control reach an equilibrium between the ages of 30 and 60 years,[35,36] older adults between the ages of 40 and 60 years were recruited. To be included in the study, patients had to be deemed "clinically stable" for at least 6 months by their consultant. Patients with coexisting ocular pathologies other than their primary diagnoses were excluded. Participants who had a clinical diagnosis of comorbidities that could affect lower limb strength (i.e., pathologies that affect motor coordination, such as arthritis, diabetic neuropathy, or Parkinsonian type disorders), or those that could affect balance (i.e., a clinical diagnosis of pathology affecting the auditory or vestibular systems) also were excluded.

Quantitative Assessment of Postural Stability

The coordinates of center of foot pressure (center of pressure; COP) were measured using a Bertec force balance platform (Bertec Corporation, Columbus, OH, USA) in the anteroposterior (AP; "front-to-back") and mediolateral (ML; "side-to-side") directions. The platform was connected to a personal computer and set at a sampling frequency of 1000 Hz.

Balance was measured under 2 visual conditions (eyes open and eyes closed), 2 surface conditions (firm platform and foam platform), and 3 touch conditions (no touch, light touch, and unrestricted touch), resulting in 12 experimental conditions. Measurements of body sway were made over a 30-second period and repeated 3 times under each condition, resulting in 36 measurements per participant. Foam platform standing involved standing on a piece of foam rubber placed on the Bertec platform, to assess the contribution of somatosensory systems on balance control. Using a foam rubber surface to reduce the reliability information received by subcutaneous mechanoreceptors in the soles of the feet is a well-used method to disrupt the somatosensory contribution to balance control.[37–39] The foam rubber pad comprised of standard polyurethane combustion modified flexible foam, size 600 × 400 × 100 mm of density 0.04 g/cm^3.

During the no touch test condition, participants were asked to stand with their feet side by side and their arms hanging loosely at their sides. During light fingertip touch, the procedure was repeated with the participant was asked to use their right index finger to lightly touch a force plate placed at hip height on a table adjacent to the platform applying a vertical force no more than 1 Newton (based on previous research studies[6,10,11,40]). For unrestricted touch, the procedure was repeated with the participant asked to apply as much force as they felt necessary to maintain stability. Vertical fingertip forces were measured using the Tekscan Flexiforce force sensor (Tekscan, Inc., Boston, MA, USA). The outputs of the force sensor were monitored visually under the light fingertip touch testing condition to ensure that the force applied did not exceed 1 Newton. The height of the table was adjusted so that the participants' arms remained straight and by their side in as relaxed a position as possible. Feet were kept parallel at a distance of 15 to 20 cm apart for each measurement. All three tasks (no touch, light fingertip touch, and unrestricted touch) were presented in a randomized order, and the participant was given a practice trial under each condition before the start of the experimental procedure.

Raw COP output data were filtered using a fourth order zero lag Butterworth low pass filter with the cutoff frequency set to 15 Hz. The global root mean square (RMS; mm) of COP displacement was used to quantify postural sway using the following formula:

$$\mathrm{RMSg} = \sqrt{\frac{1}{n}\Sigma(Xi - Xm)^2 + (Yi - Ym)^2}$$

where Xi and Yi are the COP values in the AP and ML positions at sample i, and Xm and Ym are the means of COP over the n samples of the 30-second recording period. For each experimental condition, the average of the 3 repetitions was used in the data analysis.

Data Analysis

Standing Balance, No Touch. Data were explored to evaluate the differences in balance between groups under each standing and touch condition. A 1-way ANOVA was used to evaluate standing balance under the "no touch" condition.

TABLE. Details of Patients Tested

Patient	Age, y	Sex	Diagnosis	Y Since Diagnosis	Vision, logMAR	
					Worse Eye	Better Eye
1	50.6	Male	Retinitis pigmentosa	40	1.0	1.0
2	57.5	Male	Retinal dystrophy (*PRPH2* p.R172W)	28	Hand movements	Hand movements
3	50.9	Male	Retinitis pigmentosa	23	Bare light perception	Bare light perception
4	52.6	Female	Retinal dystrophy (*PRPH2* p.R172W)	38	Hand movements	Hand movements
5	46.3	Male	*CRB1* retinopathy	40	Bare light perception	Bare light perception
6	59.0	Female	Retinitis pigmentosa	27	1.0	1.0
7	56.5	Male	Retinitis pigmentosa	38	Bare light perception	Hand movements
8	45.3	Male	Leber congenital amaurosis	40	No light perception	No light perception
9	44.8	Female	Retinitis pigmentosa	15	Count fingers	1.2
10	56.9	Female	Retinal dystrophy (*PRPH2* p.R172W)	26	1.8	1.5
11	47.1	Male	Retinitis pigmentosa	15	1.2	1.0

