Modifying the gain of the visual feedback affects undisturbed upright stance control

P. Rougier *, I. Farenc, L. Berger

Laboratoire de Modélisation des Activités Sportives, Université de Savoie, Domaine Universitaire de Savoie-Technolac,
F 73 376 Le Bourget du Lac cedex, France

Received 9 January 2003; accepted 29 April 2004

Abstract

Objective. To assess the effects of visual feedback gain, which express the amplitudes of the displacements of the centre of pressure displayed on a computer screen.

Design. The controlling variable, the centre of pressure trajectories, recorded using a force platform, were decomposed into two elementary motions: (1) the horizontal displacements of the centre of gravity and (2) the vertical projection of the difference between centre of pressure and the centre of gravity. These motions were processed through frequency analysis and modelled as fractional Brownian motion to assess their spatio-temporal linkage and their degree of control.

Background. Although tests to modify the feedback gain have already been carried out, the specific effects from a biomechanical and motor control point of view need to be assessed.

Methods. Thirteen healthy adults were tested through various visual feedback gains performed in random order.

Results. By increasing the visual feedback gain, no difference is observed between centre of pressure and centre of gravity motions whereas a progressive diminution of centre of gravity horizontal motions is seen. This latter effect is principally explained by a reinforcement of control during corrective processes.

Conclusions. When the control of centre of gravity constitutes the main flaw in undisturbed stance maintenance, the efficiency of a visual feedback rehabilitation protocol should be largely improved by using an enhanced gain.

Relevance

In-depth knowledge of the effects originating from modifications of the visual feedback gain should allow to optimise the use of this technique as a rehabilitation tool.

© 2004 Elsevier Ltd. All rights reserved.

Keywords: Undisturbed upright stance; Postural control; Visual feedback gain; Centre of gravity; Centre of pressure; Centre of pressure–centre of gravity

1. Introduction

Although the subjects are given what appears to be a simple instruction (sway as little as possible), undisturbed upright stance control is, in fact, a complex task based on an integration process involving predominantly visual, and when available, tactile and proprioceptive cues. Posturographic protocols, as a means to investigate the functional contribution of each of these inputs on motor systems, can be useful. Indeed the principle of these protocols consists in measuring, through a force platform on which the subjects stand, the displacements of the centre of pressure (CoP) (the point of application of the vertical reaction forces from the plane of support). Such a measurement could indeed be particularly useful in establishing the postural behaviours resulting from balance disabilities such as hemiparesy (Di Fabio and Badke, 1991) or cerebellar ataxia (Diener et al., 1984). In parallel to this contribution, another interesting aspect concerns training or rehabilitation sessions. With adequate parameters, this tool, which allows to evaluate the postural behaviour of...
a patient at a given time, can validate various therapies. Finally, this posturographic measurement itself can also be used for training purposes. In such cases, the successive positions of the CoP are shown to the patient in real time on a computer screen (Rougier, 2003). This kind of protocol, thought to provide the subject with enhanced sensory information, is known as visual feedback. Studies investigating the effects of visual feedback training on the postural control of patients suffering from various diseases have produced divergent results. One group of studies reported significant improvement (Hamann and Krausen, 1990; Shumway-Cook et al., 1988; Sackley and Lincoln, 1997; Simmons et al., 1998; Wannstedt and Herman, 1978) whereas a second group has indicated no beneficial effects (Di Fabio and Badke, 1990; Walker et al., 2000; Geiger et al., 2001). Thus, it could be hypothesised that it may be the way in which the visual information is fed back to the patient that influences the result obtained.

Among the possible variables susceptible of interfering with the postural behaviour is the gain, i.e. the ratio expressing the amplitudes of the displacements of the CoP and the corresponding motions on the screen. Enlarging the representation of the spot on the screen is indeed current practice for people suffering from vision impairment. The precise effects induced by this enlargement, however, remain largely unknown since, to our knowledge, only one study is concerned by this. In fact, from their study, Litvinenkova and Hlavacka (1973) announced an optimal gain of two to four. Some apparent confusion between CoP and centre of gravity (CoG) motions and recourse to out-of-date parameters such as mean velocity of the CoP displacements do nonetheless weaken the relevance of this statement.

