The balance control effects on sitting posture induced by lumbosacral orthosis wear vary depending on the level of stability

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ARTICLE INFO

Article history:
Received 14 February 2012
Accepted 11 November 2012

Keywords:
Centre of pressure
Lumbosacral orthosis
Sitting posture

ABSTRACT

This study aimed to assess the differential impacts of lumbosacral orthosis (LO) wear in different sitting conditions through posturographic measurements. Twelve healthy subjects sat on a force platform with three variable stability levels (stable and on seesaws with a long and short radius, inferring slightly and highly unstable sitting, respectively) and three orthosis conditions (no LO, neutral LO, lordotic LO). Using fractional Brownian motion modelling of the centre of pressure (CoP) displacements, it appears that a stable sitting position did not highlight any particular differences between the LO models. With the lordotic LO, a slightly unstable sitting position decreased the mean time by 72% ($p < 0.002$) before postural corrective mechanisms took over. In contrast, in highly unstable sitting conditions, the lordotic LO induced larger CoP displacements (increasing variance by 162%, $p < 0.038$). Thus, depending on the amount of perturbation and the device design, wearing an LO may have a neutral, positive or negative impact on postural control in the sitting position.

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1. Introduction

To reduce trunk movements, different models of lumbosacral orthosis (LO) (elastic and rigid) have been developed with specific mechanical effects: kyphosis, neutral, lordosis. According to the perturbations applied to the trunk during daily life (standing, sitting, walking and running), the orthosis models could be more or less efficient. Each product has an optimal operating range depending on its rigidity, which minimises postural disturbances without causing painful compensations. The capacity to compare the biomechanical effectiveness of different models is essential for selecting the appropriate LO. Regarding this objective, an ergonomic approach, consisting in measuring, in experimental conditions, the effects of the physical characteristics of the product on the subjects’ behaviours can be useful.

Since trunk movements relative to the pelvis contribute, with the legs, to upright standing stability (Genthon and Rougier, 2006), it may be relevant to use the upright balance control paradigm to assess the effects induced by various kinds of LOS (Munoz et al., 2010). To maintain the vertical projection of the centre of gravity (CoG) within the base of support, a constant displacement of the centre of pressure (CoP) is required.

To better assess the mechanisms involved in this regulation, the use of fractional Brownian motion (fBm) modelling, which highlights the relative contribution of the successive mechanisms called into play for postural control (Collins and de Luca, 1993; Riley et al., 1997; Genthon and Rougier, 2006), can be helpful. With this model, it can be seen that in the first phase, called “exploratory”, the CoP moves away from the CoG, providing information on its location, followed by a second phase, called “corrective” during which the CoP changes the direction of the CoG (Rougier and Caron, 2000). The transition point, which defines the mean spatio-temporal boundaries between these two successive phases, can be useful for assessing a reduced latency in the balance correction in standing posture induced by a lordotic LO (Munoz et al., 2010).

Nonetheless, to assess the trunk displacements with an LO, balance control evaluations in sitting posture may appear more appropriate. Compared to standing posture, sitting posture could indeed isolate the balance control of the trunk by eliminating the postural adjustments involving the lower limbs (Bousset and Duchêne, 1994). However, since the pelvic movements during quiet sitting are rather limited, a more dynamic paradigm, soliciting this part of the body in greater proportions might be worth using to assess the stabilising contribution of the LO. A fair solution might
consist in the insertion of a seesaw or an unstable seat below the sitting subjects. Compared to a flat support, a rounded support decreases the contact surface with the ground and makes postural control more difficult. Assuming the trunk behaves as an inverted pendulum pivoting about the hip joint (Winter, 1995) and that balance control is primarily regulated through the closest joints regarding the centre of rotation (Nashner and McCollum, 1985), an unstable sitting posture with fixed arms is thought to emphasise the postural activity of the hip and lumbar joints, the movements of the cervical and thoracic areas being negligible. Differing levels of the trunk disturbance can be achieved either by using different hemisphere diameters ranging from 50 cm (Cholewicki et al., 2000) to 19.5 cm (van Dieën et al., 2010) and/or by modifying the height of the seat (Silfes et al., 2003). This task, by inducing larger trunk movements, is assumed to be closer to real life.

