An investigation into the immediate effects on comfort, productivity and posture of the Bambach™ saddle seat and a standard office chair

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Abstract. *Background:* This study was prompted by the prevalence of back injury and pain in the working population, particularly amongst workers who are increasingly exposed to sedentary work in industrialised countries, and the corresponding limited evidence regarding the effectiveness of seating designs currently used in the workplace.
Objective: The purpose of this study was to investigate the differences in comfort, productivity, and posture between the Bambach^{TM} saddle seat and a standard office chair (two chair designs used within the workplace today).
Method: A single system, multiple-baseline research design across a sample of four subjects was used. A withdrawal $A_1B_1A_2B_2$ design was utilised, with the ordering of the sequence varying with each subject. "A" represented the standard office chair, and "B" the Bambach^{TM} saddle seat.
Results: Discomfort ratings tended to increase over time regardless of the seat being used. However, while the saddle seat provided reduced levels of lower back discomfort, it demonstrated higher discomfort in the lower limbs, particularly the hips and buttocks. There were no significant differences identified in productivity between the two chairs. The saddle seat consistently promoted a greater trunk-to-thigh angle for all subjects, a position associated with optimum sitting posture.
Conclusion: This study has implications for the treatment of low back injury and pain at work, as well as other daily activities that involve prolonged static sitting, such as those incorporated in self maintenance, leisure and rest activities. This study provides health professionals with a systematic investigation of the immediate effects of using both the Bambach^{TM} saddle seat and standard office chair in sitting. The findings of this study should be considered in future research.

Keywords: Seating, comfort, low back pain, standard office chair, saddle seat, single system research design

1. Introduction

Low back injury and pain is a leading cause of workers' compensation claims [33] and has an indirect cost on individual productivity. It is one of the most common reasons for missed work and decreased efficiency worldwide [34]. Low back pain is one of the most debilitating disorders of the human musculoskeletal system.

The sitting position is one of the most thoroughly studied occupational postures today because of its strong association with low back pain [9]. Poorly designed seating and inadequate education regarding

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healthy sitting postures are frequent and definitive occupational hazards resulting in inefficient operation, musculoskeletal disorders, decreased productivity and discomfort [5,7,10].

With increasing exposure to sedentary work in industrialised countries [19], implementation of interventions aimed at reducing workplace injuries associated with sedentary work is considered a priority. Within the workplace, an approach that combines the education of workers with occupational and environmental interventions focused on ergonomic principles is a priority for health professionals working to reduce the economic and social burden of low back pain.

There is a common view that the optimal sitting position is one that maintains the natural curves of the spine, as seen in standing [1,22,23]. Despite agreement of what constitutes optimum sitting posture and what is necessary to maintain spinal health, there is inconsistency about the type of chair design that achieves it.

A variety of conventional and ergonomic chair designs have evolved over the years in response to the changing views of what constitutes the ideal sitting posture. Chair designs have developed in an effort to both improve comfort and productivity, and decrease the impact of back injuries and low back pain for individuals at home and in the workplace.

Based on the conventional seating model, a standard office chair generally encourages a 90° angle between the trunk and thigh. Some research indicates that the standard office chair promotes an unstable position that places potential strain on the lumbar spine [11]. Ergonomists generally agree that the standard office chair, while useful to relieve the fatigue of standing, can contribute to the development of low back pain, as it promotes a kyphotic sitting posture that results in an increase in intradiscal pressure, increased reliance on the muscles of the back and an unstable work position [7, 11]. Within the literature there is limited evidence of an existing relationship between the standard office chair and its ability to provide comfort and/or maintain the productivity of the sitter. In fact, it is assumed, although not substantiated, that because the chair has demonstrated to be associated with low back pain, it is also associated with discomfort and reduced productivity.

The forward sloping seat and the kneeling chair both claim to provide the optimal sitting posture from an ergonomic perspective; however, research indicates that this is not without a cost [11,35]. While the forward sloping seat has been shown to preserve the lumbar lordosis, the seat surface destabilises the body, causing it to slip forward and increase the leg muscle activity to counteract such movement [11,23]. As a result, the individual may experience hydrostatic pressure in the legs in order to maintain the seated position [11]. Research also indicates that the effect of the forward sloping seat on the posture of the spine (lumbar lordosis) is to some degree counteracted by the reduced use of the backrest; resulting in increased recruitment of the muscles of the back and eventual muscle fatigue [5,7]. Research into the kneeling chair has also identified a number of problems including the following: the load on the knees and lower legs is often too great; loss of desirable plantar contact of the feet with the floor; the possibility of eventual shortening of the hamstrings; sitting becoming uncomfortable [11,35]; and increased back muscle activity [5]. The problems associated with each chair design vary, however these problems prevent either of these chairs from being 'optimal' in a seating context.

The saddle seat is another form of 'ergonomic seating' that aims to provide the user with optimal sitting posture, and research to date indicates that it is effective in its aim; however, additional research is recommended to support these initial findings [11]. The saddle seat is also claimed to be a viable alternative to the conventional office seat; however, there is no published research, other than that carried out by the developer of the chair [11], to support this. Further, there is no evidence, other than case studies [3], of a relationship between the saddle seat and its ability to provide comfort and/or maintain the productivity of the sitter, which is important for both workers and the workplace.

A comparison study between conventional seating and ergonomic seating, particularly an investigation in regard to the effects on comfort, productivity and posture, between the standard office chair and the Bambach^{TM} saddle seat was conducted, as there was little existing research in regard to the impact of these two forms of seating intervention on the user.

The null hypothesis addressed in this study was:

> There is no difference in the immediate effects on comfort, productivity, and posture on the Bambach^{TM} saddle seat in comparison with a standard office chair.

