The influence of gender and body characteristics on upright stance

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Summary. Background: Morphologic characteristics such as height and body weight determine body inertia, an important factor related to postural stability. However, whilst investigations have classically analysed these parameters separately, global morphology has been poorly researched. Secondly, the influence of gender on postural stability demonstrates opposing trends, some authors observing that men sway less than women, and others noting the contrary.

Aim: The aims of this study are to evaluate morphology and gender effects on healthy subjects during postural maintenance.

Subjects and methods: The studied subjects were categorized through the Livi index. A method associating frequential and Brownian parameters characterized the horizontal displacements of the centre of gravity (CGh) and those of the difference between the centre of pressure (CP) and the vertical projection of the centre of gravity (CP-CGv) separately. Moreover, the moments of body inertia (MI) and natural body frequency (NBF) were also used to determine the influence of morphology.

Results and conclusions: The results reveal that thinner subjects have larger CGh displacements than normal or corpulent subjects. Morphologic characteristics (NBF) can explain these behavioural differences. On the other hand, men have a larger sway amplitude for CGh motions than women. This can be explained by both morphologic (MI, NBF) and physiological (architectural properties of the soleus muscle) characteristics.

1. Introduction

The study of instantaneous upright stance is of particular interest since it corresponds to a very specific and fundamental attitude in humans. The human body, in this posture, can be modelled as an inverted pendulum. Biomechanically, the centre of gravity (CG) and the centre of pressure (CP) displacements can be used to describe undisturbed upright stance. By definition, CG is the barycentre of the centres of mass of body segments and CP is the application point of the resultant of the ground reaction forces, which results from the ankle and hip muscular torques, which, by definition, cannot be constant over time. The inertia of the human body intervenes in this task by generating a horizontal lag between CP and CG motions and the relative horizontal displacements of CG (CGh) motions induced by CP displacements. Consequently, a vertical difference between these CP and CG motions (CP-CGv) is necessarily present even though a vertical alignment can be seen for transient moments. The horizontal accelerations communicated to the CG motions, as initially demonstrated by Brenière et al. (1987), explains that the body is swaying continuously during postural maintenance. The body inertia is determined by the morphology of the subject, and can be deduced from height and weight (Ledeber and Breniere 1994). The influence of these height and weight variables on postural balance has been studied by several authors (Bessineton et al. 1976, Berger et al. 1992). To our knowledge, only Allard et al. (2001) have considered height and weight as a global morphologic factor.
On the other hand, several authors have debated the influence of gender in postural stability. Some research in undisturbed upright stance (Black et al. 1982, Maki et al. 1990, Hageman et al. 1995) reported no gender difference in either the eyes open (EO) and eyes closed (EC) condition. Conversely, others (Stribley et al. 1974, Juntunen et al. 1987, Ekdahl et al. 1989, Kollegger et al. 1992) reported differences between men and women in postural control. Juntunen et al. (1987) and Kollegger et al. (1992) suggest that these gender differences may be explained by the stabilizing part of vision, which seems more significant for men. For these reasons, our subjects were tested in both EO and EC conditions in order to assess the respective roles of visual and somatosensorial information. In the EO condition, vision constitutes the main sensorial input whereas it is recognized that postural control relies principally upon somaesthetic information in the EC condition (Diener et al. 1984, Nakagawa et al. 1993). Lastly, men and women can also be characterized by differences in muscle architectural properties such as fibre size and angles of pennation (Chow et al. 2000).