To our knowledge, the level of instability for sitting postures has never been validated for the assessment of LO. Interestingly, changing the level of perturbations could affect not only the amplitudes of the CoP displacements (Cholewicki et al., 2000), but could also significantly alter the balance control strategies and therefore change the interpretation of the results. Actually, on one hand, one can assume that insufficient instability will not cause large CoP displacements and thus will not be relevant to assessing the control of the trunk position during daily activity. On the other hand, one can assume that excessive trunk displacements induced by an unstable seat will cause increased CoP displacements due to a reduced number of degrees of freedom in the postural chain, inducing a lessened capacity to compensate for the external perturbations. The balance control effect while wearing an LO might therefore be changed by modifying the stability of the contact surface and/or the characteristics of the LO. The precise relation between these two parameters is largely unknown. Therefore, the main objective of this study was to determine from different imposed levels of postural destabilisations (low, moderate and high), the validity of an optimum operating range for inducing balance control effects while wearing an LO. This method could highlight product specificities such as rigidity and induced lordosis. Improving our knowledge of this new standardised paradigm could help designers working on medical products relative to the trunk (i.e. LOs, backpacks, dynamic seats) to test these materials in relation to the subjects' needs.

2. Material and methods

2.1. Subjects

Twelve healthy volunteers (six females and six males, 23.3 ± 1.9 years; weight: 65.3 ± 6.2 kg; height: 1.75 ± 0.1 m; mean ± standard deviation) participated in the study. None of the subjects had a history of neurological disorders, trauma or chronic or occasional back or leg pain.

2.2. Protocol

The subjects were seated on the force platform in a standardised position, with the contact area corresponding to the full surface area of the buttocks and three-quarters of the thigh surface area. The legs and feet were unsupported, while the arms were held folded in front of the chest. The subjects were instructed to close their eyes and move as little as possible, while maintaining normal breathing. Three levels of seat instability were achieved using variable radii of the seesaws: infinite (flat surface, CINF), 55 (CS5), and 35 cm (CS3). Three bracing conditions were proposed in addition for each level of instability: no LO (REF), a flat neutral LO (LO) and a lordotic LO (LLO, see details below), giving a protocol comprising nine conditions performed in random order. Subjects were barefoot and wore a nonstandardised t-shirt and trousers for each condition. As recommended by Cholewicki et al. (2000) and van Dieën et al. (2010), CoP data were collected over 30 s or even 60 s with several trials averaged. Therefore, two 64-s trials were performed, with 30 s of rest between trials (since no real fatigue was expected to interfere during the measurement procedures). The two trials belonging to the same condition were recorded in succession to allow the same LO adjustment. Subjects had 5 min of rest between each condition, allowing the LO to be installed or dismantled. Data collection lasted about 50 min.

2.3. Material

The present study was in part conducted using the Lordactiv™ LO model (Ormih-Danet, Villeurbanne, France) (Fig. 1). This LO maintains physiological lordosis with a frontal vertical panel and a curved rigid shell at the back. The textile part of the corset is made of polyamide, polyethylene foam, cotton, elastane and elastodiene. The rigid back part as well as the front frame are made of polyethylene, aluminium, steel and stainless steel. The LOs were always adjusted by the same investigator to fit the subjects' anthropometry, in order to optimise the reproducible tightening of the straps and the positioning of the front rod. The elastic pads were arranged so as to obtain maximum lordosis in the LLO condition and removed to obtain flat lordosis in the LO condition (Fig. 1). The seesaw (Satel, Blagnac, France), made of a square plate (40 cm long on each side) mounted 5 cm or 8 cm above two circular ridges with 55 cm or 35 cm radii, respectively (Fig. 2), was designed to produce translational—rotational movement (pitching) along the anteroposterior (AP) axis and was laid on a double rectangular force platform (PF02, Equi+, Aix-les-Bains, France). Its movements were assumed to be without friction with the force platform. The signals from eight dynamometric sensors (placed under each of the platform’s summits) were amplified and digitised (12 bits) prior to recording on a microcomputer at a sampling frequency of 64 Hz with no filtering.

