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Investigating the center of pressure velocity Romberg's quotient for assessing the visual role on the body sway

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Abstract The classical Romberg's test based on stabilometric tests in eyes open (EO) and closed (EC) conditions was used for investigating the influence of visual feedback in the body sway control in healthy adult subjects. Stabilograms from 144 subjects (aged 18-40) resting over a force platform were recorded for 30 s in EO and 30 s in EC conditions. The mean velocity was obtained for EO (Vm_{EO}) and EC (Vm_{EC}) in both anterior-posterior (y) and medial-lateral (x) directions and in the (x,y) plane, and thus used for computing the respective Romberg's quotient (RQ_V). All Vm and RQ_V parameter histograms presented unimodal asymmetric shapes, which were adequately fitted to lognormal distributions (Kolmogorov-Smirnov test, p > 0.05). These findings suggest a single homogeneous group in terms of visual strategy. Taking the threshold scores (95% confidence interval) of the Vm and RQ_V distributions, only four subjects (2.7%) presented values below the lower limit, as expected by the confidence level (two tailed, 5%). A strong dependence was also found between each RQ_V and the respective Vm_{EC} (Spear correlation ≥ 0.86, $R^2 \geq 74.0\%$), with Vm_{EO} presenting almost negligible coefficients of determination ($R^2 \leq 2.9\%$). One can conclude that RQ_V derived from a single stabilometric trial could be not sufficient for the diagnosis of body sway control impairment by vision. Nevertheless, the RQ_V could be useful to indicate subjects to carry out additional tests to investigate a possible deficit in the integration of the visual information in the postural control system.

Keywords Body sway control, Center of pressure velocity, Lognormal distribution, Romberg's test, Visual system.

Avaliando a importância da visão nas oscilações posturais utilizando o quociente de Romberg da velocidade do centro de pressão

Resumo *O Teste de Romberg clássico, baseado em testes estabilométricos nas condições de olhos abertos (EO) e fechados (EC), tem sido utilizado para investigar a influência da realimentação visual no controle das oscilações posturais em sujeitos adultos saudáveis. Estabilogramas de 144 sujeitos (18 a 40 anos) em posição ortostática sobre uma plataforma de força foram coletados durante 30 s na condição EO e 30 s em EC. As velocidades médias para EO (VmEO) e EC (VmEC), obtidas nas direções anteroposterior (y), mediolateral (x) e no plano (x,y), foram utilizadas no cálculo dos respectivos quocientes de Romberg (RQV). Os histogramas dos parâmetros Vm e RQV apresentaram morfologia unimodal assimétrica, aos quais foram ajustadas distribuições lognormais (Teste de Kolmogorov-Smirnov, p > 0,05). Tais distribuições sugerem haver um único grupo homogêneo no que concerne à estratégia visual. Considerando o intervalo de confiança de 95%, somente quatro sujeitos (2,7%) apresentaram valores de Vm e QRV abaixo do limite inferior, percentual este compatível com o teste bicaudal. A Correlação de Spear entre o RQV e seu respectivo VmEC foi sempre superior a 0,86, sendo o coeficiente de determinação R2 ≥ 74,0%, enquanto que com VmEO R2 ≤ 2,9%. Tais achados sugerem que o RQV obtido a partir de um único teste estabilométrico não seria adequado ao diagnóstico de problemas de controle das oscilações posturais ocasionados pela visão. No entanto, o RQV pode ser útil para indicar a realização de testes adicionais com vistas a investigar possível déficit na integração da informação visual no sistema de controle postural.*

Palavras-chave Controle das oscilações posturais, Velocidade do centro de pressão, Distribuição lognormal, Teste de Romberg, Sistema visual.

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Introduction

The human postural control during upright standing depends upon the central integration of afferent information from vestibular, somatosensory and visual systems (Bear *et al*., 2007; Jones, 2000; Kelly, 1991). The sensorimotor integration developed by the brain constitutes the strategy for controlling the body sway and also requires updating the reliable inputs available to maintain the balance (Carver *et al*., 2005; Peterka, 2002; Sozzi *et al*., 2011). It is well accepted that in healthy subjects, feedback information from different subsystems is complementary and partially redundant, contributing in several ways to the body sway stabilization (Chiari *et al*., 2000; Jeka *et al*., 2008). Otherwise, when sensory information from vestibular, somatosensory or visual systems is inaccurate, balance can be compromised (Horak and MacPherson, 1996; Maurer *et al*., 2006; McGuire and Sabes, 2009).