The above-mentioned studies suggest that morphology and gender characteristics may modify postural organization. To test the plausibility of this influence we chose a discriminating method based on the CP trajectory measured through a force platform. By modelling the CP trajectory as fractional Brownian motion (fBm), Collins and De Luca (1993) and Rougier (1999a) have demonstrated that this CP assumes two different and quite opposite tasks. On the one hand, it remains within the base of support and appears to contain the CG in its position. On the other hand, the CP is, at times, used to displace the CG in order to make it return to a position more compatible with equilibrium principles. Therefore, it seems logical to dissociate the CP into two elementary components: CG \( h \) and CP-CG \( v \) (Rougier and Caron 2000). The CG \( h \) motions, recognized as the controlled variable, represent the net performance and are exclusively controlled by the CP displacements (Winter et al. 1996). Complementarily, it can be demonstrated that CP-CG \( v \) amplitudes present a certain proportionality with the horizontal CG acceleration (Brenière et al. 1987). Thus, the larger the CP-CG \( v \), the greater the acceleration of the CG \( h \). Winter et al. (1998) have also specified that CP-CG \( v \) represents the difference between the stiffness torque and the gravitational torque. The effective stiffness appears proportional to the body’s natural frequency, which can be estimated from the CP-CG \( v \) frequential spectrum. The respective contributions of CG \( h \) and CP-CG \( v \) motions in complex CP displacements can be obtained through a frequential and fBm analyses.

The purpose of this study is to evaluate the effects of morphology and gender of healthy subjects on postural control. First, a distribution was made with the Livi index in order to evaluate the morphologic effects on postural control. This index is classically used to observe the effects of morphology (Carlberg et al. 1983). Secondly, a comparison according to gender was performed in order to highlight some of the differences between men and women. Finally, the moments of body inertia (MI) and natural body frequency (NBF) were used to investigate the dynamic implications of morphologic characteristics in the postural control process.

2. Materials and methods
2.1. Population

A total of 57 individuals, 22 women (age 26 ± 9 years; body mass 58.76 ± 4.76 kg; height 167 ± 0.06 cm) and 35 men (age 29 ± 11 years; body mass 71.35 ± 5.73 kg; height 178 ± 0.05 cm), ranging in age from 20 to 60 years were tested. These
volunteers were healthy and physically active with no known musculoskeletal impairments or neurological disorders that might have affected their sense of balance. These subjects were categorized by the index of Livi ($I$) defined by the following ratio:

$$I = \frac{100 \sqrt{\text{mass}}}{\text{height}}$$

The classification of subjects was based on the following criteria:

- Group of Thin individuals (GT): $22 \leq I \leq 22.9$
- Group of Normal individuals (GN): $23 \leq I \leq 23.9$
- Group of Corpulent individuals (GC): $24 \leq I \leq 24.9$

From this index, three morphologic groups were formed: 18 subjects belonging to GT (six women and 12 men), 27 to GN (12 women and 15 men) and 10 to GC (four women and seven men).

2.2. Experimental procedure

The subjects stood barefoot on a force platform (Equi+, model PF01) in the standard position (feet abducted at $30^\circ$, heels separated by 3 cm) and were asked to sway as little as possible, with their arms at their sides. The signals from these load cells were amplified and converted from analogue to digital form and recorded on a personal computer. The CP trajectory was subsequently processed through a specific software program, Equi+ Prog01. The coordinates system defines a horizontal plane in which ML and AP characterize Medio-Lateral and Antero-Posterior directions, respectively. Two experimental conditions were randomly tested in the Eyes Open (EO) condition, where subjects were instructed to stare at a plumb line, and the Eyes Closed (EC) condition, the latter being used as reference.

The experiment included five trials of 64 s with a 64 Hz sample frequency. Rest periods of a similar duration (64 s) were allowed between each trial and a 10 min rest was granted between each condition.

2.3. $CG_h$ estimation

Using the CP trajectories, computed from the force platform data, the $CG_h$ and consequently the CP-CG$_v$ motions were calculated. The latter motions are determined through an amplitude ratio varying as a function of frequency between the vertical projection of the centre of gravity and CP motions. Since the task of upright stance generates reduced body sway, the human body can theoretically be modelled as an inverse pendulum where CG angular oscillations corresponding to the $CG_h$ positions are considered as a simple periodic function in phase with the CP. This method is derived from a mathematical model, initially proposed in the study of gait initiation (Brenière 1996) and then extended to undisturbed stance (Caron et al. 1997). This method is given by the following formula:

$$CG_h/CP = \frac{\Omega_0^2}{(\Omega_0^2 + \Omega^2)}$$

where $\Omega = 2\pi f$ is the pulsation (rad s$^{-1}$) and $\Omega_0 = (mg/(IG + mh^2))^{1/2}$ (Hz), termed natural body frequency, is a biomechanical constant relative to the anthropometry of the subject ($m, g, h, IG$ are, respectively, mass of the subject, gravity acceleration, distance from CG to the ground, and moment of body inertia in the ML and AP direction with respect to the CG).
The main stages of this method are presented in figure 1. Note that this method was described in detail in a previous study (Rougier and Farenc 2000).

2.4. Method

Two different approaches were taken to study the CG$_h$ and CP-CG$_v$ elementary motions: (1) frequential and (2) fractional Brownian motion (fBm). The former is a global analysis that highlights the main modifications induced by control mechanisms in order to maintain equilibrium. By definition, a given movement can be characterized by an oscillatory process operating over a specific frequency bandwidth. The latter (fBm modelling) provides insight into the nature and the temporal organization of the control mechanisms called into play. Finally, the moment of body inertia (MI) and the natural body frequency (NBF) were calculated for each subject in order to determine the role played by body parameters (weight and height) in upright stance.

2.5. Frequential analysis

The frequency analysis provides mean spectral decompositions of various motions on specific bandwidths (0–0.5 Hz for CG$_h$; 0–3 Hz for CP-CG$_v$). To quantify the various spectra, several parameters are used. The root mean square (RMS), which measures the total spectrum energy, characterizes the amplitudes independent of the
frequency distribution. On the other hand, the median frequency (MF) divides the spectrum into two parts with similar energy.

2.6. Fractional Brownian motion (fBm) modelling

fBm modelling can determine the respective contribution of stochastic and deterministic processes in postural control mechanisms. It is for this reason that the concept of fBm modelling is particularly well adapted to the study of non-stationary signals (Riley et al. 1997). Initially used to study the global CP trajectories (Collins and De Luca 1993, Rougier 1999a), it was recently extended to CP-CGv and CGh motions (Rougier and Caron 2000). One interesting result of this latter study is that partially deterministic controls successively operate initially on CP-CGv and then on CGh motions. In addition, when one elementary motion is controlled, the other behaves stochastically. This approach provides insight into the nature of the control mechanisms called into play and the temporal organization. The variograms provide information that graphically expresses the mean square displacement $\Delta x^2$ as a function of increasing time intervals $\Delta t$ for both ML and AP directions. Given that two straight line portions generally characterize variograms for undisturbed upright stance (one quite flat one preceding or succeeding a steeper one), one stage in the process involves the determination of the transition point, i.e. the point corresponding to the slope inflection, using an automatic method (Rougier 1999b). The transition point represents the spatio-temporal threshold from which the corrective mechanism is initiated. By definition, CP and CG displacements being in phase, the temporal coordinate of the CP trajectories will also be that of the CGh and CP-CGv motions.

On the other hand, the scaling exponents $H$ (corresponding to the variogram’s half slopes) indexed as short and long latencies $H_{sl}$ and $H_{ll}$, characterize the degree of control of each trajectory for the shortest and longest time intervals, respectively. Thus, for each of the two CGh and CP-CGv motions investigated and each ML and AP component, two scaling exponents (indexed as short and long latencies: $H_{sl}$ and $H_{ll}$) as well as the coordinates of the transition point were extracted.

2.7. The moment of inertia (MI) and the natural body frequency (NBF)

It is believed that the body itself imposes its own constraints. Ledebt and Brenière (1994) have investigated the dynamic implications of anatomical parameters in the gait initiation process. This has led to the establishment of the moments of body inertia in both the AP (MI$_{AP}$) and ML direction (MI$_{ML}$) estimated by the following relationships:

$$MI_{ML} = 0.0533 \times m \times H^2$$
$$MI_{AP} = 0.0572 \times m \times H^2$$

where $m$ and $H$ represent the body mass and the height of the subject, respectively.