2.4. Data processing

To assess postural stability, the CoP horizontal displacements along the AP axis were analysed through the variances of the

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successive positions. A further analysis was performed consisting in fBm modelling, to determine the degree of control and the spatio-temporal linkage in terms of control mechanisms successively involved in maintaining the sitting position (Collins and de Luca, 1993; Genthon and Rougier, 2006). As demonstrated by the relation $\langle \Delta x^2 \rangle = \Delta t^{2H}$, the analysis principle consists in the relationship between the mean CoP square displacements ($\langle \Delta x^2 \rangle$) and the increasing time intervals ($\Delta t$) (up to 10 s). The graphical representation, from which this type of relationship can be expressed, is called a variogram (Fig. 3). Generally, two distinct mechanisms are successively involved in this control, as in upright standing (Genthon and Rougier, 2006). During the shortest time intervals, the CoP tends to be displaced far from the previous position, indicating an anti-persistent mechanism corresponding to an exploratory process (assessed through scaling coefficients of long latency, $H_L < 0.5$). In contrast, during the longest time intervals, this displacement tends to move closer to the previous position, indicating an anti-persistent mechanism corresponding to a corrective process (assessed through scaling coefficients of short latency, $H_S > 0.5$). A median value of 0.5 for $H$ indicates a lack of correlation, suggesting that the trajectory behaves like a random walk. On the other hand, if $H$ differs from 0.5, positive ($H > 0.5$) or negative ($H < 0.5$) correlations can be inferred, indicating an increase of the proportion of determinism in the control. The mean time intervals ($\Delta t$) and the mean square displacements ($\langle \Delta x^2 \rangle$) corresponding to the slope inflexion in the variograms, depicted through a bi-logarithmic scale, are thought to express the transition point between the two successive (exploratory and corrective) mechanisms called into play. Since postural stability and postural control mechanisms measured by variance and fBm, respectively, provided sufficient data for a characterisation of the postural balance, other variables were not presented. The data were examined statistically through a two-way (level of instability and bracing condition) ANOVA with repeated measures. To isolate which group(s) differed from the others, a multiple comparison procedure (the Bonferroni test) was used. For all tests, the first level of significance was set at $p < 0.05$.

3. Results

For all measures, no significant bracing effect appeared in the stable (CINF) condition (Table 1).

Only the two unstable conditions (C55 and C35) were able to produce different significant lordotic effects when subjects were an LLO compared to the no bracing condition (REF).

Low instability (C55) with an LLO induced a 72% ($p < 0.001$) decrease in the mean delay before the onset of the corrective mechanisms ($\Delta t$; Fig. 4(b)) and mean distances covered before the onset of the corrective mechanisms ($\langle \Delta x^2 \rangle$; Fig. 4(c)), respectively, without improving the quality of the correction ($H_S$; Fig. 4(e)) and the amplitude (variance; Fig. 4(a)) of the CoP displacements.

On the contrary, high instability (C35) with an LLO induced 125% ($p < 0.001$) and 138% ($p < 0.001$) increases in mean time intervals ($\Delta t$; Fig. 4(b)) and mean distances covered before the onset of the corrective mechanisms ($\langle \Delta x^2 \rangle$; Fig. 4(c)), respectively, without improving the quality of the correction ($H_S$; Fig. 4(e)). As a result, the variance (Fig. 4(a)) of the CoP displacements strongly increased by 162% ($p < 0.001$).

4. Discussion

The purpose of this study was to determine the most relevant way out of the three perturbation paradigms in the sitting posture (CINF, C55 and C35) to assess the postural balance effects induced by two different LO concepts. It was suggested that the balance control while wearing an LO might be changed by modifying the level of instability and the bracing characteristics.