2. Methods

2.1. Design

A single-system research design was used for this study. As this is an approach that is not commonly used,

Table 1
Subject details and assigned design sequence

Subject	Gender	Age (yrs)	Height	Assigned Design Sequence
1	Male	26	188 cm	$A_1B_1A_2B_2$
2	Female	21	158 cm	$A_1B_1B_2A_2$
3	Female	21	174 cm	$B_1A_1B_2A_2$
4	Female	21	161 cm	$B_1A_1A_2B_2$

a brief description is provided. A single-system research design involves "studying a single individual or small group (system) by taking repeated measurements of one or more dependent variables and systematically applying, and sometimes, withdrawing or varying the independent variable" [24, p. 45]. Single-system studies are also referred to as "n-of-1", small "n" and single subject studies.

Single-system designs allow for the intensive study of individual subjects and provide a viable method of documenting intervention results [15]. Single-system research is considered the "method of choice" in situations where health professionals attempt to evaluate therapeutic change in individuals [24] and "represent a powerful decision making tool for clinical research" [36, p. 1]. Further, the information obtained about how individuals respond to selected interventions (in this case the saddle seat) is considered more useful than that obtained from the "mythical average" client response in a group study [15]. Subjects act their own controls (i.e. by comparing performance in baseline or control phases (described as 'A') with intervention ('B')), rather than comparing the average performance of intervention and control groups as would occur in a conventional experimental design. It is not necessary, therefore to "normalise" performance between subjects, as each person's performance is only compared to him/herself.

There are also data analysis procedures specific to single-system designs described in Section 2.8.

This study used a single-system, multiple-baseline research design across subjects with repeated measures. A withdrawal ABAB design was selected where 'A' phases were the baseline or control when the standard office chair was used, and 'B' phases were the intervention using the Bambach^{TM} saddle seat. Multiple-baseline studies are more powerful than those with only a single 'A' phase because they are able to control for threats to internal validity, and include replication of findings across at least three subjects [2,25,36]. A withdrawal design using repeated baseline and intervention phases provides repeated measures in which the target behaviours continue to be recorded, improving the validity of the study by controlling for history and maturation within subjects [2,36]. This research design, using "multiple N-of-1's (subjects), conducted on the same intervention with the same outcomes" can be considered the equivalent of a multiple crossover trial [26].

The sequencing of phases varied with each subject to account for the possible effects of history and carryover. Subjects' assigned sequence is presented in Table 1. Baseline (A_1) and intervention (B_1) phases were paired and occurred on the same day, with the second phases occurring seven days (one week) later (Day 2: A_2B_2) for each subject.

Each phase (A or B) of the study consisted of 30 minutes data collection, and consisted of six 5-minute sub-phases. This structure allowed for adequate rest-breaks for subjects and enabled relevant data collection and recording.

Ethical approval for the study was obtained from the relevant Human Research Ethics Committee, and all subjects provided their informed consent prior to their involvement.

2.2. Chairs/seating

2.2.1. Standard office chair

The "standard office chair" used in this study is similar to the type of chair used in many office environments, and met the Australian Standard for seating [30]. It was adjustable in seat height, seat angle, backrest height and backrest angle, and had a five star castor base. The chair used was described as a 'low back chair' (see Fig. 1). This type of chair is representative of the traditional style of seating commonly used, and therefore provides the control against which the new form of seating (i.e. saddle seat) is compared.

2.2.2. Bambach^{TM} saddle seat

The Bambach^{TM} saddle seat is an ergonomic seat shaped like a saddle. It is upholstered and mounted on a gas cylinder stem with a five star castor base. In this study, the standard size Bambach^{TM} saddle seat with backrest was used (see Fig. 2). The seat was adjustable in seat height, seat angle, backrest height, and backrest angle.

Minimum and Maximum Standard Office Chair Adjustments		
Seat Adjustment	**Minimum Adjustment**	**Maximum Adjustment**
Seat Height	32cm	43.5cm
Seat Angle	90° (horizontal)	+105° (tilt downward/forward)
Back Rest Height	46cm	55cm
Back Rest Angle	90°	115°

Fig. 1. Standard office chair.

Minimum and Maximum Bambach™ Saddle Seat Adjustments		
Seat Adjustment	**Minimum Adjustment**	**Maximum Adjustment**
Seat Height	37cm	55cm
Seat Angle	-105° (tilt upward/backward)	+105° (tilt downward/forward)
Back Rest Height	59cm	68cm
Back Rest Angle	90°	115°

Fig. 2. Bambach^{TM} saddle seat.

2.3. Subjects

Four volunteer subjects were recruited to the study – three females and one male aged between 21 and 26 years (mean: 22.25 years). All subjects were university students in their fourth year of study (occupational therapy) and reported sitting "most of the time" in the preceding week. General inclusion criteria were: (i) no previous history of musculoskeletal pain or disorder that affected sitting or typing performance; (ii) the ability to type; (iii) availability to participate in the study on two separate occasions (approx. $1\,{}^1\!/_2$ to 2 hours each

Table 2
Details of workstation set-up for each subject

	Subject 1		Subject 2		Subject 3		Subject 4	
	Standard	Saddle	Standard	Saddle	Standard	Saddle	Standard	Saddle
Seat Height	43.5 cm*	43.5 cm	43.5 cm*	43.5 cm	43 cm	38 cm	38.5 cm	37 cm*
Seat Angle	90°*	+105°*	90°*	+105°*	90°*	+105°*	90°*	+105°*
Back rest Height	54.4 cm	68 cm*	55 cm	66 cm	54 cm	66 cm	54 cm	66 cm
Back rest Angle	115°*	105°	90°*	105°	105°	105°	105°	105°
Desk Height	70 cm		70 cm		73 cm		73 cm	
Screen Height	127 cm		127 cm		89 cm		89 cm	
Keyboard	flat		flat		flat		flat	

N.B. *indicates min/max chair adjustment; +105° indicates that the seat was tilted forward/downward.

time); and (iv) proficiency in written and spoken English. Subject details are summarised in Table 1. No further information was obtained regarding other anthropometric measures, such as trunk and leg length. As these students were in their final year of an occupational therapy program, they had previous knowledge of basic workstation set-up and all had similar levels of knowledge regarding ergonomics, correct posture and so on.