Over the past decade, numerous algorithms aimed at improving the discriminative power of posturographic tests have been proposed. Among them, the algorithm consisting in evaluating the degree to which various motions such as the CoP are controlled (Collins and De Luca, 1994), is worthy of consideration. Through this original method, known as the fractional Brownian motion model, evidence suggested that two distinct mechanisms operate successively: one, anti-persistent, aimed at confining the CoP within a reduced territory, and the succeeding one, persistent, aimed at moving away this CoP from its initial position. Since two distinct control mechanisms operate successively, it is of interest to assess the boundary between the two mechanisms and thus the mean distance covered and the mean time interval before a corrective process begins to intervene. In parallel, Rougier and Caron (2000), following the idea that the CoP displacements are the result of at least these two distinct goals, proposed the application of fractional Brownian motion modelling to elementary trajectories such as the horizontal displacements of the CoG (CoGh) and the difference between CoP and the vertical projection of the CoG (CoP-CoGv). The CoG is generally recognised as the main controlled variable in stance maintenance whilst it can be demonstrated that CoP–CoGv, in addition to determining the initial horizontal acceleration communicated to the CoG (Brenière et al., 1987), expresses (through its frequency decomposition) the resultant stiffness at the ankle level (Winter et al., 1998). Moreover, the amplitudes of the CoP–CoGv motions are a good indicator of the level of muscular activity (Rougier et al., 2001). By applying the fBm modelling to this partition, it can be demonstrated that the control is in fact alternatively focused on the CoP–CoGv and the CoGh motions. In addition, at a given time, only one elementary motion is controlled, the other being characterised by a complete stochastic process (Rougier and Caron, 2000). Basing a postural investigation on the CoP trajectories alone is undoubtedly unsatisfactory when considering the net performance, which concerns the CoG for the most part. Furthermore, the main risk is to wrongly associate the sway motions with the CoP displacements. An example of this is the forward leaning posture, which determines increased CoP territories and in contrast weakly affects the CoG motions (Rougier et al., 2001).

Using the same methodology, a previous study (Rougier, 2003), has recently been conducted on the effects of visual feedback on undisturbed stance. One of the main resulting characteristics was that both CoP–CoGv and CoGh elementary motions were more controlled, when compared to a simple open eyes condition. In addition, an increase in CoP–CoGv amplitudes was observed in the visual feedback protocol. These exaggerated CoP–CoGv motions could be a direct consequence of an enhanced control of their displayed CoP.

The main goal of this study is thus to investigate the effects of various visual feedback gains. A modification of postural control organisation would probably provide further insight into the conception of ad hoc training programs. A second objective was to test whether complex motions such as CoP displacements and elementary motions such as CoGh and CoP–CoGv motions can similarly highlight the encountered effects.

2. Methods

The experimental procedure and the signal processing used in this study have been partly detailed in previous reports (Rougier, 2003, Rougier et al., 2001, Rougier and Caron, 2000). Only the main and specific points will thus be evoked here.

2.1. Experimental procedure

Thirteen healthy adults (five male and eight female) volunteered for this study and gave their informed
consent. The subjects ranged in age from 20 to 39 years old (body weight 64.4 (SD, 7.3 kg); height 173.3 (SD, 9.2 cm). They stood barefoot on a triangular (80 cm each side) force platform (model PF01; Equi+, Aix les Bains, France), in a natural position (feet abducted 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 platform lays were amplified and converted from analogue to digital form and then recorded on a personal computer through a specific program (software PROG01; Equi+). The CoP trajectory, as illustrated by Fig. 1, was then processed in order to obtain a set of various parameters. In the co-ordinates system, ML and AP characterise medio-lateral and antero-posterior directions, respectively. The investigation included four experimental conditions corresponding to the four visual feedback gains retained, i.e. G2, G5, G10 and G20. These values correspond in fact to the ratio between the real displacements, as measured by the platform, and their visualisation on the 14" monitor screen placed at eye level in front of the subjects. For instance, G2 signifies that a CoP displacement of 1 cm will infer a 2 cm displacement of the spot on the monitor. In these visual feedback conditions presented at random, the subjects were instructed to control the spot representing the position of the CoP and confine it to the smallest possible zone. In fact, the data acquisition software was programmed in such a way that this spot was positioned at the centre of the screen at the onset of the trial. In order to facilitate its tracking, only the last 20 positions, corresponding to a 0.3 s duration, were displayed. The horizontal displacements of the CoP were displayed on the vertical screen from left to right for the ML component and from top to bottom for the AP one, respectively. Several practice runs were performed prior to the test to ensure that the subjects had mastered the relationship between sways and spot displacements. Each condition consisted in five trials of 64 s with a 64 Hz sample frequency. Rest periods of a similar duration were allowed between each trial.

