The influence of having the eyelids open or closed on undisturbed postural control

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Abstract

To assess the possible interactions between the physiological mechanisms involved in eyelid closure and stance maintenance, 20 healthy adults were required to keep their eyes open in the dark (EOd), in daylight (EO), or to close them normally (EC), respectively and in random order. The analysis was focused on elementary motions computed from the complex centre of pressure (CP) trajectories, that is to say the vertical projection of the centre of gravity (CGv) and the difference between CP and CGv (CP−CGv). The results indicate that the mean amplitudes of the CP−CGv spectra are statistically reduced in EOd when compared to the EC condition. This diminution is thought to express a decrease in the level of activity of lower limb muscles involved in stance control. Interestingly, the CNS does not really seem to gain from these reduced horizontal accelerations at the CG level since the CGv amplitudes are in turn only slightly reduced. It can thus be hypothesised that, despite the fact that visual information in the EOd condition remains unavailable, the somesthetic cues continue to play a minor role in the detection−correction process aimed at controlling undisturbed stance.

1. Introduction

In upright undisturbed stance, the control of the centre of gravity (CG) over the reduced base of support requires the central nervous system (CNS) to select the appropriate motor command for maintaining balance through integrative mechanisms involving various neurosensorial inputs. The main difficulty comes from the inertia of the body and the inability of the muscles to develop a constant tension. Consequently, the centre of pressure (CP), which expresses the point of application of the resultant reaction force in the plane of support, cannot be followed accurately by the whole body and CG. In order to minimise these CG motions, which could rapidly cause loss of balance, some mechanisms operating in closed-loop control need to be employed by the CNS. Among the possible inputs involved, vestibular information appears to play a minor role due to the lower thresholds, which are well below those encountered in such a task (Fitzpatrick and McCloskey, 1994; Winter et al., 1998). In addition, as demonstrated by Fitzpatrick et al. (1994), visual inputs have a minor effect on the gain of the vestibular-evoked response when appropriate proprioceptive cues are available. Furthermore, eye closure during standing does not affect the threshold for perceiving sway (Fitzpatrick and McCloskey, 1994). Undisturbed stance maintenance should thus be perceived as relying mainly on visual (when eyes remain open) and somesthetic cues.

Many investigations conducted in this field have focused on the comparison of postural performance in both closed and open eye conditions, especially through the traditional Romberg quotient (Van Parys and Njokikijien, 1976; Diener et al., 1984). Some previous studies have, for instance, highlighted that this quotient is progressively enhanced in children (Marucchi et al., 1989) and diminished in the elderly (Toupet et al., 1992), suggesting decreased and increased contributions of visual cues in maintaining upright undisturbed stance, respectively. However, the validity of such interpreta-

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tions should be considered with great caution since a recent study demonstrated that the eyelid closure–
opening mechanism interferes with the postural control system (Rougier et al., 2003). To be more precise, the postural behaviours observed in this preliminary study (involving a reduced sample of subjects in various non-
visual conditions) suggest potential involvement of structures such as the cerebral cortex or the brain
stem. From that, one may hypothesise that having the eyelids open or closed in the dark may substantially
modify the control mechanisms involved in the main-
tenance of equilibrium in upright undisturbed stance in
normal subjects. Consequently, an index such as the
Romberg quotient and its interpretation should throw
light on these postural modifications.

To look into this phenomenon, a new investigation
has been undertaken involving healthy adults required,
as is usual in this type of study, to close and open their
eyes and, as an additional test, to stand with their eyes
open in the dark. To evaluate the effects on postural
control, a discriminating method was used, which
provided more insight than the more traditional anal-
ysis, which is based solely on summary statistics. This
method consisted in a dissociation of CP trajectories
(the controlling variable in undisturbed upright stance
according to Winter et al. (1996)) into two elementary
superimposed components (Rougier and Caron, 2000):
the centre of gravity vertical projection (CGv) and the
differences between CP and CGv (CP–CGv). Indeed, at
certain moments, the CP displacements inducing CG to
move are minimised, whereas, at other times, when CG
is about to determine a loss of balance, the CP
displacements tend to induce this CG to move in order
for it to return to a position more compatible with
equilibrium maintenance.