2.4. *Workstation set-up*

Subjects set up the workstation and chairs for their comfort. As these subjects had all received education regarding correct workstation set-up and positioning as part of their undergraduate education in occupational therapy, no further information was provided. All settings were recorded and duplicated in the second data collection session. Table 2 presents the workstation set-up for each subject.

2.5. *Comfort*

A 10 cm visual analogue scale (VAS) was used to record discomfort. It was anchored by the descriptors "no discomfort at all" at 0, and "extreme discomfort" at 10. Subjects were asked to rate their level of discomfort in three areas: (1) overall; (2) low back; and (3) other areas, where subjects nominated any other areas of the body where they experienced discomfort and then rated it. Ratings of discomfort were recorded on seven occasions in each phase – prior to commencing typing, and then at the conclusion of each 5-minute sub-phase over the 30-minute period.

The VAS is a strong, simple, sensitive and reproducible measure widely used in research and practice, and suitable for crossover experiments [17], such as this study. Possible anticipation of ratings by subjects (i.e. subjects anticipating the next rating because they were occurring every five minutes) was addressed by examining if serial dependency existed in the data (see 2.8 Data Analysis). There was no serial dependency found.

2.6. *Work performance* (*productivity*)

Work performance was determined by typing net speed (number of correct words/min) and accuracy (percentage correct). Typing software (TypingMaster Express 2004®) was used to determine work performance results. The software had 5-minute typing exercises that timed the activity and produced speed and accuracy results. Typing exercises consisted of copy-typing a passage of text that appeared on screen. Each subject completed a different exercise for each sub-phase (24 exercises in total) to ensure that repeated exposure and/or familiarity with the text did not affect results. Data on speed and accuracy were collected at the end of each 5-minute sub-phase, resulting in six data points per phase.

2.7. *Posture*

Posture was analysed from videotaped data. Two video cameras were used to obtain left side and rear views of the whole body. Digital photographs from the videotape of side and rear postures were taken at the fourth minute of each 5-minute sub-phase and analysed.

Subjects had coloured adhesive markers attached at anatomical points of reference (C7 vertebra, left ear canal, acromion process, ulna styloid and anterior superior iliac crest) to assist with determining posture from videotape and digital photographs.

A *post-hoc* method of evaluating posture using photographic analysis was used, based on a previous study of the Bambach^{TM} saddle seat [11]. The side photographic view was used to determine subjects' trunk-to-thigh angle. A vertical line was drawn through the anatomical markings at the C7 vertebra and the anterior superior iliac spine. A horizontal line was drawn along

Fig. 3. Determination of trunk-to-thigh angle from photograph (still image from video).

the bottom surface of the thigh, as this was visibly evident for all subjects. The vertical and horizontal lines intersected at a point to create a trunk-to-thigh angle and were measured. Figure 3 illustrates how trunk-to-thigh angle was determined.

2.8. *Data analysis*

The data were analysed with two accepted methods typically used with single-system research designs – visual analysis of graphed data, and semi-statistical analysis. Data gathered from each subject were graphed for each variable.

Serial dependency of data was checked using autocorrelation coefficients [24]. Serial dependency "refers to the fact that sequential responses emitted by the same individual will be correlated" [25, p. 793], and its presence can lead to misinterpretation of findings when graphical analysis and visual inspection are used to evaluate the data [24]. Serial dependency for comfort, work performance and posture was calculated using Bartlett's Test ($2 \div \sqrt{n}$), where "n" is the number of baseline observations [24]. If any of the autocorrelation coefficients were greater than the results from Bartlett's Test, the coefficient would have been considered significant and serial dependency would have been identified [24]. Serial dependency did not exist in any of the 80 data phases (20 per subject).

Visual analysis of graphed data examined changes in level, variability, trend and slope [24]. Where a response pattern is systematically increasing it is described as an *accelerating trend*, and when decreasing it is a *decelerating trend* [24]. Data were graphed for each variable for each subject. Due to subjects acting as their own controls and the different order of phases for each subject it was not appropriate to combine responses and produce graphs depicting "average" responses across all four subjects. The purpose of single-subject research designs is to examine differences within individuals; therefore graphed results of individual subjects for each variable are presented to illustrate results.

The semi-statistical Two Standard Deviation Band method [24] was also used. Statistical significance ($p < 0.05$) is accepted when two successive observations in the intervention phase (B) fall outside the two standard deviation band calculated from the baseline phase (A) (Gottman and Leiblum cited in [24]).

3. Results

3.1. *Comfort*

3.1.1. *Overall body discomfort*

Overall body discomfort generally increased with time, regardless of the seat being used. This was evident through the accelerating trends present in 75% (12 of 16 phases; 6 for each chair) of the 30-minute data phases. The slopes for the saddle seat phases (B), however, were not as steep, indicating that discomfort levels increased more slowly on the saddle seat than the standard office chair. Figure 4 shows the increase in overall discomfort over time for Subject 1.

Overall body discomfort was more commonly experienced on the standard office chair, with 62.5% (5 of 8) of baseline (A) phases having higher mean levels of discomfort than paired intervention (B) phases.

