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## Romberg ratio in quiet stance posturography—Test to retest reliability

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## ABSTRACT

We investigated test to retest reliability and intraindividual variability of Romberg ratios in quiet stance posturography. Thirty-six healthy young adults (17 males, 19 females aged 15–38 years) were divided into 3 groups with different time-intervals between consecutive trials (20 min, 3 h and 24 h respectively). Each group performed 5 posturography recordings in a randomized order of eyes open (EO) or closed (EC) + once after 3 months. We measured the torque variance in posturography and calculated Romberg ratios. Total postural sway as well as sway above and below 0.1 Hz was analyzed. *Results:* Test to retest reliability was found to be poor for Romberg ratios (intraclass correlation coefficients (ICC) <0.4) despite that the individual EO and EC posturography recordings were consistent. For sway >0.1 Hz the Romberg ratios were found to be more consistent (fair to good, ICC 0.49–0.71). The variation between two consecutive tests (absolute difference (%)) was high when using the traditional Romberg ratio (EC/EO), but became less varied if an alternate formula that includes the total postural sway was used  $((EC - EO)/(EC + EO) \times 100)$ .

*Conclusion:* In healthy young adults the evaluation of ratios from repeated quiet stance posturography show great intraindividual inconsistency. This questions the Romberg ratio as being a reliable tool for evaluation of postural performance and determination of sensory preference in postural control, at least in healthy controls. Whether test–retest reliability is acceptable in patient cohorts needs to be evaluated for proper validity of intervention and outcome studies and for detection of clinical relevance.

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## 1. Introduction

Postural feedback and feed forward control is dependent on sensory input from vision, somatosensation and the vestibular organs. Within the central nervous system the inputs are processed, integrated and weighted dependent to their relative importance and to the context [1]. Assessment of the different contributions of the sensory systems, i.e. sensory weighting, and their changes has been made by the use of posturography measurements [2,3]. Although not originally intended for sensory weighting assessment, the Romberg test is frequently used in posturography by comparing postural sway in eyes open (EO) and eyes closed (EC) conditions. The ensuing Romberg ratio (EC/EO) is a set feature in the sensory organization test (SOT) in Equitest posturography [4], and it is interpreted as an indicator of proprioceptive contribution to postural stability. The same ratio

has also been used to assess visual dependency in postural stability [3,5].

Posturography is frequently used to assess the efficiency of treatments of different balance disorders and in this context test to retest reliability is of utmost importance, i.e. intraindividual variability and stability. Reliability has been investigated for EO and EC in the context of SOT. Ford-Smith et al. [6] evaluated noninstitutionalized older adults on 2 occasions, 1 week apart, and found fair test–retest reliability (intraclass correlation coefficient (ICC) of 0.51 and 0.42 respectively, using the definition from Fleiss et al. [7]). Wrisley et al. [8] tested younger adults on 5 separate sessions and found overall a fair to good test–retest reliability of the six conditions of the SOT, though the lowest reliability was found for the easiest conditions, i.e. standing without any sensory interference with EO and EC. Neither of the above studies addressed test to retest reliability of the Romberg ratio. Since the Romberg ratio in the context of posturography measurements is a mathematical construction and small variations in the different conditions (EO/EC) could yield larger differences in the calculated ratio, it would be of great interest to examine whether this ratio is stable when repeatedly measured. If any conclusion could be

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drawn whether a subject has a proprioceptive or visual preference in regulating postural stability, then the ratio would have to be consistent. The present study aimed to assess whether the Romberg ratio is a consistent and reliable tool when performing repeated measurements in healthy subjects.

## 2. Material and method

Thirty-six healthy subjects were recruited (17 males, 19 females aged 15–38 years (mean 25 years, SD 4 years), weight 41–100 kg (mean 67.5 kg, SD 13.1 kg), and height 160–197 cm (mean 1.75 m, SD 0.09 m)), and divided into 3 groups (A, B and C). The subjects were originally recruited for a study on adaptation to repeated vibratory perturbation with different intervals [9], which was the basis for the group division. Each subject performed 5 trials; group A: with 20 min interval between each of the five trials, group B: with 3 h interval and group C: with 24 h interval. All subjects save 1 from group C returned for a follow-up posturography after 3 months. All subjects were naive concerning the study protocol and the methods employed. All subjects were healthy and had no history of any otoneurological, neurological, psychiatric, orthopedic or hearing disorders. Alcoholic beverages and sedative drugs were proscribed for 24 h preceding the testing, and none of the subjects were on any form of medication. Informed written consent was obtained from all the subjects and the experiments were done in accordance with the Helsinki Declaration of 1975 as revised in 2013, and approved by the local ethical committee.