To better justify this dissociation, it is important to
emphasise that the CG motions are thought to be the
key variable in postural control (Horstmann and Dietz,
1990) and that the difference CP–CGv demonstrates
proportionality with the horizontal CG acceleration
(Brenière et al., 1987) and the resultant ankle stiffness
(Winter et al., 1998). Thus, with this method of analysis,
it becomes possible to assess whether enlarged territories
covered by the CP trajectories, viewed traditionally as
resulting from a postural dysfunction, are due to
lessened capacities to control the CG motions and/or
to exaggerated muscular activity.

Along these lines, the fractional Brownian motion
(fBm) modelling can be viewed as an interesting
contribution to the understanding of stance control
since it allows to display the nature of the control
mechanisms involved in this task and the spatio-
temporal limits over which these mechanisms operate.
Moreover, the degree to which a given motion such as
CGv or CP–CGv is controlled can be established by
comparing the various trajectories assessing postural
behaviour to a reputed uncontrolled or random walk
one. As demonstrated by Riley et al. (1998), this
approach seems appropriate since the increment time
series are stationary and display self-similarity and
Gaussian distribution. Used initially for studying CP
trajectories (Collins and De Luca, 1993; Rougier,
1999a), this model was recently extended for the
elementary CGv and CP–CGv, motions for various
topics (Rougier and Farenc, 2000; Rougier et al., 2001;
Rougier, 2003).

2. Materials and methods

The methodology has been detailed previously in
recent articles (Rougier and Caron, 2000; Rougier and
Farenc, 2000). Only the main points will thus be
presented here.

2.1. Experimental procedure

Twenty healthy subjects, nine males and 11 females,
ranging in age from 22 to 60 years (body weight, 68.1 ±
10.8 kg; height, 172.7 ± 8.2 cm; mean ± S.D.) with no
known visual or balance pathology gave their informed
consent and were included in this study. They stood
barefoot on a triangular force platform (PF01; Equi+
Aix les Bains, France), feet abucted at 30°, heels
separated by 3 cm, and were asked to sway as little as
possible with their arms at their sides. The signals issued
from the load cells, on which the plate lays, were
amplified and converted from analogue to digital form
before being recorded on a personal computer. The CP
trajectory was then automatically processed, as seen
below, in different ways through a specific software
programme (Prog01; Equi+, Aix les Bains, France),
ML and AP characterise medio-lateral and antero-
posterior directions, respectively. Three experimental
paradigms were successively and randomly performed.
For all conditions, the subjects were instructed to sway
as little as possible with their arms at their side. In the
open eyes condition (EO), the subjects were instructed to
stare at a vertical line, placed 1 m in front of them. In
the closed eyes condition (EC), the standardised pro-
dure consisted in the subjects standing on the platform
and, once their equilibrium in EO was mastered, closing
their eyes. Since the diffused lightening was above the
subject, it was not possible for him to locate, even
roughly, the source of light to gain motion information.
Lastly, they were required to stand EO in complete
darkness (EOd). To this aim, the room in which the
investigation took place was entirely darkened and the
conditions rechecked a few minutes later once their eyes
had become accustomed to the darkness. For the two
latter conditions, the light was turned off when the trial
was announced (i.e. about 10 s before the onset of the
increasing mean time inter

principle for estimating the CG

there exists a frequency relation between these two

experimental condition included fi

recording) and turned on at the end of the trial. Each

subjects, in EC, re-opened their eyes.