3.1.2. *Lower back discomfort*

Mean levels for lower back discomfort were higher in 87.5% (7 of 8) of standard office chair phases and increased over time. This was evident by accelerating trends in all of the eight baseline (A) data phases (100%). Lower back discomfort also increased over time on the Bambach$^{\mathrm{TM}}$ saddle seat; however, this was only evident in 62.5% (5 of 8) of data sessions, with the remaining 37.5% (3 of 8) demonstrating flat or decelerating trends. The trends associated with the standard office chair (50% (8 of 16) of data paths) were steeper than those associated with the saddle seat (31.25% (5 of 16) of data paths), demonstrating that lower back dis-

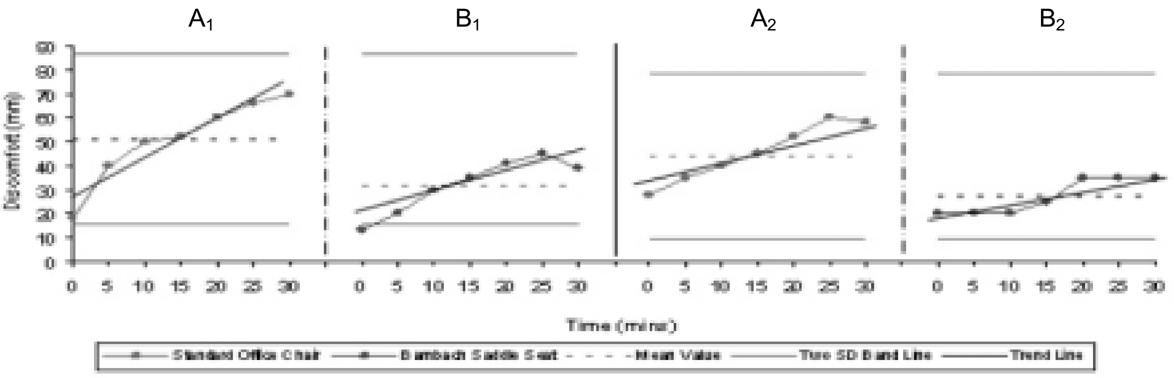


Fig. 4. Overall body discomfort – Subject 1.

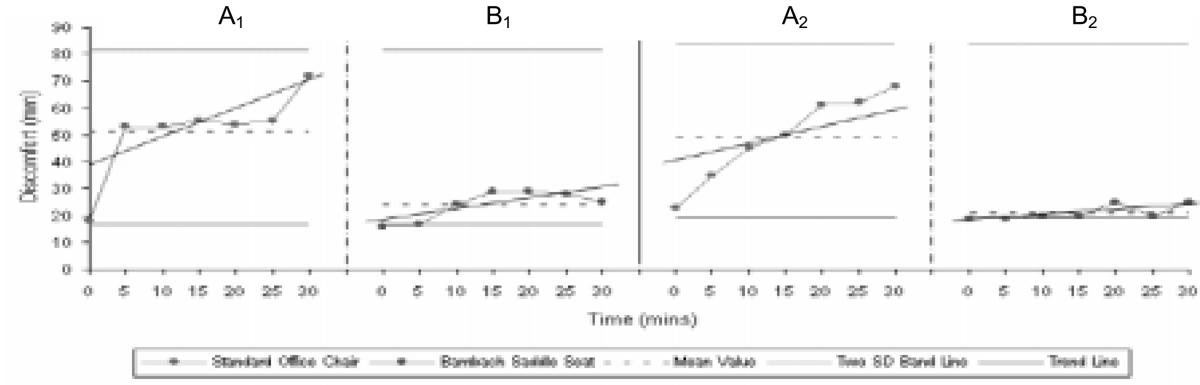


Fig. 5. Lower back discomfort – Subject 1.

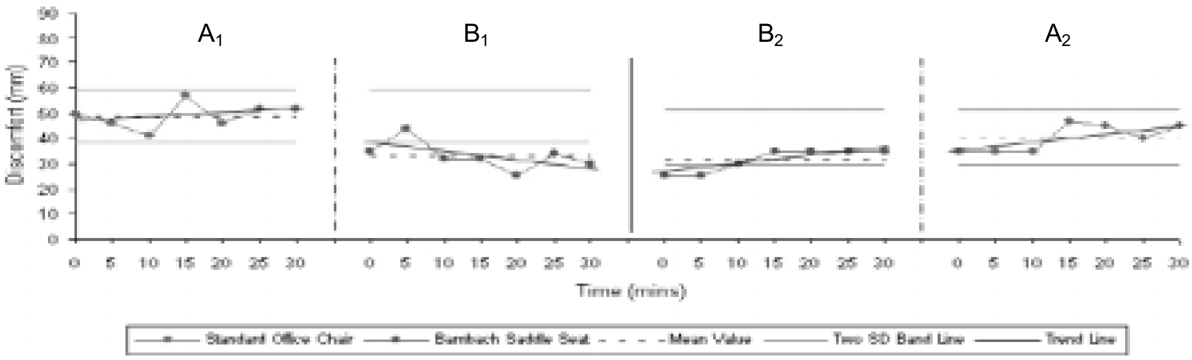
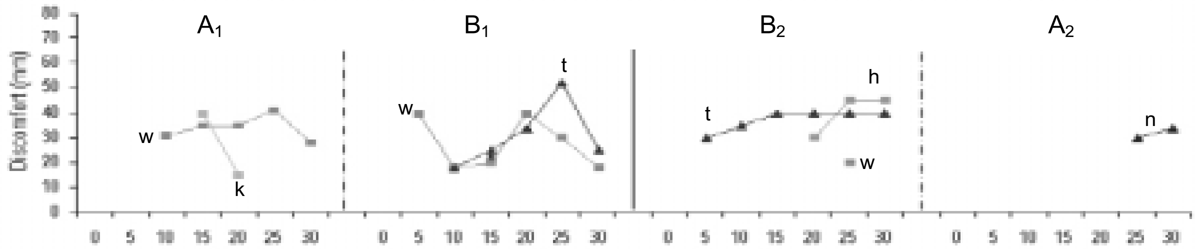


Fig. 6. Lower back discomfort – Subject 2.

comfort increased more rapidly on the standard office chair than the saddle seat.

Statistical analysis (2-SD Method) indicated that the saddle seat had significantly ($p < 0.05$) reduced levels of lower back discomfort in 62.5% (5 of 8) of data sessions (see Fig. 5 as an example of this).

In the second phase of paired data sessions (e.g. B_1 in A_1B_1 session, or A_2 in B_2A_2 session), when it may be expected that lower back discomfort had increased over time, all B phases indicated lower levels of lower back discomfort, while all A phases indicated increased discomfort (see Figs 5 and 6). These findings



Areas of discomfort: h = hips/buttocks; k = knee; n = neck; t = inner thigh; w = wrist

Fig. 7. Other discomfort ratings – Subject 2.

demonstrate higher levels of lower back discomfort to be associated with the standard office chair, and reduced lower back discomfort to be linked with the saddle seat.