Postural control was evaluated during 30 s standing on a force platform (400 × 400 × 75 mm) equipped with six strain-gauge sensors. The custom built force platform recorded torques and shear forces with six degrees of freedom using force transducers with an accuracy better than 0.5 N. Data were sampled at 50 Hz by a computer equipped with a 12-bit AD converter. After the recording of 30 s quiet stance, all subjects were subjected to vibratory calf stimulation, the results of which were presented in a previous report [9]. After information about the test procedure the subjects were instructed to stand erect but not at attention, with arms crossed over the chest and feet at an angle of about 30 degrees open to the front and the heels approximately 3 cm apart. All tests were performed by the same examiner and thus received the same instructions prior to each test. Two tests were conducted at each trial occasion, EO and EC. In the EO condition, subjects were fixating on mark on the wall at a distance of 1.5 m at eye level. The test order, EO/EC, was randomized. In order to minimize any external disturbances or cues for the test subjects, the recordings were performed while the test subjects listened to classical music relayed through headphones. The music sequence was repeated and the same through all tests. Romberg test can be measured also in tandem stance and standing on foam, we used the above-described method since it is the most used method.

We measured torque and analyzed the variance of the torque values. Postural stability during quiet stance is commonly analyzed using force platforms and the movements of the centre of pressure (CoP), i.e., the point of application of the ground reaction force. Torque correspond to Centre of Pressure (CoP); torque  $\tau$  is calculated from the formula  $\tau = \text{CoP} \times Fz$ ; where  $Fz \approx m \times g$ ; where  $m$  = the assessed subjects mass (in kg) and  $g$  = gravitational constant 9.81 (m/s<sup>2</sup>). Hence, changes in recorded torque are equivalent to changes in CoP [10], however, the information is here presented in the form of energy used towards the support surface to maintain stability [10,11], which in turn corresponds to the efficiency of standing [12]. Changes in recorded torque from the force platform correspond well to the actual body

movements and posture changes induced by vibratory stimulus [13]. The formula for variance is given by

$$\bar{\tau} = \sum_{i=1}^n \frac{\tau(i)}{n}$$

$$\text{var } \tau = \frac{1}{n-1} \sum_{i=1}^n (\tau(i) - \bar{\tau})^2$$

where  $i$  = sample,  $n$  = number of samples recorded during an analyzed period.

The torque variance values were normalized to account for anthropometric differences between the subjects, using the subject's squared height and squared mass, as height and mass are key factors influencing the body sway recorded by a force platform [11,14]. The squared nature of the variance algorithm made it necessary to use normalization with squared parameters to achieve unit agreement.

In the data analysis, the variance of torque was divided into three categories, total, low frequency (<0.10 Hz), and high frequency (>0.10 Hz). A fifth-order digital finite duration impulse response (FIR) filter [15], with filter components selected to avoid aliasing was used for spectral separation. The frequency cut-off level of 0.1 Hz was based on fast Fourier transformation (FFT) analysis of the sway composition under EO and EC conditions [16]. The frequency limit at 0.1 Hz was also based upon empirical tests on recorded body sway, which have shown that this frequency limit is efficient when separating between fast corrective movements to maintain balance, and the smooth corrective changes in the overall stance [17].

The Romberg ratio was calculated in the traditional manner, i.e. EC/EO. A value exceeding 1.0 would indicate a greater amount of postural sway during eyes closed.

We also analyzed another Romberg ratio according to the following formula [3]:

$$\frac{\text{Eyes Closed (EC) torque} - \text{Eyes open (EO) torque}}{\text{EC torque} + \text{EO torque}} \times 100$$

A ratio close to zero or negative indicates that the magnitude of body sway was similar or smaller in the condition with EC than with EO, i.e. visual information was less important for postural control. This formula considers the total amount of body sway during both visual conditions (EO and EC).