Quantifying the Visual and Somatosensory Contribution to Balance. The Romberg Quotient (RQ) was calculated to evaluate the visual contribution to balance[34] using the formula:

$$RQ = \text{Balance Eyes Closed Foam}/\text{Balance Eyes Open Foam}.$$

The higher the RQ, the greater the visual contribution to balance.

A new quotient, the somatosensory ratio (SR), was determined to evaluate the relative somatosensory contribution to balance. This was defined as:

$$SR = \text{Balance Eyes Open Foam}/\text{Balance Eyes Open Firm}.$$

The higher the SR, the greater the relative somatosensory contribution to balance control.

An independent *t*-test was used to examine difference in RQ and SR between groups.

To examine whether the somatosensory contribution to balance increased as the visual contribution to balance decreased, we performed a Pearson correlation between SR and RQ for the whole cohort.

Examining the Effects of Touch on Balance Control. A repeated measures ANOVA was performed with touch (×3; no touch, light fingertip touch, and unrestricted touch), vision (× 2; eyes open, eyes closed), and surface (×2; firm surface, foam surface) as the within subject variables and group as the between subject variable.

All analysis was performed using SPSS version 22 (SPSS statistics; IBM, Armonk, NY, USA).

Results

We recruited 11 patients (male:female, 7:4) with profound visual loss (mean best-corrected binocular logMAR visual acuity, 1.8; range, 1.0 to no-light perception with severe constriction of visual fields as measured using confrontation testing) and 11 age-similar control subjects (male:female, 6:5; mean binocular best-corrected visual acuity –0.14; range, –0.28 to 0.02) with no ocular pathology. All control subjects had full fields of vision. Diagnosis details of patients are listed in the Table. The average age (SD [range]) was 49.7 (5.3 [41–57]) years for the control group and 51.6 (5.3 [45–59]) years for the patient group (independent *t*-test, $F = 0.0$, $P = 0.99$).

Comparison of balance between groups under the no touch condition revealed that there was a significant difference between patients and controls in RMS when standing with eyes open on the foam surface (mean RMS [SD] controls = 7.6 [1.4] mm, patients = 10.1 [1.5] mm; ANOVA F statistic 15.8, $P < 0.01$; Fig. 1).

The data showed that visually impaired patients had a significantly lower RQ compared to control subjects (mean [SD] RQ controls = 1.7 [0.4], patients = 1.0 [0.2]; $P < 0.01$; Fig. 2). In contrast, visually impaired patients had a significantly higher SR compared to controls (mean [SD] SR controls = 1.2 [0.2], patients = 1.9 [0.5]; $P < 0.01$; Fig. 2).

There was a negative correlation between RQ and SR, such that as the RQ decreased, the SR increased (Pearson $r = -0.52$, $P < 0.05$). This suggests that as the visual contribution to balance reduces, the somatosensory contribution increases.

The repeated measures ANOVA indicated that there was a significant within-subject effect of touch, vision, and surface on balance control (touch $F_{(2,40)} = 68.1$, $P < 0.01$; vision $F_{(1,20)} = 20.1$, $P < 0.01$; surface $F_{(1,20)} = 200.8$, $P < 0.01$).

Figures 3 and 4 show the effects of touch on RMS in groups. Light fingertip touch improved the RMS in all subjects under all test conditions. There were no significant differences in RMS between light fingertip touch and unrestricted touch in stabilizing balance.

