JESK J Ergon Soc Korea 2014; 33(4): 255-265
http://dx.doi.org/10.5143/JESK.2014.33.4.255
http://jesk.or.kr eISSN:2093-8462

Special Topic

Evaluation of the Functional and Non-functional Seat Sponge Effect in Sitting Chairs

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Received : February 12, 2014
Revised : May 26, 2014
Accepted : July 18, 2014

Objective: The purpose of this study was to evaluate comfort levels of functional and non-functional chairs using subjective comfort rating, interface pressure measurement, muscle activity measurement, and skin temperature measurement.

Background: Chairs are used for a prolonged period of time for sitting in many places such as the office, at university, at school, in industry, and so on. Almost all people use chairs in their everyday life. The functional properties of the chair are associated with comfort.

Method: The subjective evaluation contains questions regarding chair comfort which can be rated with five point scale. The body-seat interface pressure was measured using a pressure mat system. The symmetry of sitting was measured using electromyography. The change in body part (thigh and buttock) temperature before and after sitting on a chair was measured with an infrared camera.

Results: Participants rated significantly (p < 0.05) higher comfort scores for the functional chair in relation to the buttock and thigh region. Also, the participants felt a better cushion effect in the functional chair. When using the functional chair, lower interface pressure, better thermal comfort, and better symmetry of erector spinae muscle activity were observed.

Conclusion: Overall, interface pressure measurement, muscle activity measurement, thermal imaging and subjective comfort score results showed that the functional chair was more comfortable than the non-functional chair.

Application: The adopted methodologies could be used to measure the seating comfort of train seats.

Keywords: Chair comfort, Interface pressure, Thermal imaging, Electromyography

1. Introduction

Chairs have been in existence since at least the Early Dynastic Period of Egypt. Earlier, they were much shorter than present day chairs and sometimes even only 25cm high. During the Early Dynastic Period of Egypt, chairs were made of carved wood, covered with cloth or leather (Killen, 1980). Almost all people have used chairs in their everyday life. Chairs are used for a prolonged period of time for sitting in offices, in manufacturing industries, in schools and so on. It is noted that chairs are an essential part of any learning environment (Thariq et al., 2010). In South Korea, there are on average 2,057 working hours annually. When compared to other OECD countries, South Korea has longer working hours. The discomfort of using a chair increases proportionally with extended periods of sitting (Michel and Helander, 1994; Beach et al., 2005).

The prolonged period of interface between the chair and the body surface increases the load in the buttock, thigh, and back regions. Poorly designed chairs create discomfort for the users. Also, prolonged periods of discomfort affect work efficiency and cause musculoskeletal disorders or symptoms (Knave et al., 1985; Fujimaki and Mitsuya, 2002). The comfort of a chair is greatly influenced by its design and material features. In particular, office chair comfort is greatly influenced by its cushion properties in the seat pan (Ebe and Griffin, 2001; De Looze et al., 2003; Park et al., 2011).

The requirements of comfort and functionality of office chairs is continuously increasing. Sitting comfort or discomfort has been examined from a number of different perspectives. There are many methods available to study chair comfort, namely postural analysis, physical compatibility testing, subjective rating, physiological evaluation, interface pressure measurement, biomechanical evaluation, body temperature evaluation, and so on (Kyung and Nussbaum, 2008; Ebe and Griffin, 2001; Jones, 1998; Salewytsch and Callagha, 1999).

Body pressure distribution is a one of the most important parameters for chair sitting comfort. Measurement of body pressure plays a vital role in many industries such as the medical, rehabilitation, and automobile industries, etc. (Qin et al., 2014). An extended period of sitting results in a higher risk of back problems, numbness, and discomfort in the buttocks due to surface pressure under the thighs (Ebe and Griffin, 2001). Pressure data are regarded as an objective measure, having a clear association with subjective ratings (de Looze et al., 2003). Previous studies have shown that preferred pressure levels are different between body parts as well as between anthropometric groups and chair cushion properties (Dunk and Callaghan, 2005; Kamijo et al., 1982; Kolich, 2004; Oudenhuijzen et al., 2003; Park, 1997), and that there are associations between interface pressure and sitting discomfort. De Looze et al. (2003) noted that measurements of pressure at the back rest and/or seat pan area could be compared with comfort or discomfort ratings.