2.2. Estimation of the CoGh and CoP–CoGv motions

A simple method, based solely on the CoP trajectory recordings, was used to determine the horizontal motions of the CoG (CoGh) and consequently the CoP–CoG motions. From a biomechanical point of view, the CoG, because of its inertia, cannot accurately follow the reaction forces that are applied at foot level. Consequently, a gap between the two motions is necessarily seen, hence demonstrating that the CoP-CoG magnitudes are linked to the initial horizontal acceleration communicated to the CoG (Brenière et al., 1987). The mathematical model, initially proposed by Brenière (1996) and then extended to undisturbed stance (Caron et al., 1997), is based on a relationship in the frequency domain between the amplitude ratio of CoGh and CoP motions and is given by the following formula:
where $\Omega = 2\pi f$ is the pulsation (rad s$^{-1}$) and $\Omega_0 = [mgh/(I_G + mh^2)]^{1/2}$ (Hz), termed natural body frequency, is a biomechanical constant relative to the anthropometry of the subject ($m$, $g$, $h$, $I_G$: mass of the subject, gravity acceleration, distance from CoG to the ground, and moment of body inertia around the ML or AP axis with respect to the CoG). Depending on the direction, two distinct relationships were used to characterise the subjects’ anthropometry since the moments of inertia are different. According to Ledebt and Bre- nière (1994), these moments of inertia were given by the following relationships:

$$I_{GML} = 0.0572 m \cdot H^2 \quad \text{and} \quad I_{GAP} = 0.0533 m \cdot H^2$$

where $H$ represents the height of the subjects.

This ratio appears maximal for the lower frequencies (CoG and CoP are characterised by similar positions at 0 Hz) and tend towards zero above 3 Hz. In other words, as the frequency increases the CoP motions have a reduced effect on those of the CoGh. The estimated CoG frequency spectra were obtained by multiplying those issued from CoP motions, transformed in the frequency domain through a fast Fourier transformation (FFT), by the amplitude ratio CoGh/CoP. The recovery towards the temporal domain necessitates the processing of an inverse FFT. Our assumption here is that the CoG angular oscillations correspond to the CoG horizontal positions.

### 2.3. Signal processing

The CoGh and CoP–CoGv elementary trajectories were then studied through: (i) a classical method based on parameters such as the surface of an ellipse calculated with a confidence interval (Tagaki et al., 1985), sway path lengths and variances along each direction, (ii) parameters (root mean square (RMS) and median frequency (MF)) calculated from mean spectral frequency decompositions of the sway movements on specific bandwidths (0–0.5 Hz for CoGh and 0–3 Hz for CoP–CoGv) and (iii) a mathematical model termed fractional Brownian motion (Mandelbrot and Van Ness, 1968). The RMS and the MF express a mean amplitude independently of the frequency bandwidth, and the respective contribution of lowest and highest frequencies, respectively. In the fractional Brownian motion framework, the wiggly aspect of a trajectory along one direction, expressed as a function of time, may be quantified by a fractional, i.e. a non finite, integer space dimension (greater than zero but less than one in the present case). This dimension $D$ is in fact linked to the scaling exponent $H$ since $D = 1 - H$ in the present case. Graphically, this $H$ coefficient corresponds to the half slope of the variogram linear portions (expressing mean square displacements $\langle \Delta x^2 \rangle$ as a function of increasing time intervals $\Delta t$) depicted bi-logarithmically and given by the formula