Under a stable environmental condition and a fixed support base, sensorial feedbacks are able to stabilize the body sway around the gravitational axis, producing a limited center of pressure (COP) displacement (stabilogram), which can be monitored as an output measure (Rougier, 2003). Specifically, the vision provides information about the environment to reduce body sway in a negative feedback mode (Kelly *et al*., 2005; Wurtz and Kandel, 2000). However, in a large proportion of individuals (30 to 40%), the reduction on COP sway upon eyes open condition when compared to eyes closed, is not in fact observed (Chiari *et al*., 2000; Da Silva *et al*., 2006). According to Gagey and Weber (2005), this effect might be only partially explained by the wide inter-individual differences in the maintenance of balance and can also be used for the diagnosis of impaired body sway control.

During stabilometric test (30 s recording), the position of the COP in both directions in the horizontal plane and the respective sway area have been used to obtain quantitative assessment of the sensorimotor strategy mechanisms over the sway in both eyes open (EO) and closed (EC) conditions (Chiari *et al*., 2000; Da Silva *et al*., 2006; Gagey and Weber, 2005; Percio *et al*., 2007, 2009; Rougier, 2003; Sozzi *et al*., 2011). Usually, the influence of visual input in the postural control has been studied using the classical Romberg's Quotient test (RQ) based on the elliptical sway area (RQ_A), defined as the ratio between the area values in EC and EO conditions (Chiari *et al*., 2000; Da Silva *et al*., 2006; Gagey and Weber, 2005; Lacour *et al*., 1997). Considering RQ_A as Gaussian distributed after excluding outliers and using a threshold based on the 95% confidence interval, Gagey and Weber (2005) only assumed as healthy those subjects with $RQ_A > 100$. On the other hand, Chiari *et al*. (2000), Da Silva *et al*. (2006) and Lacour *et al*. (1997) have found a bimodal RQ_A distribution in healthy subjects.

Although changes in the COP position represent valuable inputs to the central nervous system for maintaining the orthostatic posture by vision (Percio *et al*., 2007, 2009), this information is not enough to promote effective balance. According to Jeka *et al*. (2004, 2008) and Masani *et al*. (2003), the proprioceptive muscle sensors could provide additional information to stabilize body sway, since they are more sensitive to the velocity of the center of mass (COM) than to its position or acceleration. Nevertheless, undisturbed postural stance condition produces small COM sways (and hence COP sways, due to their dynamical relationship), so that those muscles sensors would be less influenced (Rougier, 2003). Additionally, the COP velocity has also the lowest reproducibility error and inter-subjects variability coefficient according to Raymakers *et al*. (2005). Thus, the RQ based on COP velocity (RQ_V) allows finding the cases where the velocity in EC condition exceeds the EO one and, according to Cornilleau-Pérès *et al*. (2005), could be more reliable to investigate the integrity of the body sway control.

In this study, the Romberg's Quotient of the COP mean velocity from a large sample of healthy subjects is used for investigating whether all of them present similar changes in body sway when the eyes are closed, or some subjects may be considered as presenting impaired body sway control. Using a single stabilometric trail with one minute recording, the methodology consists firstly in adjusting a lognormal distribution to the RQ_V data. Then, based on the cumulative density function, determining the statistical limits for which subjects can be considered as properly using the visual system to control the upright posture sway.

Materials and Methods

Participants

The sample comprised 144 healthy subjects (84 male and 60 female), age ranging from 18 to 40 years, height of 166.3 ± 21.4 cm (mean ± standard deviation) and mass of 69.2 ± 12.8 kg. All subjects present neither historical of neurological pathologies, osseous, muscles and joints diseases nor equilibrium disorder. The anamnesis was carried out to obtain information about headache, illness, vertigo, eyestrain and the use of corrective lens or glasses. Nevertheless, subjects using lens or glasses were included. Moreover, the subjects provided informed consent before inclusion in the study.