As explained above, the oscillations of subjects are assimilated to those of an inverse pendulum. In this case, the moment of body inertia against the ankle is estimated as constant (Winter et al. 1996).

In upright quiet stance, the human body, considered as an oscillating system, is characterized by specific parameters such as natural frequency. Brenière (1996) has demonstrated that the human body has a natural body frequency (NBF) which
depends mainly on the body weight and moment of inertia. The NBF is defined by the following relationship:

\[
\text{NBF} = \sqrt{\frac{(m \times g \times h_{CG})}{(\text{MI} + m + h^2_{CG})}}
\]

where \(m\), \(g\), \(h_{CG}\) and \(\text{MI}\) represent the body mass, the acceleration of the gravity, the CG height and the moment of body inertia for each direction, respectively.

2.8. Statistical analysis

To compare the postural control of morphologic groups (GT, GN, GC), a one-way ANOVA was performed on each of the frequential and mBf parameters. In addition, a two-way gender (women vs men) \(\times\) visual conditions (EO vs EC) ANOVA was performed on frequential and mBf parameters. Finally, to test the hypothesis that standing posture is related to anthropometric characteristics, a two-way gender (women vs men) \(\times\) morphologic groups (GT, GN, GC) ANOVA was performed on MI and NBF parameters for both ML and AP directions. Post hoc LSD tests were carried out to identify the groups that were statistically different from each other. The first level of significant differences was set at \(p < 0.05\).

3. Results

3.1. Differences according to body morphology

3.1.1. Frequential parameters. Some significant differences of RMS for both CP-CGv and CGh motions in the ML direction are observed (CP-CGv \(F(2,103) = 7.92, p < 0.001\); CGh \(F(2,103) = 5.57, p < 0.01\)). The RMS of CP-CGv motions demonstrates that the GT group elicit larger initial horizontal accelerations from their CG than the GN and GC groups. Indeed, the amplitudes of spectra (RMS) of CP-CGv motions are larger in the ML direction for GT when compared to those of GN \((p < 0.001)\) and GC \((p < 0.01)\). In the ML direction, GT display larger CGh motions than GN \((p < 0.01)\) and GC \((p < 0.01)\), as indicated by the RMS. These results are illustrated in figure 2.

3.1.2. fBm modelling. The main differences between the various morphologic groups (GT, GN, GC) concern the scaling exponents of short latencies \((H_{sl})\) of the CP-CGv motions in ML and AP directions (ML \(F(2,103) = 6.036, p < 0.01\); AP \(F(2,103) = 10.02, p < 0.001\)). As seen in figure 3, \(H_{sl}\) demonstrates that the CP-CGv trajectories are more controlled for the GC group in both ML and AP directions. Indeed, significant decreases in the slopes of the initial line portions \((H_{sl})\) are observed for CP-CGv motions in the ML direction for GN when compared to GC \((p < 0.01)\), and for GN when compared to GT \((p < 0.05)\). In the AP direction, similar results are observed for GT when compared to GC \((p < 0.01)\), and for GN when compared to GC \((p < 0.001)\).

In addition, the spatio-temporal coordinates of the transition point, i.e. the time interval \(\Delta t\) and the mean square distance \((\langle \Delta x^2 \rangle)\) covered at the onset of the corrective process, are also modified according to the morphologic group \((\langle \Delta x^2 \rangle)\) \(F(2,103) = 6.49, p < 0.01; \Delta t F(2,103) = 3.10, p < 0.05\) (figure 3). Indeed, in the ML direction GN elicits larger delays than GT in setting the corrective process \((p < 0.05)\). Moreover, the \(\langle \Delta x^2 \rangle\) in the ML direction demonstrates a larger increase in CP-CGv motions for the GT when compared to GN \((p < 0.01)\) and GC \((p < 0.01)\). Note that no significant difference is observed for CGh motions.
3.2. Differences between women and men

3.2.1. Frequential parameters. Firstly, it should be noted that the observed gender differences appear only in the AP direction. The frequential distribution, expressed by MF calculation for CP-CGv motions, displays a shift towards lower frequencies for women ($F(1,105)=4.95, p<0.05$). As seen in the lower part of figure 4, the women’s mean amplitudes (RMS AP) are smaller for CGh motions (CGh: $F(1,105)=6.69, p<0.05$) whereas the MF for CGh is larger than that for men ($F(1,105)=4.79, p<0.05$).