$$\langle \Delta x^2 \rangle = \Delta t^{2H}.$$  

A median value of $H = 0.5$, inferring a linear relation between $\langle \Delta x^2 \rangle$ and $\Delta t$, indicates that no correlation between past and future increments exists and that a pure random-walk or stochastic process operates. In other words, the trajectory, in this case, is totally uncontrolled. On the other hand, i.e. if $H$ differs from 0.5, positive ($0.5 < H$) or negative ($H < 0.5$) correlation can be inferred, signifying that the control of the trajectory is enhanced. Depending on whether $H$ is above or below the median value 0.5, persistent or anti-persistent regimes can be revealed, indicating the greater probability for the motion to continue in a given direction or turn back from it, respectively. Thus, an increased contribution of deterministic processes is revealed by scaling regimes $H$ moving away from the 0.5 median value. On the other hand, the closer the regimes are to 0.5, the lesser the determinism and the greater the stochastic activity.

Since two straight line portions generally characterise variograms relative to undisturbed upright stance (a quite flat one preceding a steeper one), a last step consists in the determination of the transition point (slope inflection) for both ML and AP directions. Since, by definition, CoP and CoG displacements are in phase, the temporal co-ordinates of the transition of the CoP trajectories will also be that of the CoGh and CoP–CoGv motions. Consequently, the method used for this purpose is based on the evolution, as a function of increasing $\Delta t$, of the distance between experimental and stochastic variograms (Rougier, 1999). For CoP trajectories, the latter corresponds to a 1 slope (since $(H = 0.5) + 2 = 1$), characterising a completely stochastic process, as seen above. The retained principle is that the $\Delta t$ for which this distance is maximal is the $\Delta t$ of the transition point. Once this transition has been objectively determined, scaling exponents $H$ are calculated through a least square method for preceding and succeeding points, respectively. However, the reference stochastic behaviour being modified by the filters from which CoGh and CoP–CoGv motions are computed, the filter effect leads in fact to the so-called stochastic behaviour of the curvilinear curves moving progressively apart or closer to the straight line characterising the CoP stochastic trajectories. Scaling regimes computed from CoGh and CoP–CoGv variograms must therefore be expressed relatively to these “average stochastic variograms” over the same $\Delta t$ in such a way that

$$H_{\text{calc}} = (H_{\text{exp}} - H_{\text{sto}}) + 0.5$$
where $H_{cal}$, $H_{exp}$ and $H_{sto}$ represent the calculated, experimental and stochastic scaling regimes, respectively. For this purpose, a set of CoP trajectories has been de-correlated using the surrogate data method (Theiler et al., 1992). To be more precise, the temporal order of the increments from CoP trajectories was randomly shuffled, recombined to generate stochastic trajectories (Scheinkman and Le Baron, 1989) and finally processed in order to determine CoGh and CoP–CoGv random motions, as for any other CoP trajectory.

Thus, for both CoGh and CoP–CoGv motions and each ML and AP direction, two scaling exponents (indexed as short and long latencies: $H_s$ and $H_l$) which allow to characterise the degree to which each motion is controlled during the shortest and longest time intervals, respectively as well as the spatio-temporal co-ordinates of the transition point were extracted. Finally, a maximal $\Delta t$ of 10 s was adopted to compute the various aforementioned parameters. An example of this procedure for CoP, CoGh and CoP–CoGv trajectories can be seen in Fig. 2 from Rougier (2003).

To evaluate the effects of the visual feedback gain on postural control, the results were compared through a one way analysis of variance ANOVA with a series of repeated measurements. In addition, post-hoc effects were assessed through a Newman–Keuls test. In all cases the first level of significance was set at $P < 0.05$.

