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Determination of a sagittal plane axis of rotation for a dynamic office chair

C.M. Bauer[a,*], F.M. Rast[a], C. Böck[a,b,c], R.P. Kuster[c,d], D. Baumgartner[c]

[a] Zurich University of Applied Sciences, Institute of Physiotherapy, Technikumstrasse 71, 8400 Winterthur, Switzerland
[b] Technical University Munich, Department of Mechanical Engineering, Boltzmannstrasse 15, 85748 Garching bei München, Germany
[c] Zurich University of Applied Sciences, Institute of Mechanical Systems, Technikumstrasse 9, 8400 Winterthur, Switzerland
[d] Karolinska Institutet, Department of Neurobiology, Care Science and Society, Division of Physiotherapy, Alfred Nobels allé 23, 14152 Huddinge, Sweden

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ABSTRACT

Objective: This study investigated the location of the axis of rotation in sagittal plane movement of the spine in a free sitting condition to adjust the kinematics of a mobile seat for a dynamic chair.
Background: Dynamic office chairs are designed to avoid continuous isometric muscle activity, and to facilitate increased mobility of the back during sitting. However, these chairs incorporate increased upper body movement which could distract office workers from the performance of their tasks. A chair with an axis of rotation above the seat would facilitate a stable upper back during movements of the lower back. The selection of a natural kinematic pattern is of high importance in order to match the properties of the spine.
Method: Twenty-one participants performed four cycles of flexion and extension of the spine during an upper arm hang on parallel bars. The location of the axis of rotation relative to the seat was estimated using infrared cameras and reflective skin markers.
Results: The median axis of rotation across all participants was located 36 cm above the seat for the complete movement and 39 cm for both the flexion and extension phases, each with an interquartile range of 20 cm.
Conclusion: There was no significant effect of the movement direction on the location of the axis of rotation and only a weak, non-significant correlation between body height and the location of the axis of rotation. Individual movement patterns explained the majority of the variance.
Application: The axis of rotation for a spinal flexion/extension movement is located above the seat. The recommended radius for a guide rail of a mobile seat is between 36 cm and 39 cm.

1. Introduction

Office workers in particular spend around 75% of their waking hours in sitting postures (Gorman et al., 2013). Both prolonged static sitting and sitting in unfavourable postures increase the risk of experiencing low back pain related to continuous isometric muscle activity (Lis et al., 2007; Pope et al., 2002; Van Dieen et al., 2001; Vergara and Page, 2002). Movement is beneficial to the structures of the spine, compared with static postures, particularly the intervertebral discs (Pope et al., 2002).

Dynamic office chairs are designed to reduce time spent in static sitting postures. The two contemporary types of dynamic office chairs are unstable office chairs without backrest and office chairs with adjustable seat and backrest. Although an unstable office chair without backrest might promote upright and active sitting, it also increases spinal flexion (Grooten et al., 2013), requires strong static lumbar muscular activity to maintain an upright posture (Van Dieen et al., 2001; Vergara and Page, 2002; Kingma and van Dieën, 2009; O'Sullivan et al., 2013), and also requires increased cervical and thoracic static muscular activity, which are associated with spinal pain and discomfort (Caneiro et al., 2010; Womersley and May 2006). Consequently, a dynamic office chair should be fitted with a backrest. Office chairs with an adjustable seat and backrest usually allow axial rotation (horizontal plane) and backwards tilting (sagittal plane) (Ellegast et al., 2012; Groenesteijn et al., 2009). Tilting backwards facilitates the relaxation of the back muscles, relieves load on the spine, and increases the trunk thigh angle (Pope et al., 2002; Van Dieen et al., 2001; Vergara and Page, 2002; Bush and Hubbard, 2008; Harrison et al., 1999). A disadvantage of these mechanism is that they require large amplitude upper body movements that could distract office workers from their tasks (Van Dieen et al., 2001; Bush and Hubbard, 2008). Axial rotation might be less distracting since the head is able to remain stable and the gaze fixed, but there is unfortunately no evidence that office chairs with adjustable seats and backrests increase the activity of their users (Van Dieen et al., 2001; Ellegast et al., 2012; Jensen and Bendix, 1992). Unstable office chairs with adjustable seats and backrests usually allow

* Corresponding author.
E-mail addresses: Christoph.Bauer@zhaw.ch (C.M. Bauer), Daniel.Baumgartner@zhaw.ch (D. Baumgartner).