Thermal comfort is an important aspect to be considered in the ergonomic evaluation of the office chair, which is associated with human physiological reactions. The human body generates energy and exchanges it with the surroundings. Therefore, maintaining core temperature of the body is very important. Body part temperature, especially in the thigh, buttock and back regions, mainly influences the thermal comfort while sitting for an extended period of time. The infrared thermal imaging device is the most powerful detector of problems that affect a person's physiology (Jones, 1998). Thermal imaging is a non-contact skin temperature measurement technique. Park et al. (1997) used a thermal imaging device for the evaluation of the massage chair effect on the human body. They suggested that thermal imaging can be used as a parameter to measure comfort of the chair.

There have not been many studies establishing any measure of muscle activity and rating of comfort or discomfort of chairs. Lee et al. (1988) highlighted that increased back and shoulder muscle activity over time was significantly related to increased discomfort over time. The correlation between muscle activity and comfort or discomfort variations were studied across seated conditions (Udo et al., 1999; Salewytsch and Callagha, 1999). In the authors' knowledge there have been no studies on muscle activity and rating of comfort while sitting on chairs (with different cushion types) for an extended period of time. Most studies have quantified subjective responses in seats, however, have included only a discomfort scale (Hsu and Wang, 2003; Jung and Choe, 1996; LeBlanc et al., 2003). Looze et al. (2003) found that interface pressure measurement was most clearly associated with the subjective rating.

This study evaluates the comfort levels of functional and non-functional chairs using subjective and objective measures. The objective evaluation was performed by measuring: interface pressure using a pressure mat; skin temperature using a thermal imaging camera; and erector spinae muscle activity for symmetry of sitting using electromyography (EMG).

2. Method

2.1 Subjects

This study considered ten subjects with sound health and with no history of back pain. The subjects considered were right hand and right food dominant; their demographic information is given in Table 1.

Table 1. Participants' demographic information

n = 10	Average	Standard deviation
Height (cm)	175.80	1.48
Age (years)	31.00	5.92
Weight (kg)	78.60	7.33
Sitting eye height (cm)	117.54	18.54
Sitting popliteal height (cm)	42.11	1.45

2.2 Equipment

The objective measurements considered were interface pressure, body temperature, and erector spinae muscle activity. The equipment used in this study is given in Table 2. The interface pressure was measured using a body pressure mat system, or BPMS (maximum sensing elements: 3,000 numbers; sensor size on one cell: 20 × 20mm; maximum size of sensing area: 64cm × 2,000cm) produced in South Korea. Body temperature was measured using an infrared thermal imaging device (CS-TEP, China). For measuring sitting symmetry, erector spinae muscle activities were measured using an EMG (PolyG-A, South Korea) system. To measure EMG signals, pairs of disposable Ag/AgCl surface electrodes with a sticky gel were affixed to the skin over the muscle. The skin was abraded and cleaned with alcohol before placement of the electrodes using standard placement procedures (Konrad, 2005). For the erector spinae muscles, the electrodes were placed bilaterally at the level of spinous process of L3 vertebrae, approximately 5cm from the midline. The reference electrode was placed over the superior aspect of the left iliac crest. The inter electrode distance maintained was 2cm.

Table 2. Experimental equipment

Body pressure (BPMS, South Korea)	Thermal image (CS-TEP, China)	EMG (PolyG-A, South Korea)
		

Two chairs (functional and non-functional chair) were used in this study (Figure 1), which were produced in South Korea. The seat pans of the both chairs were made with a soft cushion and the cushion dimensions (width x length x height) were 500 x 510 x 70, respectively in millimetres. The cushion was made of polyurethane foam sponge. Even though both chair cushions were made with the same material, they were different in cushion type. To reduce body part temperature and increase the pressure distribution characteristics, the functional chair's cushion was made with air cells as shown in Figure 1 (b). However, the non-functional chair cushion did not have any cells (made as a single piece), as shown in Figure 1 (a).