3. Results

3.1. Classical parameters

As revealed by the histograms of Fig. 2, no statistical effects can be found through the ANOVA test for the whole set of tested parameters (ellipse with a confidence interval, length of sway path and variances), either for those computed from the CoP displacements or the CoGh and CoP–CoGv motions all the while the visual feedback gains are modified. However, with regard to the CoGh motions, a tendency for the ellipse surfaces and variances to decrease on the one hand and an increase of the path lengths on the other is worth mentioning. However, an opposite trend is observed for the CoP–CoGv motions when the visual feedback gain is increased.

3.2. Frequency parameters

Fig. 3 represents the average spectral decomposition of the elementary CoGh and CoP–CoGv motions. The main point worth emphasising here is the progressive decrease of the amplitudes of the CoGh motions for the lowest frequencies as the visual feedback gain increases. For the higher frequencies, however, no discernible effect seems to emerge. As indicated by the ANOVA test, there are highly statistically significant results for the MF parameters characterising these CoGh motions (lower part of Fig. 4). Interestingly, this effect appears stronger in the AP ($P < 0.001$) than the ML direction ($P < 0.01$). For the AP direction, the post-hoc effects demonstrate some statistically significant results between G2 and G5 ($P < 0.05$), G10 ($P < 0.05$) and G20 ($P < 0.01$). On the other hand, G2 and G5 induces different behaviours when compared to G10 ($P < 0.001$ and $P < 0.001$) and G20 ($P < 0.001$ and $P < 0.001$), respectively. Finally, a statistically significant trend was noticed between G10 and G20 ($P < 0.05$). A similar tendency is observed for the MF computed from the CoP motions whereas the CoP–CoGv motions tend to remain constant. On the other hand, opposite effects, but statistically insignificant, can be observed for the RMS: decreases for CoP and CoGh motions and increase for CoP–CoGv motions.

3.3. Fractional Brownian motion modelling

When expressed relatively to the stochastic reference, the variograms relative to the CoGh motions present the particularity of displaying steeper slopes for the longest $\Delta t$ as the visual feedback gain increases (Fig. 5). Some subjects, however, display values close to zero for these long latency scaling regimes $H_l$, signifying an enhanced control of these motions during the corrective-anti-persistent process. Conversely, no modification is seen for
Apart from this, the spatio-temporal co-ordinates of the transition points, i.e. the inflection between the successive linear portions, seem to be unaffected by visual feedback gains, this being true for all motions (CoP, CoGh and CoP–CoGv).

These observations have been confirmed by the ANOVA test, as seen through the histograms of Fig. 6. Highly significant effects have indeed been measured for the long latency scaling regimes equivalent characterising the CoGh motions for ML (P < 0.05) and, especially, AP directions (P < 0.001), respectively. The post-hoc analysis shows that in the ML direction the G2 condition infers statistically significant differences with the three others: G5 (P < 0.05), G10 (P < 0.05) and G20 (P < 0.01) On the other hand, in the AP direction, G2 infers differences with all other conditions (G5: P < 0.05; G10: P < 0.001; G20: P < 0.001) whereas G5 differs from both G10 (P < 0.01) and G20 (P < 0.001).

Similar effects have been found for the CoP–CoGv motions. Nevertheless, it must be emphasised that the results of the statistical analysis are always slightly inferior compared to that found for the CoGh motions (ML: P < 0.05; AP: P < 0.001). The post-hoc effects concern the G2 condition in the ML direction, which presents statistically significant results with both G10 (P < 0.05) and G20 (P < 0.05). Similar trends are also observed in the AP direction between G2 and G10 (P < 0.001) and G20 (P < 0.001) on the one hand and between G5 and G10 (P < 0.05) and G20 (P < 0.01) on the other. One should also add that no significant effect was detected for the CoP–CoGv motions on the variograms characterising the shortest Δt. Lastly, a tendency towards a progressive increase of the spatial co-ordinates as the visual feedback gain is increased (for all motions) is to be noted whereas the temporal co-ordinates Δt appears constant throughout the different conditions (Fig. 6).