64 Hz sample frequency, rest periods of a similar

v

amplitude ratio between CG

v

v

Body sways being particularly reduced in this task, one may consider that body inertia remains

constant throughout the trials. In this case, CG

will be able to

fBm this relation has to be written as

\[ \langle \Delta x^2 \rangle = \Delta t^{2H} \]  \hspace{1cm} (1)

With this scaling exponent \( H \), it is, a priori, possible
to determine the fractal dimension, and consequently
the degree of control of the trajectory. If no correlation
between past and future displacements exists, \( H \) is equal
to 0.5, indicating the presence of a pure random walk or
ordinary Brownian motion. On the other hand, i.e. if \( H \)
differs from 0.5, positive or negative correlation can be
inferred, which is indicative of a given part of determin-

in this task, one may consider that body inertia remains
in the present study, the determination of the CG

in this paradigm, is computed and used to characterise each
subject in one direction. As indicated in Eq. (1),
information such as the number, the nature and the
temporal organisation of the mechanisms involved in
postural control is extracted from the shape of the variograms since the latter is depicted through a log–log
plotting. An example of this procedure for CG

and CP motions can be seen in Fig. 1. As is
classically seen for CP trajectories in bipedal undis-
turbed stance, two successive portions are still distin-
guishable in both ML and AP directions for CG

and CP motions. On the other hand, as shown for
instance by Winter et al. (1996), undisturbed stance can be theoretically modelled as an inverse pendulum where
CG

and CP behave as periodic functions in phase with
each other. Consequently, the shift between successive
mechanisms appears necessarily identical for all CP,
CG

and CP–CG

motions (Fig. 1). Thus, the method retained initially for CP trajectories can be maintained
(Rougier, 1999b). The principle lies in a comparison
between experimental and average stochastic vario-

grams in order to highlight this temporal organisation
and to objectively determine the transition point, i.e. the
time interval at which corrective mechanisms are called
into play. For CP motions, the complete stochastic
process is characterised in a log–log scaling by a one-
slope straight line. The maximal distance between
experimental and the “stochastic” straight line is
thought to correspond to the $\Delta t$ co-ordinate of the transition point.

Once this transition is identified, scaling exponents $H$, which represent the half-slopes of the successive variograms portions displayed in log–log plotting, are calculated through a least-square method for preceding and succeeding points, respectively. However, for CG, and CP–CG motions, variograms and consequently scaling regimes characterising “average stochastic variograms” over the same $\Delta t$ must be subtracted in order to take into account the lowpass and highpass filter effects through which the elementary CG, and CP–CG motions are estimated from CP displacements. Instead of the straight line characterising the CP stochastic displacements, the filter effect indeed leads to curvilinear curves moving progressively away from or closer to it for CP–CG, and CG motions, respectively. Scaling regimes relative to “average stochastic variograms” over the same $\Delta t$ must therefore be taken as a reference in such a way that

$$H_{\text{cal}} = (H_{\text{exp}} - H_{\text{sto}}) + 0.5$$

where $H_{\text{cal}}$, $H_{\text{exp}}$ and $H_{\text{sto}}$ represent the calculated, experimental and stochastic scaling regimes, respectively. Thus, for each of the two motions investigated and each ML and AP direction, two scaling exponents (indexed as short and long latencies: $H_s$ and $H_l$) and the transition point co-ordinates are extracted. Finally, since the slopes of the variograms do not seem to vary significantly after time intervals exceeding 10 s, this limit was adopted to compute the various aforementioned parameters.

Lastly, to evaluate the eyelid effects on the whole set of parameters, the results, issued from EO, EC and EOd conditions, were processed through a non-parametric one-way ANOVA of Kruskal–Wallis. Even though five trials were recorded for each subject in each experimental condition, the software gives only an average value for each parameter. On the other hand, this procedure seems quite sound in regard to fBM modelling which is theoretically based on infinite time series. Consequently, extracting parameters from average variograms seems to be the ad hoc technique in this field, as initially pointed out by the study of Collins and De Luca (1993). Post hoc comparisons and comparisons between the Romberg quotient involving either EC (EO/EC) or EOd (EO/EOd) as reference conditions were then processed through a non-parametric statistical analysis, the Wilcoxon $T$-test, the first level of significance being set at $P < 0.05$.