4.1. Bracing during CINF condition

Our data show that the trunk stabilising capacities induced by LO are negligible in a very stable condition such as CINF. Compared

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**Fig. 2.** A subject sitting on the unstable seat C55. A force plate recorded the movements of the centre of pressure (CoP).

**Fig. 3.** Example of a variogram representing the mean centre of pressure trajectory displacements as a function of increasing time intervals. The dashed horizontal and vertical straight lines correspond to the mean square displacement and $\Delta t$ coordinates of the different transitions between successive regimes involved in maintaining the sitting position.

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to upright standing, sitting is characterised by a 200% increase of the base of support and a decreased number of joints for controlling a lower positioned CoG. As a result, in the sitting position, trunk external perturbations are greatly reduced compared to upright standing (Genthon and Rougier, 2006). One of the main results of the study is that wearing an LLO during stable sitting is unable to induce significant postural control effects.

4.2. Bracing during the C35 condition

A common way to amplify trunk displacements is to use a seesaw or an unstable seat below the sitting subjects for releasing the hip joints. Up to now, for postural sitting assessment without LO, more unstable seats, i.e. with shorter radii than those involved in this study, have been used (Cholewicki et al., 2000; van Daele et al., 2007; van Deien et al., 2010). As shown by our data, a considerable negative braking effect was observed with the LLO. It is worth noting that this effect is mainly seen in this C35 condition. A more acute analysis indicates that the LLO increased both spatial (<Δx>) and temporal (<Δt>) coordinates of the transition points, revealing that more time and longer distances covered are needed before the onset of the corrective mechanisms. Nevertheless, the quality of the correction (Ht) is not really improved, explaining the increased CoP displacements (variance). This change in the closed-loop control strategy is similar to the one adopted by subjects without an LO with a higher instability (Cholewicki et al., 2000). In contrast, as reported by Cholewicki et al. (2007), a neutral LO does not increase the CoP displacements significantly compared to the reference condition (CINF). An LLO appears to be, in that case, a limiting factor. However, other factors might contribute for explaining the discrepancies in the results. In particular, the size of the contact surface was recognized to affect the hip motions, and therefore the difficulty of the sitting task even more when LO locks the remaining lumbar mobility (Kantor et al., 2001). It must be kept in mind from that condition that wearing a rigid LO during substantial disturbances degrades postural control while a soft LO has no significant effect.

4.3. Bracing during the C55 condition

To lessen the impact of the reduction in degrees of freedom of the postural chain provided by the LO, a less unstable seating surface can be used (C55). According to Cholewicki et al. (2007) and Munoz et al. (2010), a neutral LO (LO) is a priori not able to improve the balance performance. On the contrary, wearing a lordotic LO (LLO) modifies the postural control strategy by reducing the mean time before the onset of the corrective mechanisms (Δt), but the postural performance since the CoP displacements remains unchanged (variance). This feature, already observed in the standing posture on a stable support base (Munoz et al., 2010), could be explained by a speed-accuracy conflict. Indeed, faster correction (Δt) generally impairs the quality of the correction (Ht) (Berger et al., 2005). A lordotic support could thus bring a sensory rather than a mechanical benefit such as the increase of stiffness. A similar result can be found in studies aimed at testing backpacks. Their carriage causes an immediate decrease in the lumbar lordosis and appears to have a direct effect on the delay in onset of a closed-loop control strategy (Chow et al., 2010). Wearing an LO during moderate perturbations (C55) provides a beneficial effect on postural control, but interestingly only if the lordosis is facilitated.