Discussion

Our results suggested that adults with profound vision loss have an increased somatosensory contribution to balance control compared to normally sighted subjects of similar age. In addition, we found that the lower the visual contribution, the greater the somatosensory contribution to sway. During normal quiet standing, eye closure had a detrimental effect on balance control in normally sighted subjects, but little effect in severely sight impaired patients. In contrast, disruptions to the somatosensory system had a greater detrimental effect on balance in patients compared to controls. These findings are in line with those of others who also have noted the increased reliance on the somatosensory system in severely sight impaired individuals.[41,42]

Our finding that the control subjects swayed more than the patient group when all their sensory systems were intact was somewhat unexpected. One possible explanation could lie with the "focus of attention." Previous work in our laboratory has found that the introduction of a simple "visual distraction" task reduced body sway in a group of older (mean age 66 years) nonvisually impaired adults, compared to their balance during quiet standing (unpublished data). This phenomenon has been noted by previous researchers and has been attributed to the "constrained action" hypothesis[43]; asking participants to "stand still" during the quiet stance measurements resulted in a conscious effort to control sway, which interfered with the

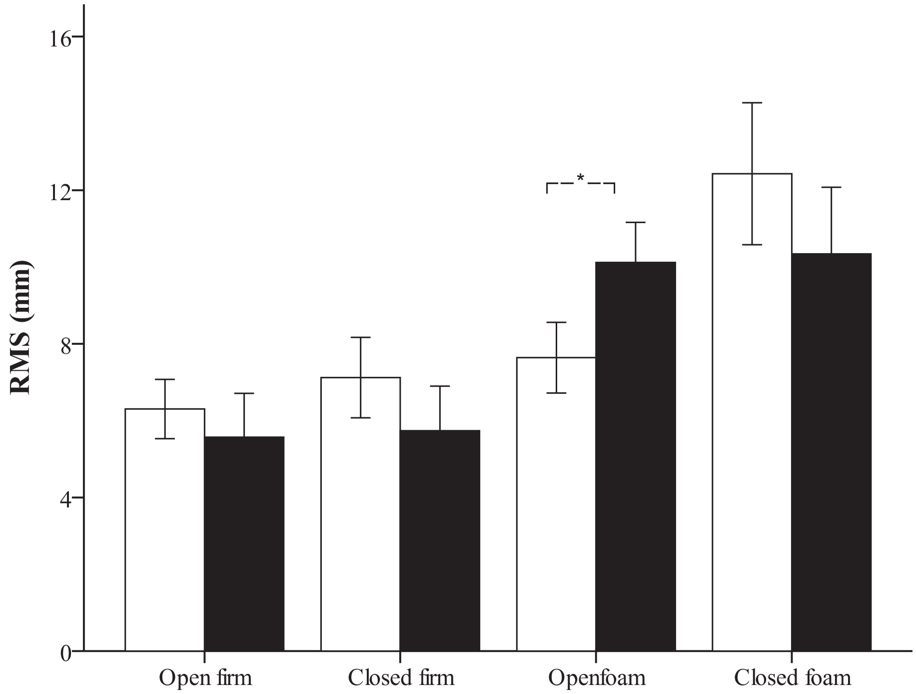

Figure 1. Mean RMS for control (*clear*) and patient (*shaded*) groups during "no touch" task condition. Under the "eyes open" condition, disrupting the somatosensory system had a greater detrimental effect on patients compared to controls. In every other standing condition, there was no significant difference in balance between groups. *Error bars*: 95% confidence intervals. *Difference between groups significant at $P < 0.01$ level.

natural postural control mechanisms. The addition of a "simple" cognitive task provided an external focus of attention, which allowed for a more "normal" postural control.[44] Thus, it may be that in the presented study, asking the participant to lightly touch the stable surface provided an external attentional focus that allowed for a more automated control of posture.

In comparison, our patient group seemed to show very stable standing balance. There is contradictory evidence in the literature regarding the quiet standing balance stability of severely sight-impaired or blind individuals compared to normally sighted counterparts. Some show that those with severely restricted or no vision have worse balance than normally-sighted subjects,[26,42,45] whereas other have found no significant differences between sighted and nonsighted subjects during quiet standing in either tandem[33] or normal bipedal[24,27] stance, and that differences between seeing and nonseeing subjects only becomes apparent when another sensory system (somatosensory or vestibular) is perturbed. There also may be an element of self-selection bias in this study; patients who volunteered to participate in the project may have had better balance than those who declined, as the latter group may not have had the confidence to participate in the study. Furthermore, the very strict inclusion criteria aimed to reduce the potential effect of confounding comorbidities that may have had an adverse effect on balance, and, as such, may have resulted in only "balance athletes" participating. It should be pointed out, however, that despite our patient group appearing to be more stable than the control group during firm surface standing, they became significantly unstable during foam surface under the "eyes open" condition, the significance of which will be discussed later.