3. Results

3.1. Frequency parameters

The average frequency spectra of Fig. 2 indicate that a decrease is observed in the CP–CG amplitudes when subjects open their eyes, whether they are in darkness or not. In addition, this effect is larger in the EO condition and concerns the whole range of the 0–3 Hz bandwidth. One should also note that these decreases are always more pronounced in the AP direction, when compared to the ML one. These visual impressions are confirmed by ANOVA computed for RMS ($H(2, 60) = 9.238$, $P < 0.0099$ and $H(2, 60) = 15.408$, $P < 0.0005$ for the ML and AP directions, respectively). Concomitantly, no real effect is seen for MF which expresses the frequency distribution of the amplitudes over the selected bandwidth, thus signifying unchanged ankle stiffness according to the study by Winter et al. (1998) ($H(2, 60) = 1.094$, $P > 0.05$ and $H(2, 60) = 0.0437$, $P > 0.05$ for the ML and AP directions, respectively). As illustrated by the histograms of Fig. 2, the post hoc comparisons reveal statistical differences between each condition for RMS and none for MF. To be precise, RMS for EOd are smaller than those of the EC condition in both directions (ML: $T = 34$, $P < 0.01$; AP: $T = 29$, $P < 0.01$). On the other hand, the EO condition demon-
parameters. The significant effects assessed by the ANOVA of Kruskal for the three conditions. Displayed on the right are histograms showing group means and standard deviations for RMS and MF frequency parameters. The significant effects assessed by the ANOVA of Kruskal–Wallis are presented above the histograms whilst those relative to the post hoc means comparisons are displayed below (the one between EO and EC on the left side, the one between EOd and EC on the right and the one between EO and EOd in the middle). ***, \(*\), \(*\), \(*\). Note the differences in amplitude between the three conditions.

Fig. 2. Spectral decomposition for each elementary component (ML and AP) characterising the whole sample population for CP–CG, motions and for the three conditions. Displayed on the right are histograms showing group means and standard deviations for RMS and MF frequency parameters. The significant effects assessed by the ANOVA of Kruskal–Wallis are presented above the histograms whilst those relative to the post hoc means comparisons are displayed below (the one between EO and EC on the left side, the one between EOd and EC on the right and the one between EO and EOd in the middle). ***, \(*\), \(*\), \(*\). Note the differences in amplitude between the three conditions.

strates lower RMS than EOd (ML: \(T = 24, P < 0.01\); AP: \(T = 14, P < 0.001\)) and EC (ML: \(T = 8.5, P < 0.001\); AP: \(T = 0, P < 0.001\)).

The horizontal motions of CG are also modified by eyelid closure. In particular, as depicted through the spectra of Fig. 3, keeping ones eyes open in the dark provokes a decrease in the amplitudes of lower frequencies, when compared to the reference condition EC. Quite similarly, visual information induces a further decrease in these amplitudes. However, these amplitudes are more widely distributed over the complete bandwidth, i.e. 0–0.5 Hz. The ANOVA of Kruskal–Wallis confirms these features since statistical results are obtained for MF (\(H(2, 60) = 14.048, P < 0.0009\) and \(H(2, 60) = 11.542, P < 0.0031\) for the ML and AP directions, respectively). However, contrary to that noticed for CP–CG, motions, no statistical results have been found for RMS. Some statistically significant differences are worth mentioning in MF between EC and EO (ML: \(T = 4.5 (n = 18), P < 0.001\); AP: \(T = 20 (n = 18), P < 0.01\)) and between EOd and EO (ML: \(T = 116 (n = 15), P < 0.001\); AP: \(T = 93 (n = 14), P < 0.01\)).

