Journal of Biomechanics 41 (2008) 3419–3425

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Body segments decoupling in sitting: Control of body posture from automatic chair adjustments

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ARTICLE INFO

Article history:
Accepted 12 September 2008

Keywords:
Wheelchair intervention
Sitting posture
Posture control
Pelvis
Body segments

ABSTRACT

Background: Individuals who cannot functionally reposition themselves adopt a passive body posture and suffer from physical discomfort in long-term sitting. To regulate body load and to prevent sitting related mobility problems, proper posture control is important. The inability to reposition underlines the importance for seating interventions that control body posture from automatic chair adjustments. We developed an adjustable simulator chair that allows the alignment of the trunk, pelvis and thighs to be controlled independently. This study describes the system for decoupled body segments adjustment and develops a predictive model that computes angular chair configuration for desired body postures.
Methods: Eighteen healthy male subjects participated in this study. The experiment involved a protocol of five trials, each investigating the effect of individual chair segment angle adjustment on body segments rotation. Quasi-static chair adjustments were performed, in which angular chair configuration and body segments orientation were measured using an infrared motion capturing system and an inertia sensor attached on the pelvis.
Results: Linear best-fit equations together with the coefficients of determination were computed. Significant relations have been found between angular chair configuration and body segments orientation leading to an algorithm that predicts chair configuration for desired body posture.
Conclusions: The predictive algorithm seems applicable to compute angular chair configuration for desired body posture when the initial body–chair configuration is known. For clinical application, future experiments must be performed on impaired individuals to validate the algorithm in terms of accuracy.

1. Introduction

Individuals who cannot functionally reposition themselves in long-term sitting adopt a passive body posture and often suffer from physical discomfort such as pressure ulcers (Collins, 1999), low back injury (Verver et al., 2003; Lengsfeld et al., 2000a; Lengsfeld et al., 2000b; Makhsous et al., 2003; van Deursen et al., 2000; Ferguson and Marras, 1997), respiratory dysfunction (Lin et al., 2006), lumbar immobility and joint stiffness (Beach et al., 2005).

It has been accepted with some certainty that most physical problems are associated with sustained mechanical body loading and that dynamic seating interventions are needed to periodically adjust body posture associated with wheelchair discomfort (Crane et al., 2007).

Able-bodied individuals do not suffer mobility problems since they continuously shift body posture. In a recent study, Linder-Ganz et al. (2007a) evaluated healthy sitting behaviour and reported significant movement of the upper extremities, trunk and pelvis when quantifying postural change in prolonged wheelchair sitting of healthy individuals.

Because body posture is mainly determined by the alignment of the trunk, pelvis and thighs, proper posture control involves the ability to move all three body segments independently. However, for individuals who cannot functionally reposition themselves, no applications are yet known that allows decoupled trunk, pelvis and thighs adjustments.

Classical wheelchairs with one pivot between the seat and backrest make it impossible to adjust the trunk, pelvis and thighs independently and introduce sliding when changing its configuration (Aissaoui et al., 2001). We therefore designed a chair that allows decoupled alignment of the trunk, pelvis and thighs by aligning the axes for angular chair adjustments with the axes for body segments rotation.

This study describes the system for decoupled body segments adjustment and develops a predictive model that computes angular chair configuration for desired body postures.

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doi:10.1016/j.jbiomech.2008.09.017

2. Methodology

This study was approved by the local Committee for Medical Ethics of Rehabilitation Centre 't Roessingh (Enschede, the Netherlands).

2.1. Subjects

Eighteen healthy male subjects (age 22.6 ± 2.4 years, weight 74.9 ± 8.0 kg, length 1.84 ± 0.05 m, BMI 22.1 ± 1.9 kg/m^2) were recruited for this study. All subjects read and signed an 'informed consent', which explained the objective and experimental protocol.

2.2. Decoupled body segments adjustment

A 'classical' chair with one pivot between the seat and backrest makes it impossible to adjust the trunk, pelvis and thighs independently and introduces sliding when changing its configuration (Fig. 1A). A concept with the axes of rotation aligned within the lumbar region and under the ischial tuberosities allows independent body segments adjustment in the sagittal plane (Fig. 1B). Based on a parallelogram from which the backrest is actuated, a mechanical concept for decoupled body segments adjustment is shown in Fig. 1C. Actuating the configuration of the parallelogram rotates the pelvis in the sagittal plane. The whole mechanism rotates around a pivot under the tuberosities and is externally actuated. In the frontal plane, actuating the relative height between the left and right seat part rotates the pelvis sideways around an axis between the ischial tuberosities. For lateral trunk rotation, the backrest is actuated around a pivot within the lumbothoracic region.