Experimental protocol

The stabilometric tests were conducted at the same environmental conditions for all subjects. In the experimental protocol the subjects were in the upright position, quite standing in the force platform with bare-footed, feet in 30° with two centimeters apart and arms along the trunk, as recommended by the French Posturology Association - Rule 85 (Bizzo *et al.*, 1985). The data was firstly collected with the subject in the eyes open condition during 30 s and then with eyes closed for the same time duration. In the EO condition, the subjects were instructed to focus a central fixed target 1.5 m in front of the force platform.

The stabilometric signal was acquired by a portable force platform composed with three load cells model MS50 (Excel Sensors, Brazil), with quadratic base of 0.16 m^2. The signal of each load cell were amplified (600×) and filtered (anti-aliasing: 25 Hz) using the MCS 100 conditioner (Lynx Technology, Brazil). The COP displacement signal was then sampled at 50 Hz (sample time interval $\Delta t = 0.02$ s), using the data acquisition system CAD 1232 (Lynx Technology, Brazil) with 12 bits resolution, stored into a standard Pentium III PC (Intel, USA) and processed using Matlab v. 6.5 (The Mathworks, USA).

Body sway velocity parameters

The COP position signal was low-pass filtered by applying a 2nd order Butterworth filter, with cut-off frequency in 7 Hz, in direct and reverse order to avoid phase shifts. Using the statokinesiogram and both COP displacement in the M/L and A/P axes (Figure 1), the mean velocity from EO (Vm_{EO}) and EC (Vm_{EC}) conditions was obtained by dividing the total COP sway path by the respective time duration.

Thus, for the M/L and A/P direction:

$$Vm(dir) = \frac{\sum_{i=1}^{K-1} \left| dir(i+1) - dir(i) \right|}{\Delta k} \quad (1)$$

where *dir* indicates the *x* variable in the M/L direction or *y* in A/P direction and $\Delta k = K\Delta t$ is the trial time duration, with $K = 1500$. In the (x,y) plane:

$$Vm(x,y) = \frac{\sum_{i=1}^{K-1} \sqrt{\left[x(i+1) - x(i)\right]^2 + \left[y(i+1) - y(i)\right]^2}}{\Delta k} \quad (2)$$

The RQ_V was thus calculated for both directions and the (x,y) plane as the relationship between the *Vm* scores with EC and EO:

$$RQ_{V\bullet} = \frac{Vm_{\bullet EC}}{V_{m\bullet EO}} \times 100 \quad (3)$$

where • indicates the M/L direction, the A/P direction or the (x,y) plane.

Posturographic analysis and statistics

Initially, for each Vm_{EO}, Vm_{EC} and the respective RQ_V parameters, the first ($\hat{\mu}$) and second ($\hat{\sigma}$) moments were estimated including all casuistry (144 subjects) and the Student t-test ($\alpha = 0.05$) was applied with the null hypothesis of equality between the mean. It is worth pointing out that just 10 subjects had $RQ_V \leq 100$.

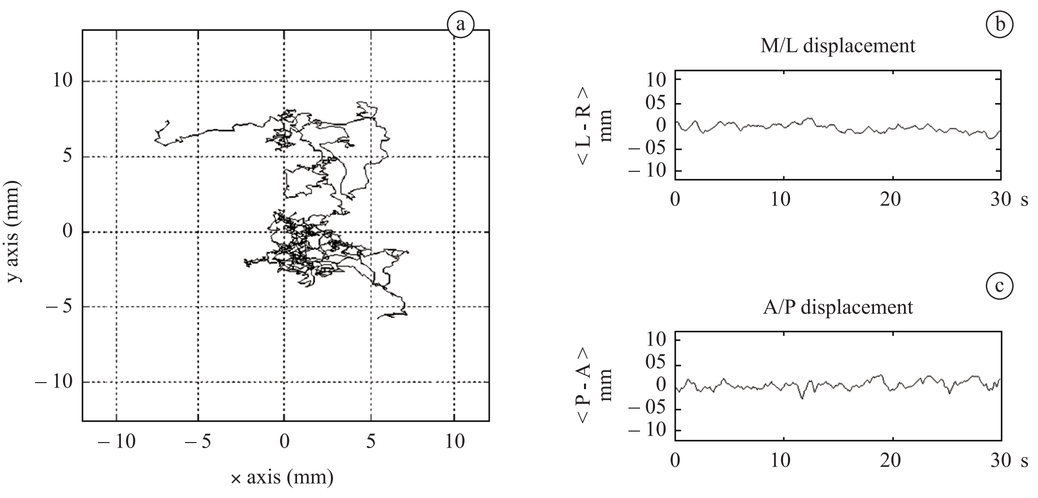

Figure 1. COP displacement in the statokinesiogram (a) and both M/L (b) and A/P (c) direction.