## 3. Data analysis

Test to retest reliability was assessed in three different ways:

- (1) Intraclass correlation coefficients (ICCs, mixed model evaluating consistency) were estimated for each trial and each parameter, i.e. torque variance for EC and EO, and for both Romberg ratios. The ICCs were also estimated according to the interval between the tests (minutes, hours, 1 day) and to the frequency of the sway (total, low frequency, high frequency sway). Test to retest reliability was assessed according to the Fleiss criteria where an ICC of <0.4 indicates poor, 0.4–0.75 fair-to-good, and >0.75 excellent reliability [18]. If the confidence interval (CI) in the analysis ranged below zero, it would mean that the test–retest measurements were unreliable. The CI also gives information about the limits of uncertainty surrounding the estimated ICCs.
- (2) The absolute difference between the Romberg ratios was calculated between each consecutive trial, i.e. between the 1st and 2nd, 2nd and 3rd etc. ((Ratioday2–Ratioday1). This

analysis estimated the coherence in percentage, i.e. how close the ratios came to each other from test to test.

- (3) The alternate Romberg ratios were stratified graphically and each individual's visual dependency determined in each trial according to Lacour et al. [3]. The border between visual dependence and independence is mathematically set to a value close to zero, and each subject were thus assigned to either visual dependency or independency in each trial, and the number of times the dependency shifted from trial to trial was assessed.

Torque variance data was analyzed using the Wilcoxon two sample test, to examine whether there were any differences between the consecutive tests.

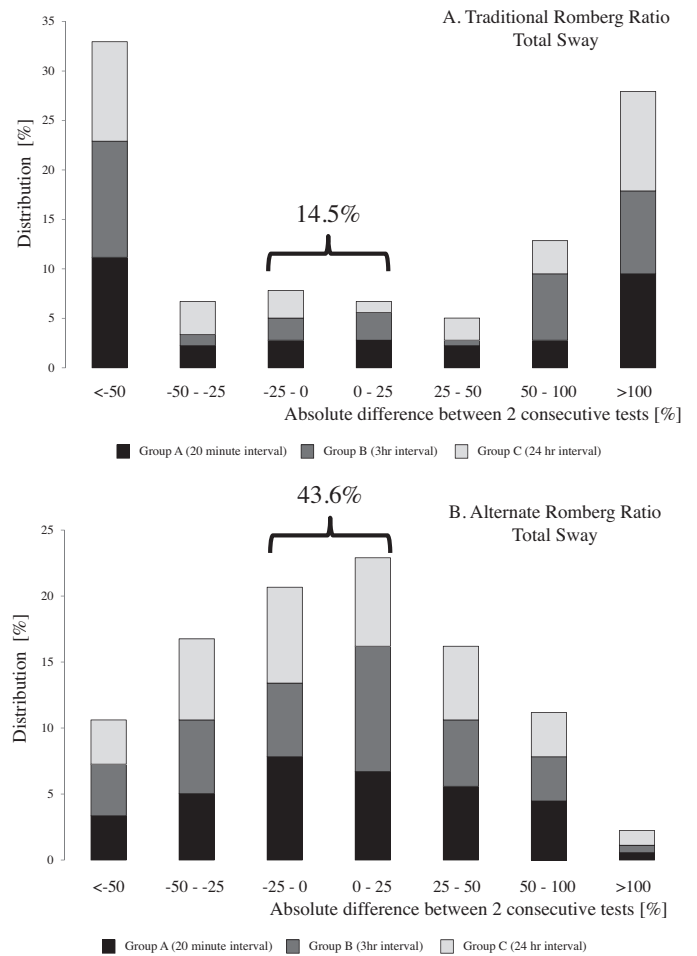
**4. Results**

There were no statistical differences in the amount of generated torque variance during quiet stance between any trials in any visual test condition (Supplementary Fig. 1A and B).

The ICC values were generally stable ranging from fair to excellent when analyzing EC and EO quiet stance parameters (Table 1). The Romberg ratios yielded mostly poor ICC values as well as CI ranging below zero, except for sway >0.1 Hz and when there were longer time intervals between the tests. Posturography tests performed with 20 min intervals as well analysis of sway <0.1 Hz showed poor test–retest correlation in all calculated ratios.