4.4. Single inverted (SIP) or multi-link inverted pendulum (MLIP) strategies

Contrary to the assessment without LO, the choice of an unstable seating surface plays a key role on the braking effect. According to Grüneberg et al. (2004), these results could be simply explained by a single inverted (SIP) or multi-link inverted pendulum (MLIP) models for trunk movements. The concept of SIP or MLIP behaviours has been extensively studied for upright stance for the movements intervening along the AP axis. According to Nasher and McCollum (1985), Kuo (1995) and Henry et al. (1998), upright postural control is primarily regulated through distal joints (SIP strategy). When instability increases, more proximal joints are gradually used to restore balance (MLIP strategy), suggesting a continuum of the available postural control strategies. According to Kuo (1995), adopting an MLIP strategy might favour a faster acceleration of the CoG and, when the disturbance increases, reduce muscular activity. An easy way to highlight the ability to change the postural control strategy according to the constraints applied to the trunk is wearing an orthosis (Grüneberg et al., 2004). In the sitting posture, mobility is principally ensured by the hip joints (distal segment), and by a progressive recruitment of the lumbar joints (the most mobile proximal joints available). The capacity to change postural control strategies, as described above, can therefore be extended to the sitting posture. Interestingly, low (C55) and high (C35) unstable surfaces could force the subjects, while wearing an LO, to change from an SIP to an MLIP strategy. These changes would explain the different behaviours observed depending on the type of LO and the unstable seating surface. In the lower unstable condition, an SIP strategy may be used for all LOs. An LLO, by stiffening the lumbar area, would provide an enhancement of the SIP strategy. In contrast, in more unstable conditions, an MLIP strategy might be preferentially used. However, an MLIP strategy is not observed when excessive external trunk perturbations are associated with reduced lumbar joint mobility resulting from rigid LLO wear. In this case, postural control may be fully regulated by the hip joints (SIP strategy), a less efficient strategy. On the contrary, an LO, which does not change the stiffness of the
lumbar part compared to the reference condition, does not interfere with the postural strategy changes observed for the two unstable conditions. Even though the overall results might be largely explained, in our mind, by the ability of the trunk to behave as an SIP or MLIP, further studies, based specifically on sitting postural control strategies and kinematic data, would be needed to further explain this interdependency.

4.5. Ergonomic benefits

Based on our results, two important points should be kept in mind for the design of LOs. Firstly, even though prescribing a rigid LO is clinically relevant to prevent lumbar mobility and its analgesic effect (Calmels et al., 2009), the impairment of the compensatory postural activity during high disturbances such as walking, due to the hip joint constraints, should be taken into account, particularly for elderly subjects, because it could predispose to falls (Grüneberg et al., 2004). Secondly, facilitating lordosis with a rigid support to prevent the flattening of this curve can be beneficial (Chow et al., 2010). This recommendation is especially important in sitting where lordosis is already strongly reduced.

In general, balance assessment through different unstable sitting postures could help designers to determine the best level of trunk disturbance for which the product is able to improve balance control. From this knowledge, the rigidity could be modified to be fitted with the perturbations encountered during the activity performed with the product (low, moderate or high). For example, this method could help to determine whether, when wearing a backpack, postural control could be enhanced by an LO and if the trunk mobility were sufficient to compensate for higher disturbances such as walking. Similarly and complementary to the measurements proposed by Ellegast et al. (2012) and Kingma and van Dieën (2009), it would be possible to determine the optimal external perturbations induced by a dynamic office chair or an exercise ball in order to stimulate postural control.

5. Conclusions

This study has highlighted the difficulties designing a postural task that would most likely reveal the effects induced by an LO for healthy subjects. Significantly, this study shows that the level of seat instability required for highlighting the behaviour induced by these products varies according to their specificity. For instance, wearing an LO has a neutral, positive or negative impact on postural control depending on the external perturbations and the device design. Posturographic measurements with different destabilising

Fig. 4. Bar charts representing for the various experimental conditions (reference (REF), lumbar orthosis (LO) and lordotic lumbar orthosis (LLO)) and during different sitting positions (stable 0, low 35 and highly unstable 55) all the parameters measured (mean and standard deviation of the sample) using temporal analysis (a) and fBm modelling: temporal (b) and spatial (c) correction parameters and short (d) and long (e) quality corrective process parameters. The significance level is represented on the diagrams (* p < 0.05).
Conflict of interest

None.

Acknowledgments

We would like to thank L Northrup for editing the English text.

References