3.2. Parameters issued from the fBm modelling

As seen on the average variograms illustrated in Figs. 4 and 5, the two successive line portions characterise postural behaviours for all experimental conditions. In particular, one may observe that the transition point temporal co-ordinate \(\Delta t\) remains quite similar throughout the different conditions. This is confirmed in the histograms from Fig. 4 and the ANOVA (\(H(2, 60) = 0.407, P > 0.05\); AP: \(H(2, 60) = 0.297, P > 0.05\)). Despite larger values seen in the EOd condition, the post hoc comparisons are unable to extract further statistical differences. On the other hand, the transition point spatial co-ordinate \(\langle \Delta x^2 \rangle\) is largely affected by the different conditions. As demonstrated by the ANOVA, statistically significant results have been found for both CP–CG, (ML: \(H(2, 60) = 9.920, P < 0.007\); AP: \(H(2, 60) = 16.681, P < 0.0002\) and CG, motions (ML: \(H(2, 60) = 14.926, P < 0.0006\); AP: \(H(2, 60) = 13.457, P < 0.001\)). By definition, the former expresses the horizontal force (proportional to the acceleration communicated to CG, the CNS has to encounter when the corrective (anti-persistent) control is initiated, whereas the latter indicates the mean square distance covered by CG during the initial persistent control. As indicated by the histograms of Fig. 4, some differences are observed between EOd and EC for both ML and AP directions, but only for CP–CG, motions (ML: \(T = 45, P < 0.05\); AP: \(T = 37, P < 0.01\)). Concerning CG, motions, some statistically lower values have been found for \(\langle \Delta x^2 \rangle\) in the EO condition, when compared to the EC conditions (ML: \(T = 21, P < 0.001\); AP: \(T = 19, P < 0.001\)) and the
Fig. 3. Spectral decomposition for each elementary component (ML and AP) characterising the whole sample population for CG, motions and for the three conditions. Displayed on the right are histograms showing group means and standard deviations for RMS and MF frequency parameters. Note the differences in the frequency distribution between the three conditions.

Fig. 4. Relative variograms for each elementary component (ML and AP) characterising the whole sample population CP—CG, motions for the three conditions. Beside them are histograms showing group means and standard deviations for parameters issued from the fBm modelling: spatio-temporal co-ordinates of the transition point ($<\Delta x^2>$ and $\Delta t$) on the median part and scaling exponents $H_{sl}$ on the right part. Note the differences in the spatial co-ordinates of the transition point characterising each trajectory.
EOd conditions (ML: \(T = 30, \ P < 0.01\); AP: \(T = 11, \ P < 0.001\)).

The other important feature, which characterises the relative variograms, concerns the slopes of the line portions, and more particularly how they may be differentiated from the average stochastic variograms (hence revealing the contribution of deterministic processes in the control of the various motions). As indicated by the histograms of Fig. 4, and statistically confirmed by the ANOVA of Kruskal–Wallis, no effect is seen for the scaling regimes \(H_{ll}\) characterising CP–CG\(_v\) motions over the shortest \(\Delta t\) (ML: \(H(2, 60) = 0.145, \ P > 0.05\); AP: \(H(2, 60) = 1.508, \ P > 0.05\)). Conversely, effects are observed for the scaling regimes \(H_{ll}\) characterising CG\(_v\) motions over the longest \(\Delta t\) (ML: \(H(2, 60) = 14.333, \ P < 0.0008\); AP: \(H(2, 60) = 13.138, \ P < 0.0014\)). The post hoc comparison indicates that the EO condition induces a lesser control of the CG\(_v\) motions, when compared to the EC (ML: \(T = 11, \ P < 0.001\); AP: \(T = 18, \ P < 0.001\)) or the EOd condition (ML: \(T = 24, \ P < 0.01\); AP: \(T = 30, \ P < 0.01\)). In other words, the probability for the CG\(_v\) motions to wiggle during the corrective process is enhanced in the EO condition. Finally, for all conditions, the scaling regimes \(H_{ll}\) for CP–CG\(_v\) motions and \(H_{ll}\) for CG\(_v\) motions demonstrate a certain parallelism between the line portions and the averaged stochastic variogram, hence indicating a lack of control for these motions.