Our findings are in keeping with those of Jeter et al.,[42] who compared the standing balance of 14 "legally blind" and 21 control subjects. They found a reduced visual contribution and increased somatosensory contribution to balance control in the visually impaired cohort, measured by sway velocity.[42] In their study of postural stability in a cohort of RP patients, Turano et al.[46] found that the visual contribution to balance was dependent on the degree of visual field constriction, with those with more constricted fields showing a lower visual contribution to balance.[46] The visual contribution to balance also has been shown to be reduced in those suffering with glaucoma.[28,30]

Recently, Willis et al.[47] qualitatively evaluated standing balance, using the Romberg standing test, in a large cohort of

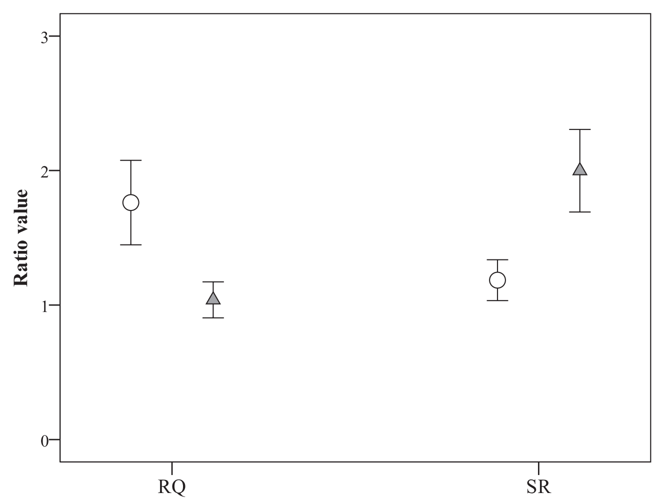

Figure 2. Mean Romberg quotient and SR for controls (*open circles*) and patients (*shaded triangles*). The data show that controls had a greater visual contribution to their standing balance compared to patients and that patients had a greater somatosensory contribution to their standing balance compared to controls. *Error bars*: 95% confidence intervals for the mean; participant group differences significant at $P < 0.01$ level.