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The histograms of the velocity parameters in both directions and in the (*x*,*y*) plane were obtained with bin widths of 1.25 cm/s for Vm_{EO} and Vm_{EC}, and 25 for RQ_V data. All histograms depict asymmetric unimodal shapes (Figure 2), which were adequately fitted to lognormal distributions (Kolmogorov-Smirnov test, $\alpha = 0.05$, Table 1).

Hence, for each parameter distribution, the first (*M*) and second (*S*) lognormal moments were estimated and the best-fitted function adjusted using:

$$P(vel) = \frac{1}{S\sqrt{2\pi}vel} e^{-(\ln vel - M)^2/(2S^2)} \quad (4)$$

where *P(vel)* is the estimated probability density function (*PDF*) of the Vm_{EO}, Vm_{EC} or RQ_V parameters. The mean, the standard deviation and the skewness values of the *PDF* for the lognormal distribution were obtained by, respectively:

$$\hat{\mu}(vel) = e^{M+(S^2/2)} \quad (5)$$

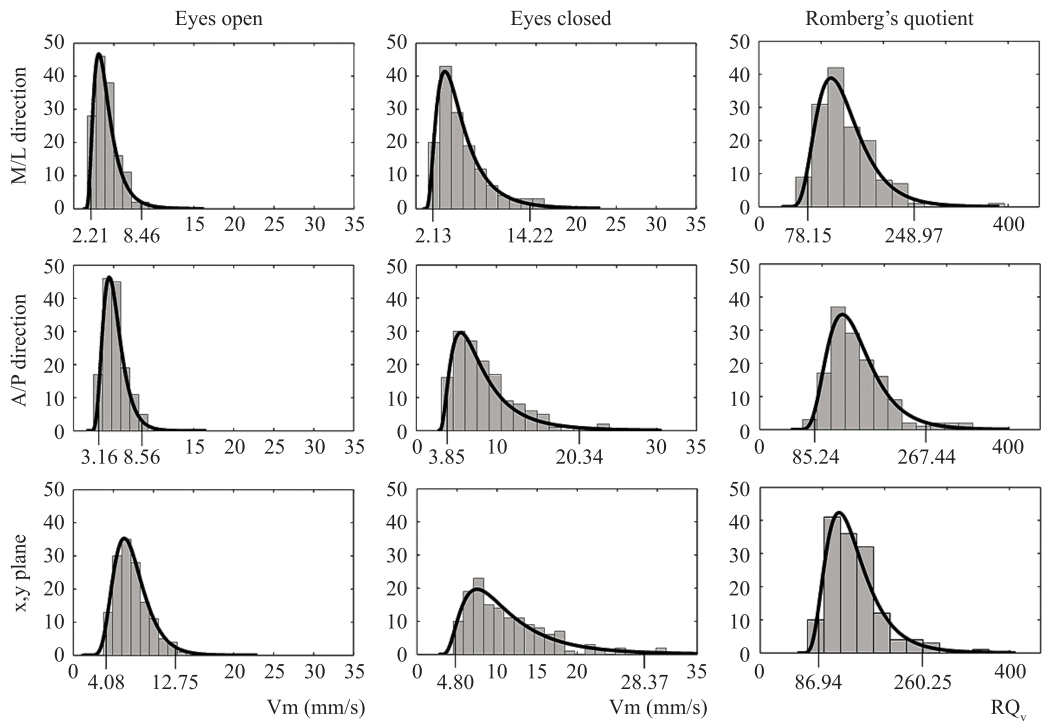

Figure 2. The histograms and the lognormal curves fitted to the experimental data. The values detached indicate the threshold scores for the 0.025 to 0.975 confidence levels.

Table 1. The mean velocity data sample and the lognormal distribution central moments for the M/L and A/P directions and for the *x-y* plane in the EO and EC trial conditions. Numbers in bold refer to $p \geq 0.8$ for the Kolmogorov-Smirnov (KS) test.