The variation of absolute ratios, as presented as proportional percentage distribution, for both Romberg ratios are presented in Fig. 1A and B for total sway (sway above and below 0.1 Hz in Suppl. Fig. 2). For the traditional Romberg ratios only 14.5% (total) and 17.3% (>0.1 Hz) were within the 50% limit of ratio variation between two consecutive tests, with the majority being either less than half or twice as high (Fig. 1A, Suppl. Fig. 2A). For the alternate Romberg ratio the consistency between consecutive tests were higher (Fig. 1B, Suppl. Fig. 2B). The variations between two tests were not different with different time intervals.

The variation of “visual dependency” is shown in Fig. 2 for total sway (sway above and below 0.1 Hz in Supplementary Fig. 3). The distribution of all alternate Romberg ratios is shown in Supplementary Figs. 4A–C. Overall 27/36 (75%) of the subjects (total sway) changed their ratio at least once during the 6 tests and most subjects several times over. There were no differences between the groups. In sway <0.1 Hz 34/36 (94%) of the subjects changed their dependence at least once, and in sway >0.1 Hz 19/36 subjects (53%) (Suppl. Fig. 3). The subjects who did not change their rated visual dependence were all using vision to stabilize posture in all trials.



**Fig. 1.** The coherence in percentage how close the ratios came to each other between two consecutive tests, expressed as absolute differences.

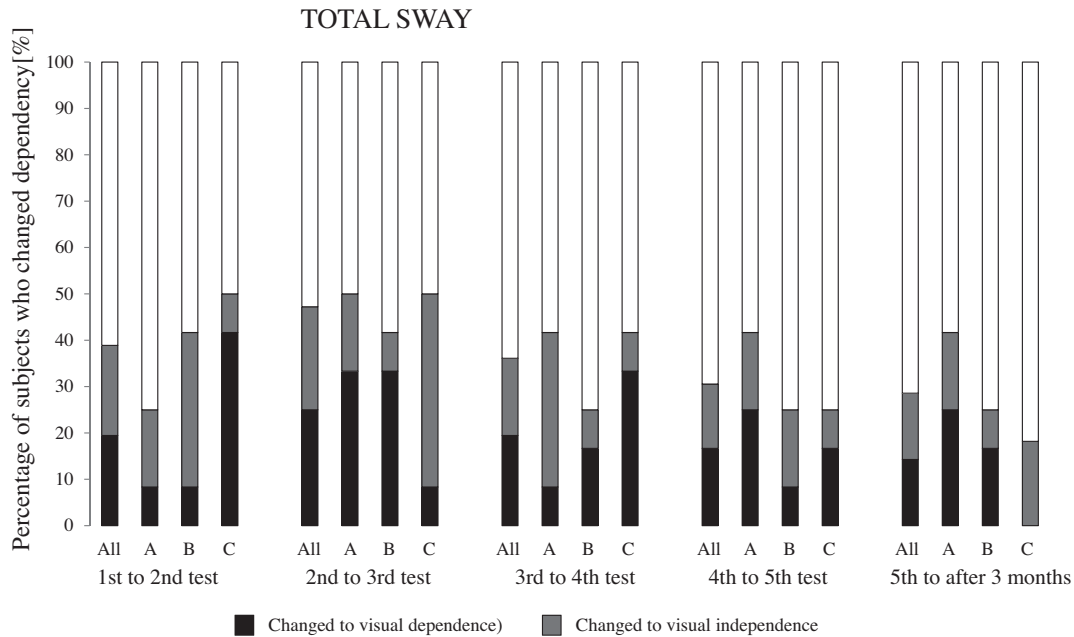
The frequency of ratio-change prompted an analysis of subjects whose Romberg ratios were definitely either very high or very low in the first trial. In Fig. 3 the alternate ratios for 10 subjects, who on the first trial yielded the most extreme ratios, are shown for all 6 trials. (For sway above and below 0.1 Hz see Supplementary Fig. 5).

**5. Discussion**

Surprisingly, considering that the method has been in use for a long time, as far as to our knowledge this is the first systematic analysis of repeated Romberg ratios in quiet stance posturography.