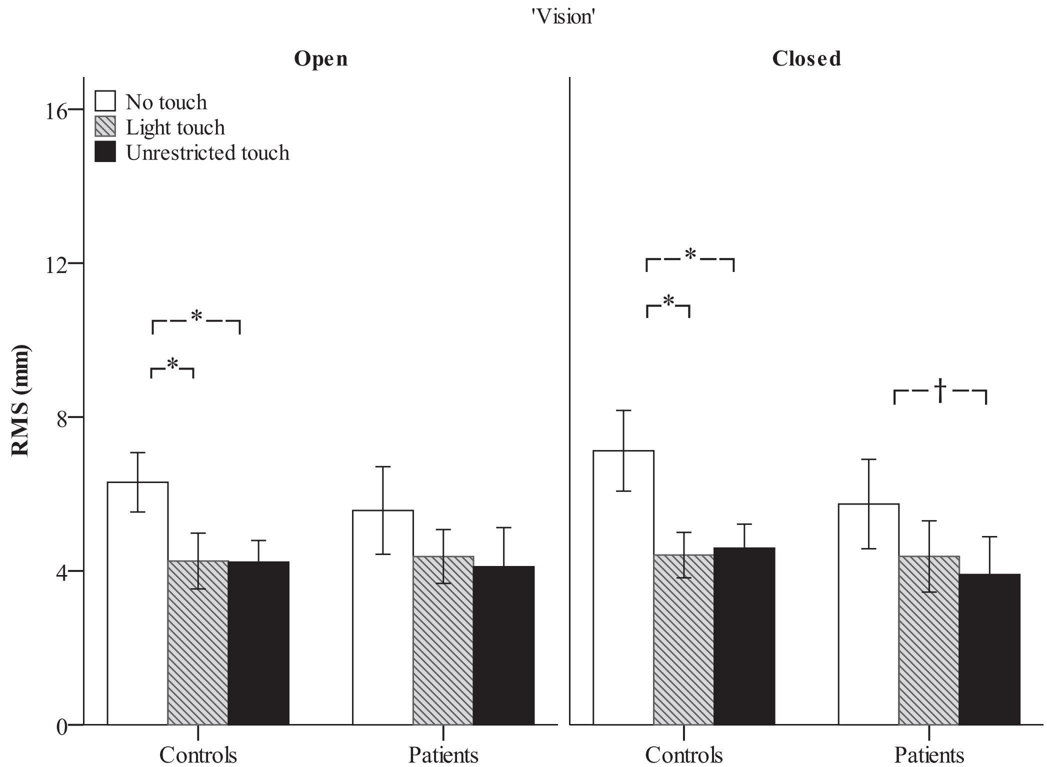

Figure 3. Mean RMS for control and patient groups when standing on the firm surface under the 3 touch conditions. Light fingertip and unrestricted touch had a significant stabilizing effect on all subjects, although only reached statistical significance for control subjects under eyes open and eyes closed conditions. *Error bars*: 95% confidence intervals. Bonferroni corrected 1-way ANOVA significant differences at the $^*P < 0.01$ and $^\dagger P < 0.05$ levels.

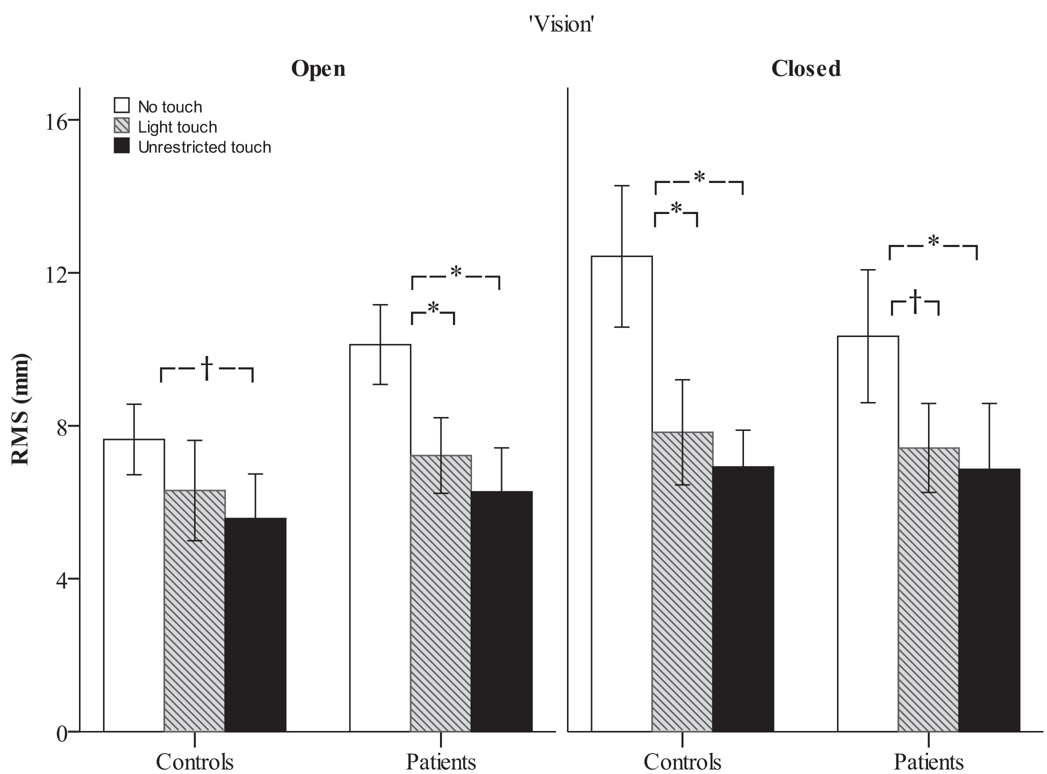

Figure 4. Mean RMS for control and patient groups when standing on the foam surface under the 3 touch conditions. Fingertip touch reduced sway in all participants. During the eyes open condition, light fingertip touch resulted in a statistically significant attenuation of sway in patients. During the eyes closed conditions, light fingertip touch had a statistically significant stabilizing effect for patients and controls. *Error bars*: 95% confidence intervals. Bonferroni corrected 1-way ANOVA significant differences at the $^*P < 0.01$ level and $^\dagger P < 0.05$ level.

