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Seat pan and backrest pressure distribution while sitting in office chairs

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A B S T R A C T

Nowadays, an increasing amount of time is spent seated, especially in office environments, where sitting comfort and support are increasingly important due to the prevalence of musculoskeletal disorders. The aim of this study was to develop a methodology for chair-specific sensor mat calibration, to evaluate the interconnections between specific pressure parameters and to establish those that are most meaningful and significant in order to differentiate pressure distribution measures between office chairs.

The shape of the exponential calibration function was highly influenced by the material properties and geometry of the office chairs, and therefore a chair-specific calibration proved to be essential. High correlations were observed between the eight analysed pressure parameters, whereby the pressure parameters could be reduced to a set of four and three parameters for the seat pan and the backrest respectively. In order to find significant differences between office chairs, gradient parameters should be analysed for the seat pan, whereas for the backrest almost all parameters are suitable.

1. Introduction

Nowadays, working in an office chair is ubiquitous. Indeed, approximately three-quarters of all employees in industrialised countries now have jobs that require working in a sitting position (Reinecke et al., 2002; Treaster and Marras, 1987). Prolonged seated working presents several problems for physical health as it increases the risk of suffering musculoskeletal disorders in the back, neck, shoulders, arms and legs (Naqvi, 1994; Winkel and Jorgensen, 1986). Despite the general opinion that extended periods of sitting can lead to back complaints, current literature suggests that a sedentary lifestyle by itself does not increase the risk of LBP (Hartvigsen et al., 2000; Kwon et al., 2011; Lis et al., 2007; Roffey et al., 2010). According to May and Lomas (2010) not finding a connection between sitting and LBP is caused by the insidious nature of back pain, since LBP is a very multifactorial condition that can hardly be localised precisely. Recent research also puts the risk of sedentary lifestyle in another perspective. According to Commissaris et al. (2014), physical inactivity is associated with cardiovascular disorders, type II diabetes, depression, obesity as well as with some forms of cancer and 3.2 million people die a premature death due to an inactive work style. Indeed, every two hours per day increment in sitting time at work increases the risk of obesity by 5% and the risk of diabetes by 7% in female workers (Hu et al., 2003). Therefore, research in the field of the office environment is critically important.

Several studies have analysed office chairs and different sitting positions by means of electromyography (Andersson and Ortengren, 1974; Gregory et al., 2006; Kingma and van Dieen, 2009; van Dieen et al., 2001), magnet resonance imaging (Baumgartner et al., 2012; Fryer et al., 2010; Zemp et al., 2013), leg/foot swelling evaluation (Bendix et al., 1985; Chester et al., 2002), motion tracking systems (Ellegast et al., 2012; Kingma and van Dieen, 2009; van Dieen et al., 2001), spinal shrinkage (Kingma and van Dieen, 2009; van Dieen et al., 2001), X-ray (Åkerblom, 1948; Schoberth and Hegemann, 1962), intra-disc pressure (Andersson and Ortengren, 1974; Rohlmann et al., 2001), subjective comfort/discomfort ratings (Carcone and Keir, 2007; Gregory et al., 2006; Groenesteijn et al., 2009), and pressure distribution measurements of the seat pan and the backrest (Carcone and Keir, 2007; Groenesteijn et al., 2009). However, there is still a lack of knowledge concerning the optimal office chair properties (surface, cushion properties, geometry, etc.) in order to prevent or reduce work-related musculoskeletal disorders caused by extended sitting periods. Pressure distribution measurements of the seat pan and the backrest are one of the most common objective methods to

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analyse or compare different chairs or sitting positions (Zemp et al., 2015) since pressure measuring systems are relatively cheap and easily applicable. For example Groenesteijn et al. (2009) evaluated a traditional office chair as well as a redesign of the same chair (more dense, 1 cm thicker and slightly more basin-shaped seat pan cushion) and analysed, among other things, the influence on the seat pan's peak pressure. They found no significant difference in the peak pressure between the two chairs. On the other hand, Carcone and Keir (2007) showed that the addition of a supplementary backrest to a standard chair is able to reduce peak and average pressure on the back in an upright posture by 35% and 20% respectively. However, according to the authors, further delineation between different objective seating parameters and comfort is still required in order to provide effective methods for understanding, reducing and preventing low back pain.

Stinson et al. (2003) analysed the pressure distribution of the seat pan of 63 subjects during sitting with different backrest reclination angles (0°, 10°, 20° and 30°). The study found that a 10° or 20° chair-recline did not significantly reduce the mean pressure, whereas a reclination of 30° had a significant effect. However, reclination angle had no significant impact on maximum pressure. Vos et al. (2006) assessed the pressure distribution of the seat pan of 24 subjects in order to investigate the influence of postural (trunk-thigh angle and use of armrest) and chair design differences (twelve office chairs). The authors concluded that chair design has the greatest effect on the pressure distribution on the seat pan, followed by participant effects and finally postural treatments (including different backrest angles and use of armrests). Pressure mats have also often been used to establish the interactions between seats and their users, since several studies indicate that pressure measures seem to be a highly associated and objective method for the quantification of subjective comfort/discomfort (De Looze et al., 2003; Mergl, 2006; Verver, 2004). However, the relationship between subjective comfort/discomfort and objective pressure measurements while sitting in office chairs remains to be demonstrated (Zemp et al., 2015).