Mean velocity		**Data**		**KS test (α = 0.05)**	**Lognormal PDF**		
		$\hat{\mu}$	$\hat{\sigma}$		$\hat{\mu}$	$\hat{\sigma}$	$\hat{\gamma}_1$
M/L	EO	4.07•	1.49	0.76	4.06	1.57	1.95
	EC	5.75•	3.09	**0.92**	5.72	3.26	2.40
A/P	EO	5.15⊕	1.42	0.74	5.15	1.40	1.24
	EC	8.32⊕	3.88	**0.92**	8.29	4.43	2.75
(*x-y*) Plane	EO	7.29‡	2.08	0.79	7.32	2.15	1.09
	EC	11.22‡	5.19	**0.92**	11.28	5.86	2.14
RQ_V	M/L	139.17*	45.80	**0.81**	140.02	43.34	1.83
	A/P	159.94*+	53.36	**0.94**	159.79	50.07	1.69
	x-y Plane	151.35+	45.50	**0.91**	151.24	39.44	1.78

• ⊕ ‡ *Student t-test (α = 0.05): p << 0.001; +: p = 0.44.

$$\hat{\sigma}(vel) = \sqrt{e^{S^2+2M} \times \left(e^{S^2} - 1\right)} \quad (6)$$

and

$$\hat{\gamma}_1(vel) = \left(2 + e^{S^2}\right) \times \sqrt{e^{S^2} - 1} \quad (7)$$

The cumulative density function (*CDF*) was then estimated as follows:

$$CDF(vel) = \frac{1}{2} \times \left[1 + \frac{2}{\sqrt{\pi}} \int_0^u e^{-u^2} du\right] \quad (8)$$

where $u = [\ln(vel) - M] / S\sqrt{2}$. Using the *CDFs*, the threshold scores classification of the mean velocity parameters was determined for a confidence level of 0.025 and 0.975.

Finally, the scatter diagrams between Vm_{EO} (or Vm_{EC}), in both direction and plane, and its RQ_V were plotted. The Spear correlation ($\hat{\rho}$, $\alpha = 0.05$), the respective determination (R^2) and variation coefficients ($CV = \hat{\sigma} / \hat{\mu}$) ware calculated to determine which mean velocity parameter characterize the variability of the RQ_V scores.

Results

The Vm_{EC} data sample presented mean values greater than those obtained for the Vm_{EO} in both directions and also in the plane (Table 1). In the EC condition, 79,16% of the subjects presented mean velocity values in the A/P direction greater than those observed in the M/L, thus indicating a relationship between the absence of the visual information and the increased A/P oscillations. Moreover, the RQ_V scores in both A/P and M/L directions were considered different (Student t-test, $\alpha = 0.05$ and $p << 0.001$). Even though the mean values in the *x,y* plane were greater than those in the A/P direction (Table 1), no statistical difference ($p = 0.44$) was found between RQ_V scores. In all cases, lognormal distributions were assumed (Kolmogorov-Smirnov test, $\alpha = 0.05$), with higher *p*-values ($p > 0.80$) for the Vm_{EC} and RQ_V parameters (Table 1).

Furthermore, the lognormal *PDF* mean values are close (error lower than 0.6%) to those estimated with the data sample. The Vm_{EC} lognormal distributions have skewness greater than the respective ones estimated for the Vm_{EO}, and hence, are more asymmetric (Table 1; Figure 2). On the other hand, similar skewness was observed among the RQ_V distributions. Taking the confidence interval from 0.025 to 0.975 and considering the A/P direction (Figure 2), 134 subjects (93.1%) have their data located within these limits (RQ_V: $\hat{\mu}$ = 167.14 and $\hat{\sigma}$ = 32.06) and just four subjects (2.7%) appeared below the lower limit ($RQ_V < 85.24$), since other six subjects (4.2%) were considered outliers ($RQ_V > 267.44$).