community dwelling older adults with visual impairment due to either uncorrected refractive error or ocular pathology.[47] They found that balance was worse during eye closure standing on a foam surface in those with visual impairment (mean age, 74.2 years) compared to normal sighted adults (mean age, 55.8 years), and suggested that those with visual impairment may have a reduced vestibular contribution to standing balance control. Our sight impaired subjects did not have significantly worse standing balance under "eyes closed foam" standing conditions compared to the control subjects. It has been shown that balance control reduces significantly with age[35] and our cohort of sight-impaired subjects was younger (mean age, 51.6 years) than that studied by Willis et al.[47] Furthermore, other comorbidities, such as hearing loss and musculoskeletal problems associated with age, or reduced levels of physical activity in those with visual impairment, may have contributed to the observations made by Willis et al.[47] Our inclusion criteria were strict to reduce the influence of any potential confounding factors.

This study showed that the effects of light fingertip touch attenuate sway in groups under all standing scenarios. The lack of statistical significance for some standing scenarios is in part related to the sample size and variability of participant responses in the different standing conditions, but this does not diminish our findings that light fingertip touch improved the standing balance of this cohort.

Our findings agree with that of others who have found that light fingertip touch improves the standing balance of healthy individuals.[7,10,11] The finding that light fingertip touch improved control subjects' balance more during eye closure is expected, and also has been reported by others.[10,48] In this scenario, when vision is removed, it is thought the highly discriminative tactile information afforded by the fingertip provides the CNS with information pertaining to the degree and direction of body sway.[6] This additional fingertip tactile sensory information compensates for the loss of visual sensory information.

Our patient group also showed less sway with the addition of light fingertip touch. However, when we compared the 2 groups we found that the effects of light fingertip touch appeared to have a greater stabilizing effect on patients during foam surface standing. During foam surface standing, the somatosensory information for balance control became unreliable, resulting in patients swaying significantly more than their sighted control counterparts (with their eyes open). This would be expected if we consider the sensory reweighting hypothesis, in that with a long-term absence of vision, this patient group became more reliant on their remaining somatosensory and vestibular systems for balance control. Thus, when the somatosensory system was disrupted, they became more unstable. The fact that light fingertip touch attenuated sway more during foam surface standing suggests that, for our cohort, the extra information provided by tactile (specifically, fingertip) sensory information could compensate for a reduction in reliable plantar/ankle somatosensory information in balance control.

Light fingertip touch on a surface is thought to increase awareness of the body's position in space, helping to control postural mechanisms to maintain balance in the absence of reliable visual information.[8,10,48] Our study showed that unrestricted touch, that is, contact that gave mechanical support to the individual, reduced sway, but light fingertip touch was as good as unrestricted touch in maintaining balance, in keeping with previous observations.[49]

Recent work has shown that Astanga yoga rehabilitation techniques are able to "up weight" the somatosensory contribution to balance control.[50] Our study adds to the evidence of the importance of somatosensory information in balance control of those with missing/incomplete visual information, and that perhaps rehabilitation techniques may also look to exploiting fingertip tactile acuity to improve balance control in this patient group.

Limitations to our study include the small sample size and, as such, the presence or absence of statistical significance should be interpreted with caution. In addition, all tests were conducted under very controlled laboratory conditions; thus, how this translates to the "real world" is yet to be explored. Nonetheless, our finding that visually impaired adults rely more on their somatosensory contribution to balance control is important.

There are important implications of our study for severely visually impaired patients and their healthcare team. Our study suggested that in conditions where somatosensory cues are present, severely visually impaired patients have similar standing stability to controls. However, conditions where somatosensory cues are unreliable (e.g., standing on thick carpet) may place a person with severe sight impairment at more risk of falls. Light fingertip touch contact under these conditions, for example, lightly touching a wall, could help attenuate sway. This information should be incorporated during patient counselling so as to inform the patient of techniques to improve standing stability.

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