3.1.3. Other discomfort ratings

When asked to nominate other areas of discomfort, subjects reported more areas when using the Bambach$^{\mathrm{TM}}$ saddle seat than the standard office chair. All subjects consistently reported lower limb, hip and/or buttock discomfort when using the saddle seat (Fig. 7). Neck discomfort was more commonly reported when using the standard office chair. It did appear, however, that over time subjects became more familiar with the chairs and there were fewer reports of discomfort in other body areas.

3.1.4. Comfort summary

Comfort results indicate there was a small but discernable difference in overall body discomfort between the standard office chair and saddle seat. Generally, the standard office chair demonstrated greater overall body discomfort for most subjects, and discomfort increased most rapidly on this chair.

There was a significant difference in lower back discomfort on the standard office chair compared to the saddle seat, where greater lower back discomfort was experienced on the standard office chair.

There was also a considerable difference between the chairs in regard to other discomfort ratings. The saddle seat not only had more selected areas of discomfort than the standard office chair, but all subjects consistently reported lower limb discomfort with the saddle seat.

Overall, these findings indicate that subjects reported more lower back discomfort when using the standard office chair. While the lower back was more comfortable when using the saddle seat, other body areas (particularly the lower limbs) had greater discomfort. However, as subjects became more familiar with the chairs, particularly the saddle seat, these reports of discomfort in other body areas appeared to decrease.

3.2. Productivity

3.2.1. Typing accuracy and net speed

Productivity results indicate that there were no obvious differences identified in the mean levels of typing accuracy and net speed between the standard office chair and saddle seat within subjects. These findings indicate that typing accuracy and net speed were relatively stable for each subject irrespective of the chair used (see Figs 8 and 9).

Overall, typing net speed increased slightly over time for both the standard office chair and saddle seat. However, these changes were not statistically significant.

Also of importance was the possible relationship found between comfort and productivity. Generally, it was identified that when productivity decreased, this coincided with increases in both overall body discomfort and lower back discomfort.

3.3. Posture

3.3.1. Trunk-to-thigh angle

Mean levels for trunk-to-thigh angle were higher in 75% (6 of 8) of the data phases where the saddle seat was used; indicating greater trunk-to-thigh angles were more commonly experienced on this chair.

It was apparent upon visual inspection that the trends for trunk-to-thigh angle varied between subjects and data phases. Trunk-to-thigh angle increased with time in 43.75% (7 of 16) of the data phases, as indicated by the slight accelerating trends present. Trends for trunk-to-thigh angle were flat in 31.25% (5 of 16) of data phases, and slightly decelerating in the remaining 25% (4 of 16) of data phases.

Significant differences ($p < 0.05$) were identified in 75% (6 of 8) of data phases where the saddle seat was used (e.g. Figs 10 and 11). On the saddle seat, 62.5% (5 of 8) of data phases represented greater trunk-to-

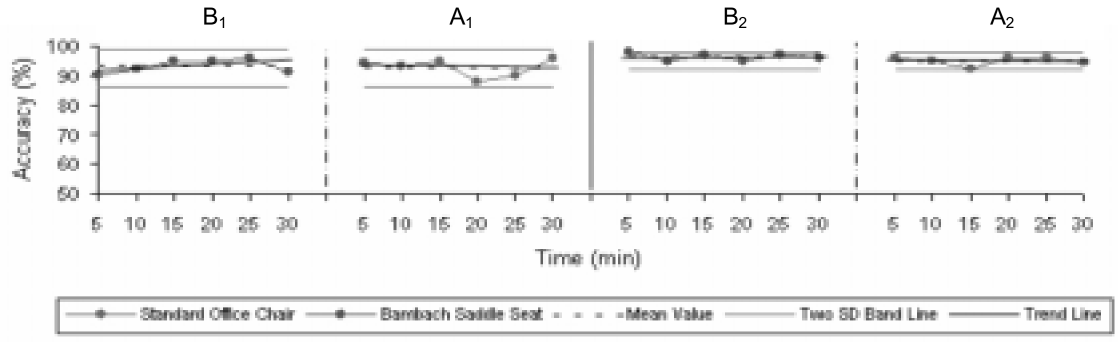


Fig. 8. Productivity – Typing accuracy – Subject 3.

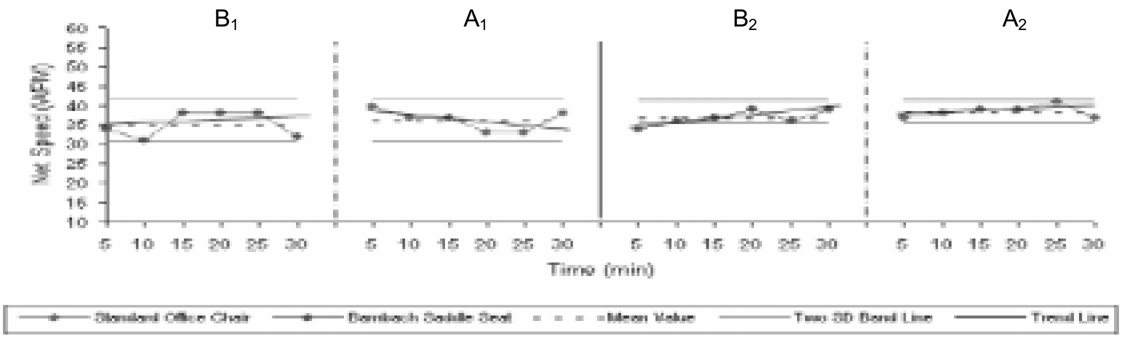


Fig. 9. Productivity – Typing net speed – Subject 3.