4. Discussion

4.1. The effects induced by modifying the visual feedback gain are further emphasised through the elementary CoGh and CoP–CoGv motions

One of the objectives of the study was to assess whether global motions such as CoP displacements were as able as elementary CoGh and CoP–CoGv motions to
highlight the behavioural effects resulting from a modulation of the visual feedback gain. As demonstrated by the various parameters (see histograms of Figs. 2, 4 and 6), it appears that the larger effects always intervene on the CoGh components. This is true for instance for the long latency scaling regimes $H_{ll}$ which demonstrate a progressive increase as the gain itself increases. In such a case, the ANOVA indicates more highly significant results for the CoGh than for the CoP motions, either for the ML ($F = 4.06$ vs. 3.61) or AP direction ($F = 21.45$ vs. 12.39). For most parameters, similar tendencies are observed for both CoGh and CoP motions. This similarity in the effects induced might be principally explained by the fact that the CoGh motions largely contribute to the CoP displacements, as illustrated by the classical parameters displayed as histograms in Fig. 2.

A second feature concerns the opposing effects observed on both elementary CoGh and CoP-CoGv motions for several parameters. Thus the lack of statistical results for the CoP displacements is not surprising. This point is particularly well expressed by the results from surfaces, variances or RMS parameters.

Another interesting observation concerns the capacities of the various kinds of analysis to highlight these
postural behaviours. The most striking result is that the classical results are only capable, at best, to elicit tendencies. On the other hand, recourse to frequency analysis and fractional Brownian motion modelling allows to extract statistically significant results for the median frequency MF of CoGh spectra on the one hand and the long latency scaling regimes $H_l$, again originating from the CoGh component and from the CoP displacements, on the other. As seen in the next sections, these results provide interesting clues about the way the central nervous system uses this real time information.

4.2. Increasing feedback gain leads to an increased control of the corrective process

As emphasised by the results, the fractional Brownian motion modelling method produces the largest effects in the long latency scaling regimes whereas the largest effects seen in the frequency analysis method are the median frequencies. For the former analysis, these results indicate a better control of the CoGh motions during the anti-persistent corrective control. It should nonetheless be emphasised that this improved control of the corrective strategies, deduced from $H_l$ values, occurs when the initial control of the other component, i.e. the CoP–CoG motions, remains constant throughout the different feedback gains. This feature is important since it demonstrates that the two successive controls involved in upright undisturbed stance maintenance are totally independent. This is not the case, for instance, when the visual feedback technique is compared to a condition based only on visualising surroundings (Rougier, 2003). In that case, both $H_l$ and $H_d$ parameters are enhanced, indicating an increased control of CoP–CoG, and CoGh motions during shorter and longer time intervals, respectively.

Theoretically, the shift of the FM parameter towards higher frequencies observed in the present study could be explained, at least in part, by this increased control during corrective processes. One may indeed hypothesise that improved control may induce a reduction in the duration of this process. Another parameter serving to explain this shift could be the mean onset of the corrective process issued from the fractional Brownian motion modelling. These $\Delta t$, expressing no real change throughout the different conditions, suggest that the increased MF is mainly explained by the enhanced control resulting from the larger gain.

4.3. Modifying the feedback gain can be of interest for rehabilitation purposes

From the present method of analysis consisting in modelling elementary CoGh and CoP–CoG trajectories as fractional Brownian motions, three factors that contribute to the reduction of body sway motions in undisturbed upright stance can be theoretically assessed. Depending of the patients’ deficiencies, the particular effects could be helpful in re-establishing functional postural control mechanisms.

The first factor concerns the amplitudes of the CoP–CoG motions whose importance can be demonstrated through the biomechanical relationship they have with the initial CoG acceleration (Brenière et al., 1987). From this we deduce that the increased CoP–CoG motions observed for the larger gains should infer larger horizontal accelerations for the CoG and, consequently, a priori, increased difficulty in controlling a return to an initial position. On the other hand, the scenario proposed by Winter et al. (1998) whereby upright stance maintenance would be solely achieved through stiffness control would be incorrect, at least for this specific task. In such a case, the observed constancy of the CoP–CoG motions and more precisely of the median frequencies of the spectra would determine similar CoGh motions. Conversely, it is worth emphasising that, as the visual feedback gain increases, the decreased CoGh motions do not induce proportional reductions at the CoP–CoG level either. Also, one should bear in mind that the CoP–CoG amplitudes are thought to express the level of neuro-muscular activity developed for this equilibrium task. 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. As deduced from the CoGh/CoP ratio, the higher the frequency, the smaller the relative displacements of CoGh and thus, the larger the amplitudes and the higher the MF of the CoP–CoG spectra (Caron et al., 2000; Winter et al., 1998).