3.3. Romberg quotients

The Romberg quotients calculated for both EC and EOd conditions demonstrate statistically significant differences, in particular with regards to the CP–CG\(_v\) motions. As illustrated by the histograms of Fig. 6, the Romberg quotients computed from RMS of the CP–CG\(_v\) motions spectra are reduced for the EO/EC ratio, when compared to the EO/EOd one. This result concerns both ML (\(T = 33, \ P < 0.01\)) and AP (\(T = 29, \ P < 0.01\)) directions. These modifications can mainly be explained, through fBm modelling, by some increased ratios involving the transition point spatial co-ordinate \(\langle \Delta x^2 \rangle\) (ML: \(T = 33, \ P < 0.01\); AP: \(T = 53, \ P < 0.05\)). Finally, no statistically significant trend is indicated from the parameters calculated from the CG\(_v\) motions.

4. Discussion

By demonstrating the effects that closing the eyelids could have on undisturbed upright stance, this study highlights de facto the limits of protocols aimed at diagnosing possible diseases in postural control through the classical Romberg quotient (which consists in comparing postural performance in seeing and non-seeing conditions (Diener et al., 1984)). As shown by our results, large differences can be inferred in these Rom-
berg quotients depending on the chosen reference condition (EOd or EC). For instance, as indicated by the Romberg quotient computed from RMS parameters, its decrease (based on CP displacements) generally observed for the elderly (who were, in most cases, required to close their eyes) could also be explained by effects other than a hypothesised lesser contribution of visual cues. Other such effects include exaggerated CP—CG motions or reduced capacities in controlling the CG motions for corrective purposes. Further research will thus be necessary to assess whether the present effects, observed for healthy adults, can again be found in various disabilities or across lifespans.

On the whole, our results confirm that visual input plays a major role in undisturbed upright stance control, thus confirming all previous investigations (Edwards, 1946; Paulus et al., 1984). When visual inputs are available, both elementary CG, and CP—CG, motions are indeed diminished, suggesting that the reduced CP territories in fact express both reduced sway motions and muscular activities aimed at controlling them. What is more, modelling the elementary trajectories as fBm reveals that, when visual inputs are removed, the control is endowed with more determinism, a feature previously highlighted by Collins and De Luca (1995). Complementarily, a first interesting result of the present study is that keeping the eyelids open in the dark induces smaller displacements for both CG, and especially CP—CG, motions than when the eyelids are closed, confirming our previous observation based only on a frequency approach (Rougier et al., 2003). Very little research has been made on this topic with the exception of studies made by Amblard and Crémieux (1976) and Paulus et al. (1984) who failed to reveal any differences in postural behaviours.

4.1. Biomechanical effects

Undoubtedly, the most striking result in this investigation concerns the decreased amplitudes for CP—CG, motions observed in the EOd condition, when compared to the EC one. As stated in Section 1, the main consequence is that the horizontal accelerations communicated to CG are themselves decreased, hence indicating that control by the CNS should be facilitated. On the other hand, this CP—CG, decrease can be interpreted as reduced motor unit recruitment. Indeed, according to the size principle initially described by Henneman et al. (1965), the muscular force increase is achieved by recruiting additional motor units whose mechanical properties in terms of contraction times tend to progressively decrease. In the CG,CP ratio proposed by Brenière (1996), the higher the frequency the smaller the relative displacements of CG, (because of body inertia) and thus, the larger the difference CP—CG,.

Consequently, the RMS decrease for EOd, when compared to EC, could be interpreted as reduced muscular activity at the plantarflexor muscles level. This relationship has recently been highlighted in a study of the postural control of healthy subjects required to maintain a forward leaning body stance (Rougier et al., 2001).