**Table 1**  
ICC values and 95% CI interval of EC and EO quiet stance parameters as well as both Romberg ratios.

		Eyes closed	Eyes open	Traditional Romberg ratio	Alternate Romberg ratio
Total sway	All	0.67 (0.46–0.81)	0.73 (0.56–0.85)	0.24 (–0.23 to 0.57)	0.37 (–0.03 to 0.64)
	Minutes	0.56 (0.01–0.85)	0.72 (0.36–0.91)	–0.25 (–1.80 to 0.58)	–0.50 (–2.37 to 0.50)
	Hour	0.78 (0.51–0.93)	0.69 (0.29–0.90)	0.27 (–0.63 to 0.76)	0.07 (–1.09 to 0.69)
	Day	0.71 (0.33–0.91)	0.73 (0.38–0.92)	0.58 (0.04–0.87)	0.62 (0.11–0.88)
Sway <0.1 Hz	All	0.56 (0.29–0.75)	0.68 (0.48–0.82)	0.20 (–0.29 to 0.55)	0.37 (–0.02 to 0.64)
	Minutes	0.48 (–0.17 to 0.83)	0.58 (0.06–0.86)	0.06 (–1.11 to 0.69)	0.32 (–0.52 to 0.78)
	Hour	0.58 (0.06–0.86)	0.67 (0.25–0.89)	0.29 (–0.59 to 0.77)	0.16 (–0.88 to 0.86)
	Day	0.71 (0.32–0.91)	0.73 (0.38–0.92)	0.50 (–0.17 to 0.84)	0.54 (–0.07 to 0.86)
Sway >0.1 Hz	All	0.78 (0.64–0.88)	0.63 (0.40–0.79)	0.49 (0.18 to 0.71)	0.59 (0.34–0.77)
	Minutes	0.77 (0.50–0.93)	0.78 (0.51–0.93)	–0.62 (–2.62 to 0.46)	0.14 (–0.93 to 0.71)
	Hour	0.90 (0.79–0.97)	0.60 (0.10–0.87)	0.60 (0.11–0.87)	0.73 (0.40–0.91)
	Day	0.57 (–0.01 to 0.87)	0.52 (–0.12 to 0.85)	0.71 (0.32–0.91)	0.64 (0.15–0.89)



**Fig. 2.** Percentage of subjects who changed their 'visual dependency' from one test to the next test. Approximately 30–50% of subjects changed from one test to the next. Group A: 20 min intervals, Group B: 3 h intervals, Group C: 24 h interval.

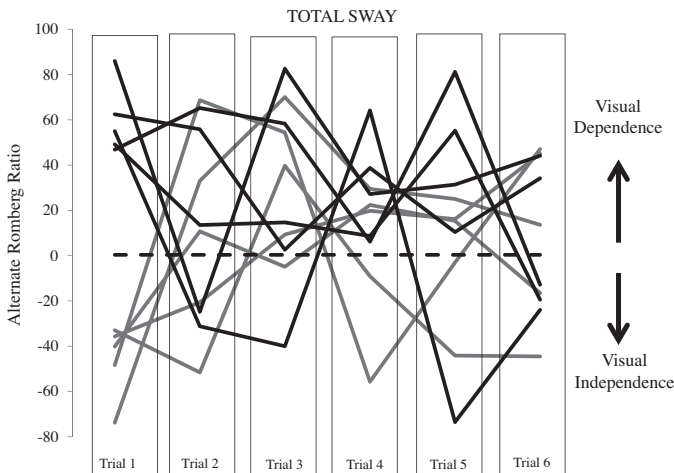
The Romberg ratios, whether traditional or alternate, yielded inconsistent results when repeatedly tested in healthy young subjects, irrespective from the fact that the reliability of repeated quiet stance posturography was fair to excellent. The calculations of ratios seem only to amplify the variations of the measurements, making ratio-analyses questionable. The alternate Romberg ratio seems to be a more stable calculation, both with regard to ICC as well as the variation of absolute ratios, which probably is due to the fact that the total postural sway is included in the formula. "Although the alternate ratio had a better test–retest reliability, the sensitivity of extreme value analyses and the variation of absolute values, advocates caution even if the alternate Romberg ratio is used."

When analyzing the raw data no trend towards more or less postural sway during the trials could be discerned in either visual condition, consistent with the findings of Wrisley et al. [8] as well as previous work on postural adaptation [17]. Since the variation in torque values that occurred during the tests was not subject to an

adaptation process, the differences in calculated Romberg ratio must be due to intra-individual variations on each test occasion as well as during different visual conditions. Just standing on a platform is not a difficult task and the abundance of information from sensory systems overlap each other [19] which means that during unchallenged conditions the postural control system has a great redundancy, at least in healthy young subjects. In this sense, the subjects can choose whether to stabilize themselves with or without vision. They probably also can, if they feel relaxed enough, let go of co-contraction of postural muscles during stance, thus creating more torque in any condition. It could be that ratios would show a greater consistency in repeated measures in pathology [3] or with some kind of postural perturbation [20]. This remains to be properly investigated.