A second factor is the capacity for the subjects to initiate corrective motions once a potential imbalance has been detected through an integrative process by the central nervous system. From fractional Brownian motion modelling, this capacity belongs exclusively to the CoGh (Rougier and Caron, 2000). Given the constancy of the degree of control of the CoP–CoG motions, deduced from their scaling regimes $H_d$, changes in the spatial co-ordinates of the transition points would express a concomitant change in the temporal one. Even though a slight tendency to increase with the visual feedback gain can be perceived (Fig. 6), once again no real influence is detected.

The third and last factor is the postural strategy adopted by the subjects in order to make the CoG return to an equilibrium position. As revealed by the present results, a decreased probability for the CoG motion to wiggle in its backward motion to an equilibrium point is observed as the visual feedback gain increases. In addition, this increasing control expresses the capacity to return to a given identical position, on a regular basis. This characteristic could be linked to the preferential
zone described earlier by Gurfinkel et al. (1992). Although an infinite number of available places for the CoGh inside the support surface would theoretically allow to ensure balance, this latter investigation indicates that there may exist a particular position for each individual. This particularity can indeed be demonstrated by inducing sudden postural perturbations. In every case, the strategy performed by the subjects is to return to this preferred zone in the shortest time possible. This feature becomes naturally easier as the visual feedback gain increases and thus would largely explain the increased control in the correction of CoGh motions.

From a rehabilitation point of view, the difference in effect between CoGh and CoP–CoGv motions could be a very poignant element in the establishment of ad hoc protocols aimed at focusing on one or several of the factors listed above. If modulating the feedback gain seems meaningless for patients demonstrating a high level of CoP–CoGv motions due to the lack of effect observed on them, it can be of great interest for those presenting difficulties controlling these corrective motions. Moreover, although only observed as a tendency, increasing the gain appears unsuitable for patients whose main deficiency concerns a difficulty initiating corrective responses, as highlighted by the spatial coordinates of transition points, i.e. the mean distance covered before the corrective control begins to intervene. Lastly, by inducing larger effects in the AP direction, modulating the feedback gains would principally concern individuals unable to appropriately regulate their posture in this direction through the plantar flexor muscles.

This capacity to modulate postural behaviours by modifying some variables of the visual feedback technique highlights the necessity to relate the basic mechanisms for the maintenance of upright stance may be damaged to the specific effects supposedly induced by this technique. The fact that several studies (Shumway-Cook et al., 1988; Sackley and Lincoln, 1997; Simmons et al., 1998; Wannstedt and Herman, 1978) in the past decades have clearly demonstrated the determining effects arising from such feedback techniques, either in cases of neurological diseases or traumatic injuries, serves to demonstrate their beneficial nature. On the other hand, the lack of significant results for other studies (Di Fabio and Badke, 1990; Walker et al., 2000; Geiger et al., 2001) could arise from inadequacies between the patients’ needs and the postural effects induced by the protocol.

5. Conclusion

By applying a mathematical model such as fractional Brownian motion to elementary motions, the effects of various visual feedback gains on undisturbed stance control can be differentiated. Naturally, this particularity constitutes a strong and additional argument for affirming the pertinence of such an analytic procedure. In addition, the specificity of the postural effects induced should contribute to improving the reliability of rehabilitation protocols based on visual feedback techniques. Naturally, further investigations involving individuals with balance impairment are needed to strengthen the potential clinical value of this approach.

Acknowledgement

The authors are pleased to acknowledge D. Goodhew for correcting the English text.

References