By modelling the trajectories as fBm, it should be noted that visual deprivation induces augmented spatial thresholds for the transition points. In other words, the distance covered before the onset of a corrective mechanism is larger. Interestingly, this feature is more pronounced for the EC than the EOd condition. Lastly, such differences cannot be explained by concomitant changes in the variogram primary slopes (H,) due to the distinct lack of difference in the degree to which these CP—CG, motions are controlled, i.e. the probability of
these motions to wiggle. As this study demonstrates, these reduced thresholds for the CP–CG motions, along with the reduced RMS, tend to suggest some kind of relationship between the eyelid closure and the lower limb muscular command.

One interesting result of the decreased CP–CG motions in the EOd condition, when compared to the EC one, is the a priori easier control of CG since, as demonstrated by Brenière et al. (1987), the latter receives significantly lower accelerations. To be precise, the reduced spatial threshold $\langle \Delta x^2 \rangle$ of the transition point for the CP–CG motions indicates that the horizontal forces, aimed at making CG return to a position more compatible with equilibrium principles, are themselves diminished at the onset of the corrective process. However, our results, by demonstrating insignificant differences in the overall CG RMS, would rather suggest a slight deterioration, when the eyelids remain open, of the control of these CG motions. By modelling this latter as an fBm, one may observe a slight tendency for less control of the corrective CG motions during the EOd condition. The observed lack of significant differences between EC and EOd conditions for the parameters issued from the fBm modelling would seem to express that several postural strategies can be used to control body sways. One such strategy involves modulating (in opposite directions) the spatial thresholds of the transition point and the degree to which the corrective CG displacements are controlled.

4.2. Neurophysiological involvements

In order to explain the observed differences in the CP–CG motions between EC and EOd conditions, the few investigations conducted on eyelid closure physiology should be taken into consideration. Uchida et al. (1999) studied the effects of periodically performed ocular saccades on postural control. They raised the hypothesis that circuits originating from the brain stem, in particular those of the reticular formation and the hypothalamus, may also exert a certain influence on these motions (Bodis-Wollner et al. 1999), through functional MRI, have shown that various cortical areas such as the medial part of the superior frontal gyrus and the posterior parietal cortex and to a lesser extent the precentral and posterior middle frontal gyri and visual cortex are activated in voluntary blinks. Even though stability control was not the main issue in their study, Ouchi et al. (1999) have put forward that closing the eyes in upright undisturbed stance leads to a supplementary activation in the bilateral middle frontal gyri, i.e. some areas already known to be involved in imaginary mental tasks (Cohen et al., 1996) and in the motor command of the saccades through the superior colliculi. Consequently, a direct modulation issued from the cortical structures cannot be excluded in the explanation of the above-mentioned effects either.

The weak effects on CG motions resulting from the nonetheless decreased CP–CG amplitudes could at least be partially explained by the respective weight of the different cue involved in stance control. As stated in Section 1, undisturbed stance control relies mainly on somesthetic information when eyes remain closed. This could probably be extended to the condition of open eyelids in the dark. In order to explain the proportionally less optimised control of CG motions in the EOd condition, one could imagine an organisation in which the respective weighting of both visual and non-visual information would be dependant of the closure–opening of the eyelids. This would explain why, despite the eyelids being open, the non-visual cues remain poorly usable by the CNS in order to control CG and make it return towards a position more compatible with equilibrium principles. In other words, the CNS, in this particular condition, would behave as if the visual cues, despite being inoperative, were still able to play this predominant role. A previous study, in which long-term blind individuals were compared to healthy ones required to close their eyes, showed the plasticity of this non-visual contribution which can be largely enhanced, in the longer term, in the visually impaired (Rougier and
Farenc, 2000). Several studies have indeed shown the increased visual prominence in the elderly (Hay et al., 1996) and the effects of different types of sporting activity on this topic (Crémieux and Mesure, 1994).

To conclude, two opposite effects making individuals sway more can be clearly noted. On the one hand, closing the eyelids would appear to induce recruitment of further motor units in order to stiffen the lower limbs and to reinforce the role played by non-visual inputs. On the other hand, the muscular aspect would be less affected when the eyes remain open but non-visual cues would play a lesser role in sway control.

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References