(a) (b)

Figure 1. Chairs considered (a: non-functional chair; b: functional chair)

2.3 Procedures

Before the start of the experiment, the purpose and procedure of the experiment were explained to the participants. The participants continuously sat on each chair for 30 min. To avoid fatigue due to an extended period of sitting, a 5min break was given between tests and the Latin square design was used to reduce carry-over effects (Min et al., 2012). As per ergonomic chair requirements, the seat pan-backrest angle needed to be greater than or equal to 90 degrees. In general ergonomics practice it is best to have the backrest at a 90-100 degree angle to encourage upright sitting (Ergonomic Self-Assessment Checklist, www.newcastle.edu.au). And also it is obvious that increasing the angle between the trunk and thighs decreases the stress and load placed on the spine (Rohlmann et al., 2002; Ferguson and Marras, 2011). Therefore, we maintained 100 degrees as a backrest

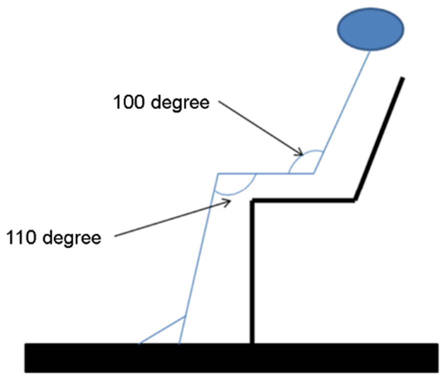

Figure 2. Sitting posture of participants and inclinations of their body parts

inclination angle for all the participants. In order to keep the knee joints below the hip joints and also keep the ankle joints in front of the knees, all participants were asked to maintain a 110 degree knee-thigh angle (which they felt comfortable with) (Figure 2). They were asked to ensure the whole back was in contact with the backrest. The participants wore comfortable pajamas for the experiment. Thermal imaging was conducted using an infrared camera at two different times: before going to sit on a chair and after 30 min of sitting. The thermal image was assessed in the buttock and thigh region. The EMG signals were continuously recorded for 30 min while the participants sat on the chairs. Subjective comfort ratings were provided by the participants for each chair. Various questions regarding the chair, assessed using a five point scale, were used to gauge comfort levels. The experiments were conducted in controlled room conditions with temperature 24.0 ± 2.0℃, humidity 55.0 ± 5.0% and intensity of illumination 25.0 ± 5.0lx.

2.4 Analysis

2.4.1 Pressure distribution

To measure the interface pressure (buttock/seat surface and thigh/seat surface) a static test was performed with a pressure mat system. The pressure distribution in the seat pan region was measured. The seat pan region was divided into four quarters: the right thigh, left thigh, right buttock, and left buttock (Figure 3). The interface pressure ratio was calculated using Eq. 1.

$$\text{Pressure ratio} = \frac{\text{pressure}_{\text{area } i}}{\text{pressure}_{\text{total area}}} \qquad (1)$$

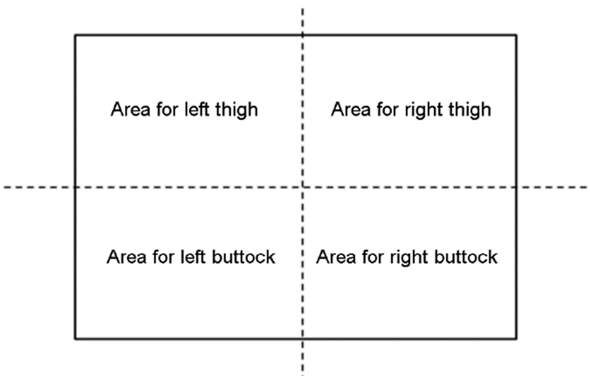

Figure 3. Division of body parts for interface pressure measurement

2.4.2 Thermal image

The thermal images were taken from the participants before and after sitting on the chairs. The captured images were downloaded to a personal computer. Then, using DALI software, the thermal images were analysed for body part temperature (left and right side thigh, left and right side buttock). The change in temperature before and after sitting on the chair was calculated using Eq. 2.