It could be claimed that 30 s is a too long time to stand still, and processes labeled as vicarious, i.e. factors that are not strictly related to the task of maintaining postural control (e.g. mental preoccupations, fleeting distractions etc), could influence the recordings during quiet stance [21]. This is however the reason why the recordings are so long, in order to reduce the impact from external and internal influences or sudden (normal) random shifts of center of pressure. Another reason was to catch the low frequency movements and to be able to analyze changes also in that spectrum of body movements [22].

The Romberg ratio was more consistent in frequencies >0.1 Hz and predominantly yielding "visually dependent" ratios, which probably reflect that visual cues reduced the need for fast regulatory corrective body movements [17]. The sway composition during EC and EO conditions constituted one of the rationales for the frequency separation [16], and as a consequence of biasing the data in sway >0.1 Hz, probably also hampers the ratio for analyses on sensory weighting. The consistency of repeated tests was greater when the interval between the tests increased. This might reflect that the preceding postural perturbations induced by vibration might have influenced the ensuing quiet stance recording [9]. Performing repeated tests always means a risk for that the first test could have influenced the subjects' anticipation for the forthcoming tests. However, in this study the vast majority of the subjects continued to change their Romberg ratio throughout all



**Fig. 3.** The five most 'visually dependent' vs the five most 'independent' subjects and their alternate Romberg ratio through the six tests.

repetitions. The practice of most assessment programs of postural control consists of making repeated recordings under somewhat different stability conditions, i.e. sway recording with eyes open/closed during quiet stance, followed by some sort of sensory manipulation. Thus, in the perspective of consecutive sensory testing the analysis of only Romberg ratio during quiet stance, as made in this study, is in line with standard posturography procedure.

Altogether the results suggest that more research is needed before ratios in posturography recordings can be properly used. Test-retest reliability should be investigated on patients with stable known deficits to the postural control system, in order to evaluate the effect from interventions, whether that is physical therapy, surgery or medical therapy. Also it would seem that other ratios involved in SOT [4], need to be developed and evaluated. As is shown with these results, the fact that individual measurements of test–retest are consistent [6,8] does not mean that the ratios are.

Since the ratios yielded so variable results, it could be questionable as a useful tool in assessing sensory weighting of postural control in subjects with an abundance of sensory inputs, nor in assessing the outcome from various interventions. Again this could possibly be different in another population, but for reasonably healthy persons, the ratio does not seem to help in the understanding or evaluation of an individual's postural control function. There are other ways to assess visual dependence or visual field dependence, such as the Rod&Frame test and the rotating disk test [23,24]. These have rarely been used together with posturography with no postural perturbation and seldom been associated with the Romberg ratio. Isableu et al. [25] performed posturography test while at the same time exposing subjects to a rotating visual frame and could effectively demonstrate a positive correlation between postural sway (i.e. ratios) and visual dependence. However the rotating visual frame is a postural perturbation in itself and thus affects subjects that are more visually dependent and therefore has little or no correlation to quiet stance posturography. Investigations have sometimes found a correlation between visual field dependence (Rod & Frame test) and Romberg ratio in patients [26] with deficits in their postural control system, but not in healthy subjects [26,27]. This argues that that there might be a relationship between visual field dependence and the Romberg ratio in quiet stance, at least if the postural control is compromised in some way and thus in the need of more visual cues. However the consistency of these findings in repeated measurements and a possible assessment of sensory weighting in postural control need further exploration. That visual weighting differs among individuals, in a more stable manner, when facing postural challenging conditions is not in doubt, however a reliable method to assess the dependency of visual cues in quiet stance seems so far to be elusive.

## 6. Conclusion

Romberg ratio calculations of quiet stance posturography yield inconsistent values when repeatedly tested in healthy adults. The ratios test–retest reliability increases if an alternate formula is used and only postural sway above 0.1 Hz is analyzed. The Romberg ratio of quiet stance does not seem to provide reliable information on sensory weighting, at least not in healthy subjects.

## Conflict of interest statement

There are no conflicts of interest.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.gaitpost.2014.12.007>.

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