3.2.2. fBm parameters. The main differences between women and men concern the scaling exponents of short latencies ($H_{sl}$) of the CP-CGv motions. A significant
The decrease in the slopes of the initial line portions demonstrates that the CP-CG$_v$ trajectories are less controlled in the case of the men in the AP direction. The scaling exponents corresponding to the shorter $\Delta t$ illustrated by the variogram and histograms in figure 5 (lower part) confirm this. Indeed, the decreases observed in $H_{sl}$ for CP-CG$_v$ motions in the AP direction appear significant for men when compared to women ($F(1,105) = 7.30, p < 0.01$). It is worth noting that no significant difference is observed for $H/C_1 t^2$ and $H/C_2 t^2$ for both CP-CG$_v$ and CG$_h$ motions.

Note that no differences between women and men are observed for both frequential or fBm parameters.

3.3. Differences according to morphologic characteristics, moment of body inertia (MI) and natural body frequency (NBF)

Some significant differences in morphologic characteristics are observed for both gender (women vs men) and morphologic groups (GT, GN, GC), as illustrated in figure 6. Indeed, as expected, differences arising due to the subjects’ height are observed for morphologic groups ($F(2,52) = 7.64, p < 0.01$): GT are taller than GN...
Concerning gender groups, men are taller \((F(2,52) = 43.10, p < 0.001)\) and bigger \((F(2,52) = 41.95, p < 0.001)\) than women (figure 6, upper part). MI and NBF results demonstrate some differences for both gender (women vs men) and morphologic groups (GT, GN, GC). Concerning gender groups, women have smaller MI than men in both ML and AP directions \((\text{MI}_{\text{ML}} F(1,53) = 79.81, p < 0.001; \text{MI}_{\text{AP}} F(1,53) = 79.81, p < 0.001)\). On the other hand, women sway at a higher frequency than men in both ML and AP directions, as indicated by the NBF parameter \((\text{ML} F(1,53) = 57.36, p < 0.001; \text{AP} F(1,53) = 57.36, p < 0.001)\) (figure 7, upper part).

\((p < 0.001)\) and GC \((p < 0.01)\) (figure 6, lower part). Concerning gender groups, men are taller \((F(2,52) = 43.10, p < 0.001)\) and bigger \((F(2,52) = 41.95, p < 0.001)\) than women (figure 6, upper part).
Concerning the morphologic groups, some differences are observed between GT, GN and GC for NBF parameters in both ML and AP directions (ML $F(2,52) = 7.45$, $p < 0.01$; AP $F(2,52) = 7.45$, $p < 0.01$). Indeed, GT have lower NBF than GN (ML $p < 0.01$; AP $p < 0.01$) and GC (ML $p < 0.001$; AP $p < 0.001$) in both ML and AP directions (figure 7, upper part). Note that we observe no significant differences between morphologic groups for the MI parameter.