2.3. Experimental setup

A fully adjustable computer-aided simulator chair was developed which contained the concept for decoupled body segments adjustment (Fig. 2). The backrest is mounted on a sledge to allow vertical trunk translations and to align the axes for body segments rotation exactly with the axes for chair adjustment. The weight of the backrest is counterbalanced. The backrest, seat, parallelogram and footrests are adjustable to align body posture with chair configuration. The parallelogram height and backrest depth were set in a way that the axis for sagittal backrest adjustment would be around the middle of the lumbar spine. This was determined from pilot experiments on healthy male subject with posture characteristics similar to those recruited for the present study.

Reflective markers were placed on the chair and selected anatomical landmarks. Three-dimensional chair configuration and body segments orientation were obtained using an infrared camera motion capturing system (VICON®, Oxford, UK). To prevent skin artifacts during pelvis movement, a pelvis mold (PM) was shaped around the left and right lateral iliac crest and clamped the anterior–superior iliac spine and posterior–superior iliac spine for optimal fixation (Fig. 3). To prevent problems with pelvis marker visibility, an inertia sensor (MT®, Xsens, Enschede, the Netherlands) was attached on the PM as an alternative to estimate pelvis orientation. The line of gravity was used to derive sensor inclination that we related to the orientation of the PM as shown in Fig. 3.

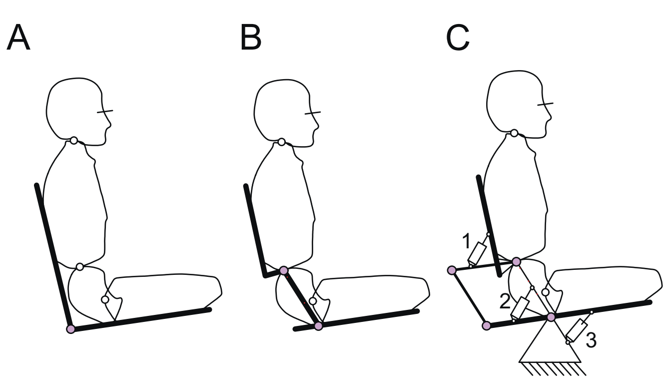

Fig. 1. Principle for sagittal postural adjustments. (A) Classical chairs with one pivot between the seat and backrest do not allow independent trunk, pelvis and thighs adjustments. (B) Concept with two axes of rotation aligned within the lumbar region and under the ischial tuberosities enables independent body segments control in the sagittal plane. (C) Based on a parallelogram, a mechanical concept for decoupled body segments adjustment is shown. The backrest is adjusted from the parallelogram (1), the parallelogram from the back seat (2) and the seat from the under frame (3).

A pressure mapping device (Tekscan®, Boston, USA) was placed over the seat to locate the position of the tuberosities.

2.4. Reference coordinate frames and joint centre locations

The x–z and y–z planes of the global reference frame (G) aligned respectively the frontal and sagittal planes of the simulator chair.

The local trunk frame (R_t) was constructed from the 7th Cervical ($C7$), upper sternum (US) and processus xypoid (PX). The y-axis of R_t runs from $C7$ to US. The x-axis points right and is normal to the plane containing $C7$, US and PX. The z-axis is the cross product of the x- and y-axis. The local pelvis frame (R_p) was constructed from four markers placed on the PM. Two markers were placed on the left and right anterior superior iliac spines (LASIS and RASIS) and two markers (LSIS and RSIS) on the line between the anterior- and posterior superior iliac spines. The x-axis of R_p runs from the LASIS to the RASIS. The z-axis points cranially and is normal to the plane containing the LASIS, RASIS and the midpoint between LSIS and RSIS. The y-axis is the cross product of the z- and x-axis. The midpoint of RASIS and LASIS defined the origin of R_p. Local coordinates for the left and right hip joint centres (HJCs) were estimated from pelvic width (distance between RASIS and LASIS) and expressed in R_p according to the regression equations as reported by Bell et al. (1990). In case of problems with pelvis marker visibility, information from the inertia sensor was used to construct a local sensor frame (R_i) that we related to R_p (Fig. 3). The local coordinate frames for the thighs (R_{th}) are constructed from the HJCs, lateral femoral epicondyles (LFEs) and medial femoral epicondyles (MFEs). The knee joint centres (KJCs) are estimated at the midpoint between the LFEs and MFEs. The y-axis of R_{th} runs from the HJCs to the KJCs. The z-axis points cranially and is normal to the plane containing the HJCs, LFEs and MFEs. The x-axis is the cross product of the y- and z-axes.