The scatter diagrams of the COP velocity parameters (Figure 3) show that Vm_{EC} are positively correlated with RQ_V. In EO condition, although the correlation is statistically significant ($p < 0.05$), the Spear correlation coefficients $\hat{\rho}$ are very low, ranging from 0.16 to 0.23 (Table 2). On the other hand, in the EC condition, this coefficient varies from 0.86 to 0.91 ($p << 0.001$, Table 2). Hence, based on the coefficient of determination (R^2) for A/P direction (Table 2), 75.7% of the variability of the RQ_V can be explained by the variability of the Vm_{EC}. Moreover, the coefficient of variation (*CV*) indicates that Vm_{EC} has higher variability than Vm_{EO}, particularly in the A/P direction (Table 2).

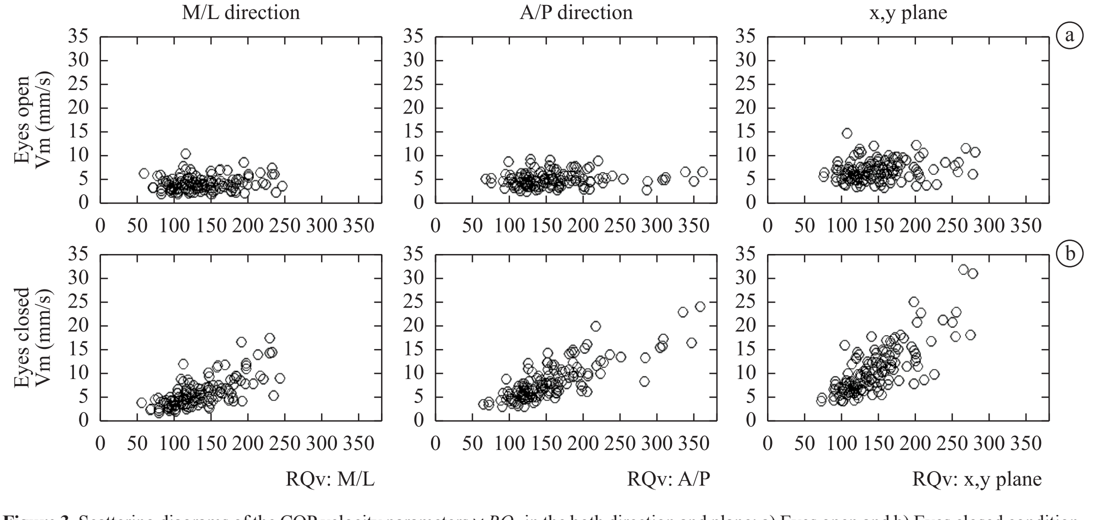

Figure 3. Scattering diagrams of the COP velocity parameters × RQ_V in the both direction and plane: a) Eyes open and b) Eyes closed condition.

Table 2. The Spear correlation ($\hat{\rho}$) and respective R^2 and *CV* coefficients between RQ_V and mean velocity for EO and EC data, for both M/L and A/P directions and the plane.

Mean velocity parameters		$\hat{\rho}$	R^2 **(%)**	*CV*
M/L	EO	0.16‡	2.6	0.37
	EC	0.86*	74.0	0.54
A/P	EO	0.17‡	2.9	0.28
	EC	0.87*	75.7	0.47
(*x*, *y*) Plane	EO	0.23‡	5.3	0.29
	EC	0.91*	82.8	0.46

**p-value* << 0.01 and ‡ *p-value* < 0.05.

Discussion

As well known, the sensory feedbacks in the postural control system provide complementary and partially redundant information for body sway stabilization. The experimental protocol adopted in this study in which the subject is maintained in orthostatic position without any stimulus, is expected to cause small postural changes as a result of effective visual and proprioceptive feedbacks, as pointed out by Jeka *et al.* (2004, 2008). Besides, in such kind of experiment, the EO condition improves the balance control (Ray *et al.*, 2008; Sozzi *et al.*, 2011), reducing the mean velocity (*Vm*) of the sway (Cornilleau-Pérès *et al.*, 2005).

In the present study, changes in the visual condition affected more the COP mean velocity in the A/P direction than in the M/L, which is in accordance with Berencsi *et al.* (2005), Jeka *et al.* (2008), Ray *et al.* (2008) and Sozzi *et al.* (2011). Moreover, the Romberg Quotient of *Vm* (RQ_V) in the A/P direction does not statistically ($p = 0.44$) differ from that in the (*x*,*y*) plane (t-student, $\alpha = 0.05$) and hence they provide similar information, as reported by Cornilleau-Pérès *et al.* (2005). Thus, changes in the M/L direction appear as not constraining the results in the plane, suggesting the use of the COP velocity in A/P direction for investigating the mechanism of postural control by vision.