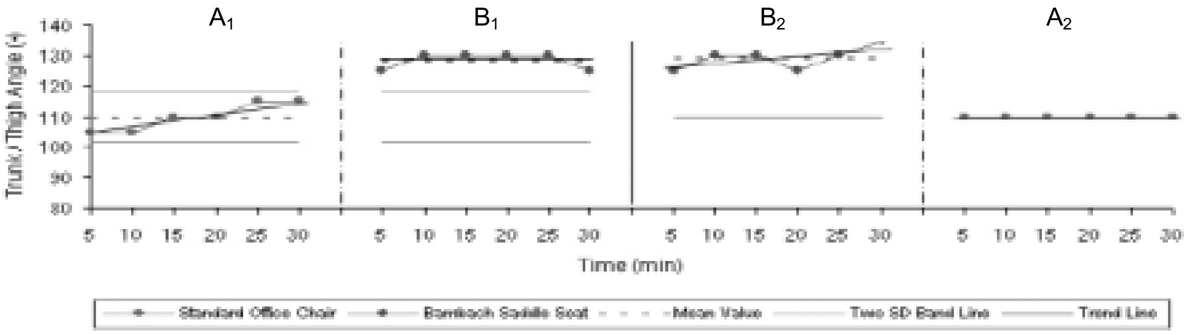


Fig. 10. Posture – Trunk-to-Thigh angle – Subject 2.

thigh angles, while 12.5% (1 of 8) of these data phases represented a smaller trunk-to-thigh angle. It is also important to note, Subjects Two and Four were shorter in height compared to Subjects One and Three, and repeatedly demonstrated (in both data sessions) significant differences ($p < 0.05$) in trunk-to-thigh angle on the saddle seat.

There was little variability identified in trunk-to-thigh angle data within and across data phases for all subjects.

3.3.2. Posture – Trunk-to-thigh angle and comfort

The relationship between trunk-to-thigh angle and comfort is also important. Generally, greater trunk-to-thigh angles were promoted on the saddle seat in all data phases and for all subjects, with the exception of Subject Three in data session one (B_1). Results indicated that overall body discomfort was reduced on the saddle seat for all subjects, except Subject Four. This coincided with greater trunk-to-thigh angles. Back discomfort was also consistently lower on the saddle seat for all

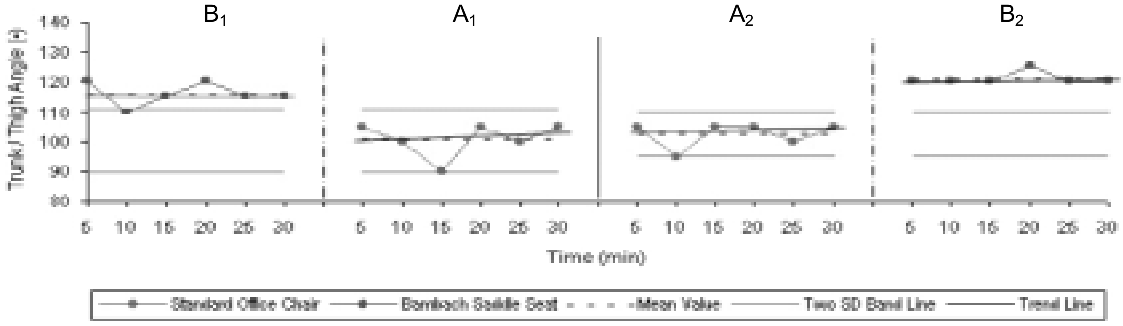


Fig. 11. Posture – Trunk-to-Thigh angle – Subject 4.

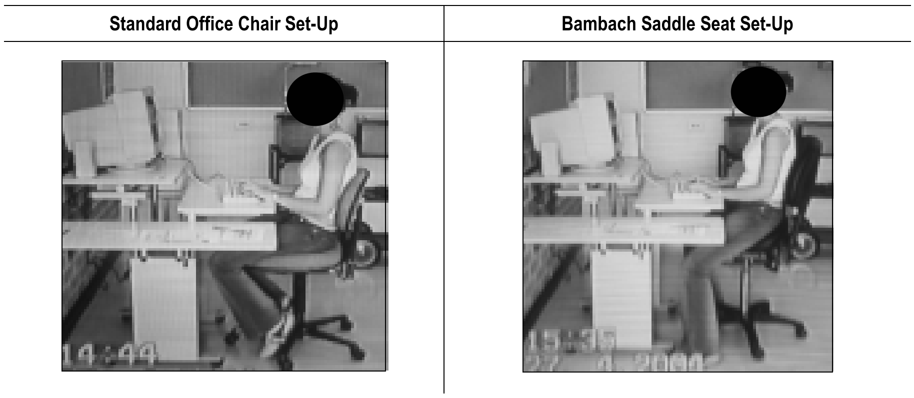


Fig. 12. Subject 2 seated at both chairs – note the increased trunk-to-thigh angle produced on the saddle seat.

subjects, when trunk-to-thigh angles were greater (e.g. compare Figs 6 and 10).

3.3.3. Posture – Trunk-to-thigh angle summary

Post-hoc postural analysis from photographs revealed there was a small, but evident difference in trunk-to-thigh angles between the standard office chair and saddle seat. Statistically significant ($p < 0.05$) data and repeated measures indicated the saddle seat was associated with greater trunk-to-thigh angles compared to the standard office chair.

Results also indicated trunk-to-thigh angle was influenced by subject height, with shorter subjects displaying greater trunk-to-thigh angles, predominantly on the saddle seat (Fig. 12).

There was a clear relationship between trunk-to-thigh angles and comfort. Specifically, greater trunk-to-thigh angles were associated with reduced levels of overall body discomfort, particularly lower back discomfort. This relationship was consistently observed on the saddle seat across data phases.