In the sagittal plane, the local coordinate frames for the backrest (R_1), parallelogram (R_3) and seat support (R_5) were constructed from angular chair configuration as shown in Fig. 2. In the frontal plane, the local backrest frame (R_2) was constructed from angular backrest adjustment. Fig. 2 also shows how we constructed a local coordinate frame (R_4) from the contact areas under the ischial tuberosities. This was done from the angle (φ) that we derived from the height difference d [mm] between the left and right seat part assuming an average ischial tuberal width of 120 mm (Linder-Ganz et al., 2007b): $\tan(\varphi) = d/120$.

2.5. Body- and chair segments orientation

Helical angles were computed for all body- and chair segments. In the sagittal plane, the orientations of R_t, R_p and R_{th} relative to G defined the sagittal body segments angles for the trunk (α_x), pelvis (β_x) and thighs (γ_x), respectively. The orientations of R_1, R_3 and R_5 relative to G defined the sagittal chair segments angles for the backrest (A_x), parallelogram (B_x) and seat support (H_x), respectively. In the frontal plane, the orientations of R_t and R_p relative to G defined the frontal body segments angles for the trunk (α_y) and the pelvis (β_y), respectively. The orientations of R_2 and R_4 relative to G defined the frontal chair segments angles for the backrest (A_y) and seat support (H_y), respectively.

2.6. Angular chair configuration vs. body segments orientation

The experiment involved five trials (Fig. 4), each investigating the effect of *one* specific chair segment angle adjustment on the alignment of *all* body segments. Trial 1–5 concerned sagittal backrest angle adjustment (Trial 1), frontal backrest angle adjustment (Trial 2), sagittal parallelogram angle adjustment (Trial 3), frontal seat part adjustment (Trial 4) and sagittal seat angle adjustment (Trial 5). Linear relations between angular chair configuration and body segments orientation were assumed. For every trial, we related angular chair adjustment to the alignment of all body segments and computed the linear best-fit equations together with the coefficients of correlation (r) and accompanying significance (p). We then calculated the coefficients of determination (r^2) which gives us an indication about the strength of the relation. High coefficients of determination ($r^2 > 0.8$) indicate strong relations. The computed linear equations were used to formulate the matrix equation Eq. (1) in which each column of C was filled with the slope coefficients from the results of corresponding trial number.

$$q = C \cdot u \tag{1}$$

in which

$$q = \begin{bmatrix} \Delta\alpha_x \\ \Delta\alpha_y \\ \Delta\beta_x \\ \Delta\beta_y \\ \Delta\gamma_x \end{bmatrix} = \begin{bmatrix} \alpha_x - \alpha_{x0} \\ \alpha_y - \alpha_{y0} \\ \beta_x - \beta_{x0} \\ \beta_y - \beta_{y0} \\ \gamma_x - \gamma_{x0} \end{bmatrix} \quad u = \begin{bmatrix} \Delta A_x \\ \Delta A_y \\ \Delta B_x \\ \Delta B_y \\ \Delta H_x \end{bmatrix} = \begin{bmatrix} A_x - A_{x0} \\ A_y - A_{y0} \\ B_x - B_{x0} \\ B_y - B_{y0} \\ H_x - H_{x0} \end{bmatrix} \quad \begin{matrix} C = \lfloor C_{ij} \rfloor \\ i = j = 1,\ 5 \end{matrix} \tag{2}$$

$A_{x0\ldots}H_{x0}$ and $\alpha_{x0\ldots}\gamma_{x0}$ define the initial segment angles for angular chair configuration and body posture, respectively. Inverting C gives the equation that predicts angular chair configuration for desired body segment alignment.