$$TM = |TM_a - TM_b| \qquad (2)$$

TM : change in temperature before and after sitting on the chair
TM_a: body part temperature before sitting
TM_b: body part temperature after sitting

2.4.3 Erector spinal muscle activity symmetry

The symmetry of sitting on a chair was measured using right and left side erector spinae muscle activities. The recorded EMG signals were normalised and root mean square (RMS) values were calculated. The symmetry of erector spinae muscle activity was then calculated with Eq. 3. The symmetry of sitting can be measured using the difference in the erector spinae muscle activities.

$$RMS_{symmetry} = |RMS_{Nor.(right)} - RMS_{Nor.(left)}| \quad (3)$$

$RMS_{symmetry}$: symmetry
$RMS_{Nor.(right)}$: normalised RMS value of right side erector spinae muscles
$RMS_{Nor.(left)}$: normalised RMS value of left side erector spinae muscles

2.4.4 Subjective comfort evaluation

Sitting comfort was evaluated using subjective comfort rating. The rating was provided by the participants for each chair. The subjective comfort questionnaire requested subjects' demography information. It also included various questions about the chair, namely on chair cushion comfort under the thigh, and for the inner thigh, and buttocks; back support; and overall feeling level. The subjective rating included a five point scale, in which a higher score represents higher comfort (1: highly uncomfortable, 2: mildly uncomfortable, 3: neutral, 4: mildly comfortable, 5: highly comfortable).

3. Results

Pairwise T-tests were used to investigate the significance of the interface pressure ratio, body part temperature, erector spinae muscle activity symmetry and subjective discomfort ratings for the functional chair and non-functional chair (Table 3). The confidence level for statistical significance was set at alpha equal to 0.05. The subjective comfort rating was significantly greater ($p < 0.05$) for the functional chair than the non-functional chair in the buttock and back region. Also, the participants rated significantly ($p < 0.05$) higher values for the functional chair's cushioning effect than for the non-functional chair's cushioning effect. The results of skin temperature measured using thermal images showed that the temperature in the right and left side buttock regions were significantly ($p < 0.05$) increased after sitting in the non-functional chair for 30min. The difference between the left and right side erector spinae muscle RMS values showed significantly ($p < 0.05$) greater muscle activity when sitting in the non-functional chair for 30min. The body pressure ratio was significantly ($p < 0.05$) greater in the left and the right side buttock region for the non-functional chair.

Table 3. Paired T-tests for objective and subjective comfort

		Functional	Non-functional	*p*-value
Subjective rating	Under the thigh	3.8±1.14	4.5±0.85	0.19a
	Inner thigh	4.2±1.14	4.5±0.71	0.46a
	Buttock	4.1±1.10	3.1±1.23	0.02**

Table 3. Paired T-tests for objective and subjective comfort (Continued)

		Functional	Non-functional	*p*-value
Subjective rating	Back	3.8±1.18	3.0±1.32	0.08*
	The overall feeling	3.8±1.23	4.0±1.15	0.75a
	Cushion	2.4±0.52	1.4±0.52	0.00***
Thermal image	RT-Buttock	0.82±0.56	1.12±0.14	0.04**
	RT-Thigh	1.26±0.33	1.37±0.30	0.86a
	LT-Buttock	0.73±0.73	1.38±0.17	0.03**
	LT-Thigh	1.73±0.17	1.15±0.24	0.53a
Erector spinae muscle symmetry		4.6±4.56	5.50±4.51	0.07*
Pressure ratio	RT-Buttock	0.96±0.64	1.89±0.18	0.02**
	RT-Thigh	1.98±0.02	1.9±0.2	0.22a
	LT-Buttock	0.94±0.63	1.9±0.18	0.04**
	LT-Thigh	1.77±0.42	1.88±0.22	0.52a