On the other hand, the NBF parameter is sensitive to both gender and morphologic groups in both ML and AP directions (ML $F(2,49) = 3.85$, $p < 0.05$; AP $F(2,49) = 3.65$, $p < 0.05$). Indeed, thin women sway at a lower frequency than normal (NBF$_{ML}$ $p < 0.001$; NBF$_{AP}$ $p < 0.001$) and corpulent women (NBF$_{ML}$ $p < 0.001$; NBF$_{AP}$ $p < 0.001$) in both ML and AP directions (figure 7, lower part). The same tendency is observed for men: thin men sway at a lower frequency than normal (NBF$_{ML}$ $p = 0.051$; NBF$_{AP}$ $p = 0.052$) (figure 7, lower part). The totality of MI and NBF results for gender and morphologic groups are presented in figures 5 and 6.
4. Discussion

4.1. Morphologic influence on the postural control

Classically, height and body weight constitute two investigated parameters that have a significant effect on body inertia and consequently postural control. To our knowledge, only Allard et al. (2001) have considered morphologic somatotypes in studying the standing posture equilibrium in able-bodied girls. Through this somatotype determination, it was shown that ‘the endomorphs’ (endomorphy: the relative fatness of the body) display a better postural stability than ‘the ectomorphs’ (ectomorphy: ratio of height to weight depicting the relative linearity of the body). Indeed, the surface area of CP displacements of ectomorphs was larger than that of endomorphs. To explain such an effect, it is suggested that the ectomorphs present a relatively low muscle component, a high height–weight ratio and an elevated position of the body’s centre of mass. These results quantify the postural performance but are nevertheless insufficient when it comes to providing an accurate explanation for postural control. Indeed, without the CP decomposition in CG\textsubscript{h} and CP-CG\textsubscript{v} elementary motions, it is rather difficult to disentangle the various postural strategies. For a similar performance in terms of CP trajectory, different strategies aimed at controlling CG\textsubscript{h} and CP-CG\textsubscript{v} motions can theoretically be utilized by the subject. For instance, various investigations on blindness and the forward body leaning effects on postural control (Rougier and Farenc 2000, Rougier et al. 2001) have demonstrated the importance of focusing the analysis on CG\textsubscript{h} and CP-CG\textsubscript{v} motions.
In the present study, some differences are observed according to various morphologies (GT, GN, GC) defined by Livi’s index. The main result is that the thin subjects (GT) demonstrate larger CG \( h \) displacements, mainly in the ML direction, when compared to normal (GN) and corpulent (GC) subjects. According to the RMS results of CP-CG\(_v\) motions, the thin subjects display an increase in CP-CG\(_v\) motion amplitudes, which, from a biomechanical point of view, cause an increase in the horizontal accelerations communicated to the CG (Brerière et al. 1987).

According to Winter et al. (1996), an MF increase for CP-CG\(_v\) motions in the ML direction involves an increase of abductor–adductor muscles in the thin subjects. This increased level of muscular contraction would be due to a larger recruitment of motor units. Indeed, since the pioneering work by Henneman et al. (1965), it is well established that an increase in strength is generated by recruiting additional motor units, inducing a tendency for the MF parameter to be shifted towards higher frequencies. Bearing in mind the amplitude ratio between CP and CG motions, and due to this recruitment principle, the displacements of the CP over higher frequencies theoretically produce reduced CG motions and consequently larger CP-CG\(_v\) motions.

Complementarily, the fBm modelling demonstrates that the increase in the CP-CG\(_v\) amplitudes of thin subjects can be explained by a lesser control in both ML and AP directions (significant decrease of \( H_{\text{sq}} \)). On the other hand, the distances covered

Figure 7. Histograms of the NBF parameter show group means and standard deviations for morphologic (GT, GN, GC) and gender (women vs men) groups in both ML and AP directions. On the one hand, the thin group has a lower frequency than the normal and corpulent group in both ML and AP directions. On the other hand, women sway at a higher frequency than men in both ML and AP directions. Finally, thin women sway at a lower frequency than normal and corpulent women in both ML and AP directions. The same tendency is observed for men (***\( p < 0.001 \); **\( p < 0.01 \); *\( p < 0.05 \)).
by the trajectories before a corrective mechanism intervenes are longer for the thin subjects when compared to normal and corpulent subjects, mainly in the ML direction (significant increase of $\langle \Delta x^2 \rangle$ for CP-CG$_v$ motions). Consequently, the horizontal accelerations communicated to the CG when a corrective mechanism does intervene are augmented, thus making the return of the CG to a position more compatible with equilibrium principles more difficult.