The RQ_V unimodal distribution indicates the existence of just one group in terms of visual strategy. Using similar setup, Cornilleau-Pérès *et al.* (2005) and Elliot *et al.* (1998) also reported only one visual category group when investigating the COP velocity of a healthy population. The positive skewness observed in all *Vm* and RQ_V distributions reveals that these parameters are not normally distributed. By assuming a lognormal distribution for the 144 RQ_V and taking the inferior confidence limit (85.24), only four subjects (2.7%) are outside of it, which is in accordance with the significance level (α = 0.05, two tailed). This result agrees with Elliott *et al.* (1998), who also observed an asymmetric distribution in *Vm*, reporting no case of impaired body sway control in a sample of 30 subjects. Additionally, the study reported by Cornilleau-Pérès *et al.* (2005) deserves consideration. Using only 21 subjects with $RQ_V > 100$ and assuming this parameter as Gaussian distributed, these authors pointed out that 99.8 is the lower threshold for which the postural sway control by vision could be considered abnormal. Applying the Cornilleau-Pérès procedure to the 132 subjects with $RQ_V > 100$, it was obtained a lower limit of 98.72, resulting that eight of the 10 healthy subjects with $RQ_V < 100$ could present an inadequate visual feedback to postural control. However, this finding differs from that obtained using a lognormal distribution.

The low variability of the COP mean velocity parameters during eyes open and the positive correlation with their respective RQ_V scores indicated that the effect of using the visual information to improve postural control is similar between all subjects. According to Levi and Klein (2003) and to Maeda *et al.* (1998), during visual feedback impairment, the sway in EO condition is higher for the lower *RQ* values, implying in a negative correlation (not observed in this work). Additionally, Ray *et al.* (2008) reported that subjects with visual impairments present an inadequate postural control, increasing the sway when compared with a healthy population. Therefore, not all subjects with $RQ_V \leq 100$ can be considered as presenting impaired visual control (or postural blind) and, unlike pointed out by Gagey and Weber (2005), the RQ_V can not be used alone as a normalcy index for the diagnosis of visual impairment sway control.

The removal of visual inputs increased the COP velocity in 93.1% of subjects, indicating that during eyes closed the COP sway increased, when compared to eyes open, which is in accordance with Sozzi *et al.* (2011). This finding suggests that the absence of visual feedback is not fully compensated by the other sensory inputs, increasing the variability of the COP displacement. Furthermore, the highest Spear correlation observed only during eyes closed condition ($\hat{\rho} \geq 0.86$, $R^2 \geq 74.0\%$) demonstrated that the RQ_V increased mainly because the Vm_{EC} have increased. Therefore, these results suggest the sensory integration as vision-dominant in the postural control, as pointed out by Cornilleau-Pérès *et al.* (2005) and Rougier (2003). Moreover, even for the four subjects outside the lower confidence limits, this is no evidence of impaired postural control system. Hence, this study support the hypothesis of the sensory integration control proposed by Jeka *et al.* (2008), in which the postural control adaptively use available sensory inputs for compensating a removed feedback, for stabilizing the body. According to Maurer *et al*. (2006) and McGuire and Sabes (2009), the presence of multiple inputs allows optimizing the use of the available sensory information under static environmental condition. It also can explain why eventually some healthy subjects (without visual deficit) reduce the sway during eyes closed condition.

Conclusion

The unimodal distribution observed in all *Vm* and RQ_V histograms suggests that the subjects can be considered as coming from a single group in terms of visual strategy. The orthostatic stability during eyes open condition seems to be similar between the subjects, independently of their RQ_V values. Hence, the *RQv* inter-individual variability may be mainly related to the spread in mean velocity during eyes closed condition. Therefore, the use of sole Romberg Quotient of the COP mean velocity in a single stabilometric trial with just one-minute total duration could be not enough for the diagnosis of body sway control impairment by vision. Nevertheless, the RQ_V could be useful to reveal the subjects having this index below the threshold, who are then indicated to carry out additional tests, and hence, to investigate a possible deficit in the integration of the visual information in the postural control system.

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