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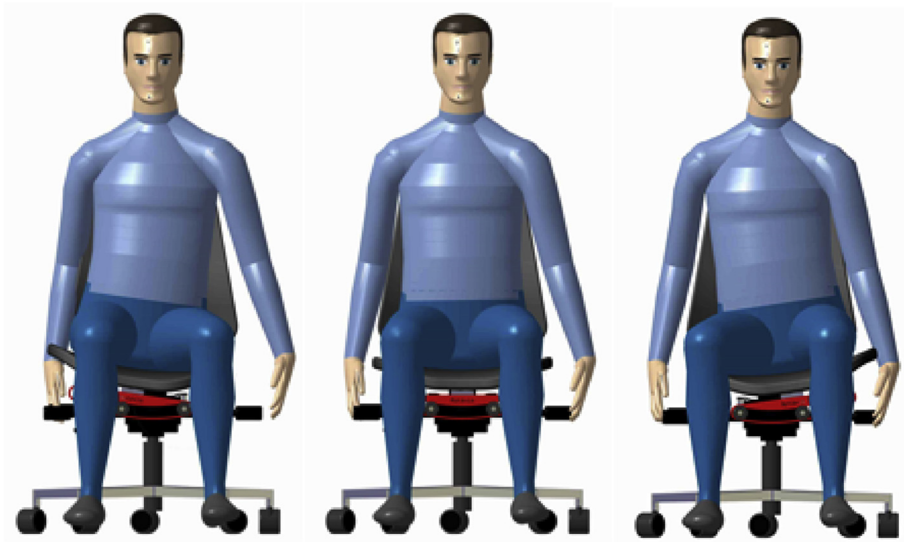

Fig. 1. Dynamic Office Chair supporting a stable upper body.

additional range of motion of small magnitude, with 0.6°–2.7°, 0.2°–2.8°, and 0.8°–1.8° for sagittal, lateral or rotational inclination respectively (Ellegast et al., 2012; Groenesteijn et al., 2012; Lengsfeld et al., 2000). A stable gaze and upper body are mandatory for comfortable office work, where the undisturbed use of keyboard and mouse is a basic requirement (Van Dieen et al., 2001; Bush and Hubbard, 2008). Current dynamic office chairs facilitating backwards tilting and rotation might not promote the intended active sitting because they result in large upper body movements and a disturbed field of view (Kuster et al., 2016a) since their axis of rotation is below the seat of the chair. Consequently, the operator's movement is restricted and her/his performance impaired.

To promote active sitting with a stable upper body posture an office chair with a frontal plane axis of rotation above the seat was recently developed Fig. 1 (Kuster et al., 2016a).

This office chair supports lateral flexion of the lumbar spine (resembling the lateral flexion observed during normal walking) while minimizing movement of the upper body. The axis of rotation of this office chair is located on average at the level of the 11th thoracic vertebra, but is dependent on body height (Kuster et al., 2016a). Movement in the sagittal plan was not taken into account in that study, despite the fact that any movement in the spine creates coupled or secondary movements in the other planes (Izzo et al., 2013). Therefore, the aim of this study was to investigate the location of an average axis of rotation for pelvic movements in the sagittal plane with a fixed shoulder girdle. Since pelvic movement in the sagittal plane during walking is dependent on the movement direction (flexion and extension) (Perry and Davids, 1992) and human bodies are, contrary to the frontal plane, asymmetric in sagittal plane, this study investigated whether the location of this axis is dependent on the movement direction. Furthermore, this study investigated whether the location of this axis is dependent on a person's body height.

2. Method

2.1. Participants

Twenty-one healthy participants (eleven female) were recruited from the university's staff. To be eligible the participants had to fulfil the following inclusion criteria:

- Age 18–65 years
- BMI ≤25
- Body height within the 5th and 95th percentile of a representative sample of the German population (Size)

Age and body height were limited to recruit a representative of the general office worker population. Overweight participants were excluded due to an increased error of soft tissue artefacts which would bias the calculation of the axis of rotation. Further exclusion criteria were musculoskeletal or other disorders that would impede sitting on a chair or maintaining upper arm hang on parallel bars. The study was conducted according to the declaration of Helsinki. It was verified jurisdictionally by the local ethics committee (Req-2016-00034). Participants provided their written informed consent.

2.2. Procedure

Participants attended one measurement session in a movement laboratory. Their body height was measured during upright standing and defined as the distance between the ground and the cranial vertex. Their spinal length was defined as the distance between the 7th cervical vertebra to the level of the midpoint of posterior superior iliac spines and measured using a flexible ruler (Ernst et al., 2013). Five reflective markers of 16 mm diameter were placed on the left and right anterior iliac spines, the left and right iliac crest and the sacrum (Fig. 2). Three additional markers were placed on the seat of a wooden stool to form a plain surface area.

The participants initially performed one reference trial of sitting upright on the wooden stool for two seconds. Following this, they performed a free sitting trial while hanging by their upper arms on a parallel bar, in 90° hip and knee flexion, with a black roll to control the position and orientation of the shoulder girdle (Fig. 3). The participants were instructed to « Keep your thorax in contact with the blackroll at all times. Flex and extend your spine while keeping your feet on the ground. Initiate the movement with your pelvis. Do not move your feet."

This setup enabled unrestricted spinal and pelvic movement with a fixated shoulder girdle, thus minimizing upper body movement as envisioned for the dynamic office chair. The free sitting trial consisted of six cycles of maximal spinal flexion and extension. The participants were asked to maintain contact between their shoulder girdle and the black roll during the whole trial. The free sitting trial was repeated three times.