A biomechanical analysis shows that thin subjects sway spontaneously at lower frequencies than normal and corpulent subjects. This result may appear surprising at first. Nevertheless, it can be explained by the key parameter for the NBF calculation: the height of the subject. These results of natural body frequency (NBF) demonstrate that weight and mainly height characteristics constitute determinant parameters in postural control, especially in a gravitational physical environment.

4.2. Women and men: a different postural stability?

Several authors have highlighted the influence of gender in postural stability for healthy adults. Juntunen et al. (1987) and Kollegger et al. (1992) found that men swayed significantly more (larger total length of CP motions) than women. The results of the present study encourage the differentiation of gender. Indeed, several statistically significant differences between men and women are observed for frequential parameters. It should be emphasized that the observed differences between men and women appear only in the AP direction. Men display larger sway amplitudes (RMS$_{AP}$) for CG$_h$ motions than women under both conditions. Although the RMS parameter used in the present study is different from total length, which is the classical parameter used by Juntunen et al. (1987) and Kollegger et al. (1992), there are similarities in the way global postural performance is quantified. Consequently, the present results are in accordance with the findings of Juntunen et al. (1987) and Kollegger et al. (1992). In particular, the latter explain these gender differences by the stabilizing part of vision, which would be more significant for men than for women. Should this hypothesis be true, the differences observed in postural control between men and women would be more significant, particularly in the EC condition. This is not seen in the present study. Consequently the hypothesis that vision would be a stabilizing factor in the postural control of men is not confirmed. On the other hand, the displacement of frequential distribution towards higher frequencies for CG$_h$ spectra (larger MF$_{AP}$) in women in the AP direction could be linked to a decrease of the distances covered by the trajectories before the correction process operates. The fBm modelling suggests that the mechanisms ($H_{sl\ AP}$) involved in the control of the CP-CG$_v$ trajectories of women are endowed with more determinism than those of men. Indeed, women have a better control of these trajectories during the shorter $\Delta t$ than men under both EC and EO conditions.

The moment of body inertia (MI), larger for men, and natural body frequency (NBF), higher for women, can also be used to explain the differences observed according to gender. The greater MI, generating a greater inertia of CG motion, by definition induces an increased gap between CP and CG$_h$ motions. Indeed, women have larger amplitudes for the lowest frequencies of CP-CG$_v$ motions when compared to men, as illustrated by figure 4, and demonstrate a better control than men, as illustrated by figure 5. Interestingly, Breniére (1999) did not observe any change in NBF values from one adult to another, despite large variations in anthropometric characteristics. On the other hand, the NBF results of the present study indicate that women sway spontaneously at higher frequencies than men. This
difference between women and men adults is very close, in a way, to the difference between adults and children, as observed by Brenière (1999). Indeed, children demonstrate higher NBF values than adults. The common factor between women and children is that they are smaller and lighter than men. These results highlight the fact that body characteristics influence postural control. However these behavioural differences between women and men cannot be attributed solely to anthropometric characteristics, since some physiologic differences also play a role. Physiologically, the soleus muscle, an antigravity muscle, is permanently recruited during quiet standing (Okada and Fujiwara 1984). It is recognized that soleus muscles of women have longer fibres, smaller angles of pennation and are not as thick as male muscle (Chow et al. 2000). These differences in muscle architectural properties have, in turn, significant implications with respect to force and velocity. These muscular properties would contribute to a greater force generation for men (Chow et al. 2000). These physiologic explanations are in accordance with our results. Indeed, women demonstrate lesser ankle stiffness than men, according to the MF results of CP-CGv motions.

Consequently, the current results bring us to the conclusion that the lessened sway exhibited by women can be explained by both physiologic and morphologic characteristics.