4. Discussion

4.1. Comfort

Results indicated that discomfort levels (overall body and lower back) generally increased with time regardless of the seat being used. This result supports the already well-established relationship between time and discomfort [19,23], where discomfort tends to increase with the length of time a work task is performed [29]. The static and constrained posture of sitting has been identified as a posture of particular concern, not only because of its evident relationship with discomfort and fatigue [19,23], but also its potential to result in low back pain [7,14,21]. In order to reduce discomfort associated with the static posture of sitting, Waersted and Westgaard [32] recommend taking breaks or rotating work activities.

4.1.1. Overall body discomfort

Comfort results indicated that there was a small but discernable difference in overall body discomfort between the standard office chair and saddle seat. Generally, the standard office chair demonstrated greater overall body discomfort for all subjects, which also increased more rapidly than on the saddle seat. This supports the suggestion that all seats are eventually uncomfortable; yet, some become uncomfortable faster than others [13]. This appears the case for the standard office chair when compared with the saddle seat.

The durable comfort of a seat is a function of its capacity to distribute load to support the musculoskeletal structure, and to allow variation in posture and pressure distribution whilst maintaining support [13]. Comfort ratings reported in this study indicated that the standard office chair and saddle seat distributed load differently. In particular, lower back discomfort was greater when using the standard office chair, while lower limb discomfort was greater when using the saddle seat. As a result, overall body discomfort was compromised for each chair due to differences in their load distribution.

4.1.2. Lower back discomfort

Comfort results indicated that the standard office chair was predominantly associated with greater levels of lower back discomfort than the saddle seat. This may be the result of the self-selected workstation set-up used by subjects, which was based on subjects' perceptions of initial comfort, rather than necessarily conforming to ergonomic principles or standards. As a result, subjects generally maintained what may be considered less than optimal static sitting postures as a consequence of inappropriate workstation set-up, particularly poor chair adjustment.

All subjects selected a seat angle of 90° when using the standard office chair, and a forward inclination of +105° on the saddle seat. This forward inclination of the saddle seat also resulted in a greater trunk-to-thigh angle, and was associated with greater lower back comfort.

The position of the seat pan on the standard office chair resulted in a flattening of the lumbar spine. This kyphotic posture is reported to increase intradiscal pressure [1,12,16], and to be associated with lumbar complaints with time [23].

The forward inclination of the saddle seat results in a reduction of the posterior rotation of the pelvis and promotes lumbar lordosis [18]. This posture has been recommended for sitting [1,22,23,28]. A previous study demonstrated that the saddle seat design facilitated the maintenance of the lumbar lordosis, and reduced lower back discomfort [11].

The backrest size also varied between the chairs, with the standard office chair having a smaller backrest than the saddle seat. This restricted the amount of support provided by the standard office chair may have affected lower back comfort by reducing the biomechanical and postural support available [7]. Many current models of standard office chairs, however, are available with larger/higher backrests.

Back support was also reduced by the backrest heights selected by subjects, which varied between the chairs. Most subjects selected a backrest height for the standard office chair that was within its adjustment range. This was consistently lower on the standard office chair for all subjects. There is a known relationship between backrest support and muscle activity, specifically lack of support and resultant muscle fatigue [5], particularly on the standard office chair [11].

Interestingly, although subjects varied considerably in height, Subjects One (height = 188 cm) and Two (height = 158 cm) used basically the same chair, desk and computer set-up, as did Subjects Three (height = 174 cm) and Four (height = 161 cm). Subject Four in particular spent the greatest time adjusting both chairs to the workstation set-up. Although we have considered the possible implications of chair design and adjustment on comfort, it is not possible to determine the extent to which other aspects of workstation set-up may have affected comfort ratings.

4.1.3. Other areas of discomfort

Subjects selected more areas of discomfort when using the saddle seat compared to the standard office chair. Most consistently, subjects experienced lower limb discomfort with the saddle seat. This area of discomfort may be attributed to the unique design of the saddle seat. The saddle seat and its forward inclination may result in increased pressure through the ischial tuberosities and weight bearing through the lower limbs, possibly resulting in decreased blood circulation to these areas and ultimately lower limb discomfort [5]. A self-selected seat height that was too high may also have had an impact. This was possibly the case for Subject Two, explaining the discomfort in the hips and buttocks as well as the inner thigh [5].

Two subjects (S1 & S2) reported neck discomfort. This may have been the result of poor computer monitor placement (i.e. too low), resulting in the adoption of an awkward static posture of the head and neck [8].

4.2. Productivity – Typing net speed and accuracy

Consideration of the effect of interventions on productivity is relevant and necessary. Literature suggests that a more comfortable worker is a more productive worker [6], and when individual comfort is compromised productivity is reduced [23]. In this study it was generally found that typing accuracy decreased when overall body discomfort and lower back discomfort increased, although not significantly.

The productivity results of this study indicate that generally both typing net speed and accuracy were maintained or slightly improved for all subjects regardless of the seat being used. Following visual analysis, a trend was identified that indicated that the saddle seat was more commonly associated with slight improvements in typing net speed and accuracy compared to the standard office chair. However, these differences were not statistically significant.

4.3. Posture

4.3.1. Trunk-to-thigh angle

Statistically significant ($p < 0.05$) data and repeated measures indicated the saddle seat was associated with greater trunk-to-thigh angles compared to the standard office chair. These results are related to the seat pan and backrest angles selected by subjects for both chairs. All subjects adjusted the saddle seat to the same seat angle (+105°) and backrest angle (105°), which promoted a much larger trunk-to-thigh angle than for the standard office chair. On the standard office chair all subjects selected the same seat angle (90°), yet, backrest angle varied (90°–115°).

Subject One was the only person who had a similar trunk-to-thigh angle on the standard office chair and saddle seat. This was achieved by adopting a more reclined posture (slouched) on the standard office chair, where the buttocks were pushed forward in the chair and the backrest angle was adjusted to 115° (which was the greatest backrest angle selected by any subject). On the saddle seat, Subject One was able to maintain a more upright position, and achieve a similar trunk-to-thigh angle by tilting the seat incline forward (105°). This study therefore supports earlier research that indicates greater trunk-to-thigh angle can be achieved by either reclining the backrest of the chair or tilting the seat pan forward [28].