There are currently several measurement systems for assessing the contact pressure between a chair and its user by means of resistive and capacitive sensor mats (Giacomozzi, 2010). Hochmann et al. (2002) evaluated four different modern seat pressure mapping systems (FSA, Xsensor, Tekscan ClinSeat, Novel Pliance) concerning, in particular, their accuracy, linearity and hysteresis. The relationship between the measured force (integration of all sensors) and the applied force (in this case an applicator with a diameter of 12 mm) did not increase strictly linearly for the Tekscan ClinSeat sensor mat, whereas the Novel Pliance mat showed almost a perfect linear characteristic curve. Furthermore, the study also revealed that the Novel Pliance sensor mat had the greatest accuracy out of the four analysed measuring systems. In terms of hysteresis, the systems of FSA and Novel showed almost no difference between the loading and unloading phase. The hysteresis errors were lower than 2% and 5% for the FSA and the Novel system, respectively. Further important source of errors – but not investigated in the described studies – are the bending effects of the pressure mat, which have also to be taken into account while interpreting the data of pressure mapping systems.

In order to be able to compare different office chairs or sitting positions by using pressure measurements, suitable outcome parameters have to be determined. Since many different parameters are used throughout the literature, there is little or no agreement in choosing the most appropriate ones. For example Carcone and Keir (2007) analysed the mean and peak pressure, the contact area as well as the centre of pressure for the office chair's seat pan and backrest. Others have examined parameters of pressure distribution such as the mass/force (Gutierrez et al., 2004), the standard deviation of the pressure map (Gil-Agudo et al., 2009) and the peak, the circular as well as the transverse pressure gradients (Aissaoui et al., 2001; Hobson, 1992; Moes, 2007). Other studies looked at different regions of the human-chair contact area individually and analysed several pressure parameters for every segment (Zenk et al., 2012). In order to account for variability in this parameter, Vos et al. (2006) used principle component analysis to reduce the number of parameter domains and found that the mean and the peak seat pan pressure could be represented as a single parameter, which was able to explain 76.2% of the total variance. However, no studies exist that have examined the relationship between more than only the peak and mean pressures, as well as the different parameters' potential for evaluating and identifying different office chairs and sitting positions. Hochmann et al. (2002) emphasised that pressure mats are very sensitive to differences in the surface area properties of the product analysed. It would therefore appear to be important that sensor mats are calibrated for the corresponding surface. If the pressure values are not calibrated for a specific office chair, the calculated pressure parameters will be distorted. By calibrating the pressure distribution values, all pressure parameters, including parameters that describe the shape of the pressure distribution (e.g. pressure gradient), can be corrected.

The primary aim of this study was therefore to develop a chair-specific sensor mat calibration methodology in order to be able to compare the pressure distribution of different office chairs. Secondly, in order to allow effective and efficient analysis of sitting behaviour, we aimed to understand the inter-relationships and correlations between different pressure parameters during sitting. The final aim was to identify appropriate pressure parameters with the intention of being able to analyse and compare various office chairs appropriately.

2. Materials and methods

2.1. Chair-specific sensor mat calibration

As pressure mats are known to be influenced by the surface area, material properties as well as the geometry of the analysed product, the sensor mat of each seat pan was calibrated prior to subject measurements. Here, the pressure distribution of the buttocks of a sitting calibration dummy loaded at the centre of mass of the unloaded buttocks with different weights was analysed (5 s, 10 Hz) for each office chair three times (Fig. 1). The buttocks were modified with modelling clay and foam material as well as clothed with shorts in order to imitate the pressure mat response of a human buttock as closely as possible. The total weights of the calibration dummy were 4.40 kg, 6.41 kg, 9.30 kg, 14.20 kg, 24.30 kg and 44.20 kg in order to calibrate the pressure sensor mat for the full pressure range of our subject measurements. Attention was paid to ensure that the contact surface of the calibration dummy remained within the sensitive area of the pressure mat. The relationship between the mean pressure values was then assessed using the pressure on the mat measured using the calibration dummy with the different additional weights (p_{mat}) and the theoretical pressure value calculated using the known weights of the calibration dummy divided by the assessed contact area (p_{calib}). In order to determine each chair's pressure correction factor, f_{corr}, based on the assessed pressure (p_{mat}), f_{corr} was defined as p_{calib} divided by p_{mat}. Finally, x–y plots of the calibration measurements (p_{mat} against f_{corr}) clearly indicated an exponential function through the values of f_{corr} and p_{mat} with three parameters a_1, a_2 and a_3 (1). This function was then used to correct the pressure values of the seat pan mat at each time point.