To conclude, the results of the present study encourage the consideration of subject morphology as well as the differentiation of gender. Indeed, the fact that thin subjects display larger CGh motions and different postural strategies than corpulent ones demonstrates the influence of global morphology on postural control. On the other hand, some differences between women and men have been highlighted, suggesting the need to differentiate between men and women’s postural behaviours. Interestingly, the complete set of these results could constitute normative data of healthy adults and consequently could be used as referent behaviour for clinical studies.

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Effects of gender and morphology on stance


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Ziel: Die Ziele dieser Untersuchung ist es, Morphologie und Geschlechtsseffekte auf gesunden Subjekten während der Bewegung auf die Bewegung auszuwerten.

Momente von Körper-Trägheit (MI) und der natürlichen Körper-Frequenz (NBF) benutzt, um den Einfluß der Morphologie zu bestimmen.


**Résumé.** *Etat actuel des connaissances:* Des caractéristiques morphologiques telles que la taille et le poids corporel déterminent l’inertie corporelle, un facteur important de la stabilité posturale. Cependant, tandis que des investigations ont classiquement analysé ces paramètres séparément, la morphologie globale a fait l’objet de peu de recherche. Par ailleurs, l’influence du sexe sur la stabilité posturale indique des tendances contradictoires, certains auteurs observant que les hommes oscillent moins que les femmes et d’autres notant le contraire.

**But:** Cette étude a pour objet d’évaluer les effets de la morphologie et du sexe sur des sujets en bonne santé pendant le maintien postural.

**Sujets et méthodes:** Les sujets étudiés ont été classés sur la base de l’indice de Livi. Une méthode associant des paramètres de fréquence et des paramètres browniens caractérisait séparément les déplacements horizontaux du centre de gravité (CGh) et ceux de la différence entre le centre de pression (CP) et la projection verticale du centre de gravité (CP-CGv).

De plus, on a également utilisé les moments d’inertie corporelle (MI) et la fréquence corporelle naturelle (NBF) pour déterminer l’influence de la morphologie.

**Résultats et conclusions:** Les résultats révèlent que les sujets les plus minces ont des déplacements du CGh plus grands que les sujets normaux ou corpulents. Les caractéristiques morphologiques (NBF) peuvent expliquer ces différences de comportements. Par ailleurs, les hommes ont une amplitude d’oscillation des mouvements du CGh plus grande que celle des femmes. Ceci peut s’expliquer par des caractéristiques à la fois morphologiques (MI, NBF) et physiologiques (propriétés architecturales du muscle soleus).

**Resumen.** *Antecedentes:* Características morfológicas tales como la estatura y el peso corporal determinan la inercia del cuerpo, un importante factor relacionado con la estabilidad postural. Sin embargo, mientras que las investigaciones han analizado clásicamente estos parámetros por separado, la morfología global ha sido poco investigada. En segundo lugar, la influencia del sexo sobre la estabilidad postural demuestra tendencias opuestas: algunos autores observan que los hombres se balancean menos que las mujeres y otros señalan lo contrario.

**Objetivo:** Los objetivos de este estudio son evaluar los efectos de la morfología y el género sobre sujetos sanos durante el mantenimiento postural.

**Sujetos y métodos:** Los sujetos estudiados fueron divididos en categorías mediante el índice de Livi. Un método que asociaba parámetros frecuenciales y Brownianos caracterizó los desplazamientos horizontales del centro de gravedad (CGh) y los de la diferencia entre el centro de presión (CP) y la proyección vertical del centro de gravedad (CP-CGv) de forma separada. Además, también se utilizaron los momentos de inercia corporal (MI) y la frecuencia corporal natural (NBF) para determinar la influencia de la morfología.

**Resultados y conclusiones:** Los resultados revelan que los sujetos más delgados tienen desplazamientos mayores del centro de gravedad (CGh) que los sujetos normales o corpulentos. Las características morfológicas (NBF) pueden explicar estas diferencias de comportamiento. Por otra parte, los hombres tienen una amplitud de balanceo mayor que las mujeres para los movimientos CGh. Esto puede explicarse tanto por las características morfológicas (MI, NBF) como fisiológicas (propiedades arquitecturales del músculo sóleo).