Shorter subjects had greater trunk-to-thigh angles. When combined with the seat height selected the results suggest subject height is a factor influencing trunk-to-thigh angle.

4.4. Education and workstation set-up

Allowing subjects to adjust both chairs and other workstation components to comfort, provided an insight into the way most workers would set themselves up in the workplace, and in turn the real life effects that one might experience on comfort, productivity and posture as a result of self-selection without education or other forms of intervention.

Seating designs that provide correct biomechanical and muscular support may assist in reducing back injuries and pain [10]. This study has demonstrated, however, that providing individuals with supportive and adjustable chair designs is only one component in the overall management of back injury and pain in the workplace. Seating designs cannot assist in reducing the risk of low back injury and pain if workers are not aware of how to adjust or use the chair for themselves and the task(s) they are performing. This study reinforces that ergonomic training and education are fundamental components of interventions aimed at reducing back injury and pain [20,27] even amongst workers who have basic knowledge in the area.

4.5. Study limitations

Several limitations are associated with this study – the participant sample, data analysis constraints, and procedure utilised.

Single-system research designs are generally considered to have limited generalisability due to the small sample size [24]. To address this concern, both repeated measures and a sample of four subjects were used to enable greater generalisations to be made in this study. Repeated measures were used to strengthen the relationships found between each type of seating intervention and the variables of comfort, productivity, and posture. This was done through the use of an ABAB design, which provided strong evidence of intervention effects, as subjects' responses to intervention were observed and measured on two separate occasions. Further, the sequencing of each phase and the presentation of each type of seating intervention differed for each subject to avoid possible sequencing effects. It should be noted, however, that results cannot be generalised to the workplace as this study was conducted in a controlled environment.

The calculation of significance for variables was based on the two standard deviation band method [24]. For significance to occur, two consecutive data points from the intervention phase (B) had to lay more than two standard deviations from the mean in the baseline phase (A). In several data phases, the baseline data showed rapid increases, therefore resulting in large standard deviations. As a result, this made it difficult to determine statistical significance, despite there being obvious differences in data between the baseline (A) and intervention (B) phases. Other statistical procedures were not possible due to the number of data points.

The *post-hoc* measure of photographic analysis used was successful at conveying the obvious visual differences in subjects' posture; there were also several limitations of this measure:

1. While the procedures employed were based on Gale et al. [11], there were some that could not be followed as it was a post hoc measure:
   - First, anatomical reference points were placed on top of subject clothing, as subjects were fully clothed, movement of clothing was not controlled and reference points were not recalibrated during data collection; and
   - Second, a grid was not placed behind subjects during data collection; therefore it was not used to assist in the calculation of angles.
2. Photographs were taken from videotape footage (not first hand data).

It is important to recognise, although there were limitations of this post-hoc measure, the procedures used to obtain trunk-to-thigh angle were kept consistent within and between data sessions for all subjects, which enabled comparisons to be made.

Other limitations in this study are related to the set-up procedures used. First, the workstation was self-selected by subjects rather than conforming to ergonomic principles or standards. This set-up procedure was planned prior to data collection and based on the workstation set-up used by Straker, Jones, and Miller [31]. It was anticipated that allowing subjects to adjust their own chairs and other workstation components would give a better indication of the real-life effects that are experienced on both chairs. While this could be considered a strength of the study, it is also considered a limitation, as a less than optimal set-up of both chairs and the other workstation components may have impacted on the results obtained from each variable (comfort, productivity and posture). It is important to realise, however, subject self-selection remained consistent within and between data sessions for all subjects, which enabled results to be compared.

5. Conclusions

This study was prompted by the prevalence of back injury and pain in the working population, particularly amongst workers who are increasingly exposed to sedentary work in industrialised countries [19], and the corresponding limited evidence regarding the effectiveness of seating designs currently used by sedentary workers within the workplace [4].

A comparison study, using a single system multiple baseline design across subjects with repeated measures, was used to determine the immediate impact of conventional seating (standard office chair) and alternative seating (Bambach^{TM} saddle seat) with regard to comfort, productivity and posture on four normal adults.

The results of this study demonstrated both consistencies with existing literature and some unique findings:

- General discomfort increased with time regardless of the seat being used and is consistent with discomfort levels increasing as the time spent performing work tasks increase [29].
- Lower back discomfort was greater when using the standard office chair, which was consistent with Gale et al.'s [11] findings.
- All subjects reported lower limb, hip and/or buttock discomfort more frequently when using the saddle seat. This was attributed to the unique design of the chair that may result in increased pressure, decreased blood circulation and discomfort in affected areas [5], however this decreased as subjects became more familiar with the chair.
- Productivity results demonstrated a general maintenance or a slight trend towards improvement in both typing net speed and accuracy over time on both chairs. Although there were no statistically significant differences between the two chairs, the saddle seat was more commonly associated with slight improvements in productivity. These results may reflect a relationship between comfort and productivity [6,23]; however, more research is required to examine this.
- Post-hoc analysis of trunk-to-thigh angles confirmed that greater trunk-to-thigh angles were found on the saddle seat in comparison to the standard office chair. Due to the relationship between greater trunk-to-thigh angles and lumbar lordosis [18,28], these results indicate that the saddle seat promoted a sitting posture that is considered preferable by some authors, and also supported the findings of previous research [11].

– As a result of subjects self-selecting the workstation set-ups used in this study, less than optimal postures may have been adopted. This demonstrates that even though chair designs may promote a preferable seating posture, education regarding appropriate workstation set-up for chair, desk and computer (keyboard and monitor) remain a necessity in a comprehensive approach to ergonomic interventions.

This study provides health professionals with a systematic investigation of the immediate effects of using both the Bambach™ saddle seat and standard office chair in sitting. The findings of this study should be considered in future research. Based on these findings it is not possible to definitively recommend a saddle seat over a standard office chair; however, a saddle seat may provide a viable alternative for those who do not find a standard seat suitable.

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