*: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$, a: non-significant

4. Discussion

This study evaluated the comfort levels of functional and non-functional chairs by measuring interface pressure, body part temperature, and erector spinae muscle activities. Chair comfort was also evaluated using subjective comfort questionnaires. The significant results are summarised in Table 4.

Table 4. Summarised results

		Comparison	*p*-value
Subjective rating	Buttock	functional > non-functional	0.02**
	Back	functional > non-functional	0.08*
	Cushion	functional > non-functional	0.00***
Thermal image	RT-Buttock	functional < non-functional	0.04**
	LT-Buttock	functional < non-functional	0.03**
Erector spinal muscle symmetry		functional < non-functional	0.07*
Pressure ratio	RT-Buttock	functional < non-functional	0.02**
	LT-Buttock	functional < non-functional	0.04**

*: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$

The participants rated significantly higher ($p < 0.05$) comfort for the functional chair in the buttock and thigh region. Also, the participants significantly ($p < 0.05$) felt better cushion effect from the functional chair than from the non-functional chair. Looze et al. (2003) found that interface pressure was most clearly associated with the subjective rating. The interface pressure ratio was significantly (p < 0.05) greater for the non-functional chair in both the left and right side buttock. Higher interface pressure in the buttock region causes discomfort. Ebe and Griffin (2001) stated that less total pressure in the buttock region (ischial bones) was judged to be more comfortable. Also, they concluded that the pressure beneath the ischial bones may reflect two comfort factors: the bottoming feeling and the foam hardness feeling. Brienza et al. (2001) indicated that higher interface pressure is associated with a higher incidence of sitting-acquired pressure ulcers.

Results on the symmetry of the erector spinae showed significantly (p < 0.05) increased muscle activity when setting in the non-functional chair compared with the functional chair. The increased muscle activity over time would cause discomfort for the participants. Lee et al. (1988) reported that increased back and shoulder muscle activity over time was significantly related to increased discomfort over time. Kim and Kim (2013) evaluated the effectiveness of women's pelvic correction boards. They found sitting on a correction board to be more effective in decreasing pelvic asymmetry by narrowing the pelvic region tightly. With this in view, we could say that the functional chair used in this study could narrow the pelvic region more tightly compared with the non-functional chair. However, further study is required to confirm this effect.

The change in skin temperature before and after 30min of sitting showed that the temperature in the right and left side buttock regions were significantly (p < 0.05) increased and also greater with use of the non-functional chair than with use of the functional chair. These results showed that the functional chair provided better thermal comfort for the participants during an extended period of sitting. Candas (2005) stated that being thermally neutral guarantees comfort, and also mentioned that not being thermally neutral leads to discomfort. Lan et al. (2008) found the existence of gender differences in thermal comfort. However, the present study did not considered gender difference and its association with thermal comfort. Future studies could consider gender difference and its association with thermal comfort while sitting on chairs for a prolonged period of time. Also further study could consider subjects doing office tasks, since present study considered subjects sat on each seat without doing anything.

5. Conclusion

This study evaluated the comfort levels of functional and non-functional chairs using subjective and objective measures. The subjective comfort rating confirmed that the functional chair provided better comfort to the participants than the non-functional chair. Also, the functional chair provided better cushion effects. The interface pressure was higher when sitting on the non-functional chair for an extended period of time, which caused discomfort in the participants' buttock region. The clear association between objective pressure measurement and subjective rating was observed. Better symmetry of erector spinae muscle activity was observed when using the functional chair. Also, better thermal comfort was provided by the functional chair. The adopted methodologies could be used to measure the seating comfort of train seats.

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