Ergonomic chair design for school computer laboratories in the Cape Metropole, Western Cape, South Africa

by Sjan-Mari van Niekerk

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Promoter: Prof QA Louw PhD (UniSA)
Department of Interdisciplinary Health Sciences

Co-promoter: Prof K Schreve PhD (Stell)
Department of Mechanical and Mechatronic Engineering

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DECLARATION

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ABSTRACT

Background: Computers have become increasingly accessible in developing countries. Such increased computer usage is also noted in the Western Cape, South Africa. Prolonged posture whilst using computers and a learner-chair mismatch is associated with spinal pain in adolescents. In South Africa, the prevalence of spinal pain among high school learners has been reported as being about 70%. Consideration of learner anthropometrics and school furniture design is essential to evolving strategies to be adopted to promote adolescent spinal health.

Aim: The aim of this project is to determine whether the school computer laboratory chair or a commercially-available chair matches the anthropometric profile of high school learners and, if not, to develop and test a prototype chair that will also facilitate postural changes, whilst the sitter is using a desktop computer.

Methods: This study consisted of two phases. Phase one dealt with the anthropometric match of the learners to their school chair and to commercially-available chairs. The following body dimensions were measured: stature; popliteal height (PH); buttock-to-popliteal length (BPL) and hip width (HW). These body dimensions were matched with the corresponding chair seat dimensions; and height, depth and width, using standard matching criteria. During Phase two, a prototype chair was designed according to the anthropometric profile of the learners concerned. The chair's ability to reduce static sitting postures by facilitating postural changes in sitters whilst they are seated at a desktop computer was evaluated. The three-dimensional (3D) sitting posture of twelve learners was evaluated while they were sitting on the school and the prototype chairs. The anthropometric and 3D data were analysed using descriptive statistics, including means (and standard deviations), medians (and interquartile ranges (IQR)) and ratios. To determine the difference in the number of postural changes between chairs, the Wilcoxon match pair test was used.

Results: The sample consisted of 689 male and female learners aged 13 to 18 years, for the anthropometric study (phase 1). Of the learners, 65% to 80% did not match the school chairs' dimensions. Five commercial chairs offered a good match for the seat height, but neither the seat depth nor the seat width matched 50% of the learners. The prototype chair matched 97% for height, 65% for depth and 60% for seat width. The prototype chair was associated with more postural changes in the frontal and transverse planes for the pelvis (ρ <0.05).

Conclusions: This thesis is the first to report on the lower body anthropometric size of high school learners in the Cape Metropole area, Western Cape, South Africa. Neither the school computer laboratory chair nor commercially-available adjustable computer chairs offered an acceptable fit for the anthropometric profile of the learners. The prototype "Dynamic" chair was consequently developed and provided the best match for the anthropometric profile. The prototype chair was also associated with an increased number of postural changes, particularly of the pelvis. The promising results obtained warrant further exploration of the prototype chair to determine the effect on the musculoskeletal pain experienced by school learners in South Africa.

OPSOMMING

Agtergrond: Rekenaars is toenemend in ontwikkelende lande beskikbaar. Hierdie toename in rekenaargebruik is ook in die Wes-Kaap, Suid-Afrika, sigbaar. Gebrek aan postuurafwisseling tydens rekenaargebruik en ’n stoel wat nie die fisiese afmetings van die leerder pas nie, kan tot spinale pyn in adolessente lei. ’n Deursnee-studie in Suid-Afrika toon dat rugpyn onder meer as 70% van hoërskoolleerlinge in die Wes-Kaap voorkom. Die antropometrie van leerders en die ontwerp van skoolmeubels is bepalende faktore in die ontwikkeling van strategieë om die spinale gesondheid van adolessente te bevorder.

Doel: Om te bepaal of die afmetings van rekenaarstoele wat in skole gebruik word en in die handel beskikbaar is met die antropometriese afmetings van hoërskoolleerlinge ooreenstem; en, indien nie, om ’n prototipe te ontwikkel van ’n stoel wat posturale beweging tydens rekenaargebruik aanmoedig.

Metode: Hierdie studie is in twee fases uitgevoer. In fase 1 is leerders se antropometrie vergelyk met die afmetings van hulle skoolstoele en stoele wat in die handel beskikbaar is. Die volgende liggaamsafmetings is geneem: lengte, popliteale lengte, boud-tot-popliteale lengte en heupomtrek. Hierdie afmetings is vergelyk met die volgende ooreenstemmende stoelafmetings: sitplekhoogte, -diepte en -breedte. Die verhouding tussen die fisiese afmetings van leerlinge en dié van hulle stoele is met behulp van standaarddefinisies bepaal.

Tydens fase 2 is 'n prototipe van ’n stoel wat volgens die optimale afmetings wat in fase 1 verkry is, ontwerp is. Die stoel se vermoë om meer beweging tydens rekenaargebruik aan te moedig, is ondersoek. Twaalf leerders se drie-dimensionele sitposisie terwyl hulle dieselfde rekenaarverwante taak uitgevoer het, is ontleed. Die meting het 15 minute lank geduur in die skoolstoel, gevolg deur 15 minute in die prototipe. Die driedimensionele antropometriese profiel is beskryf aan die hand van beskrywende statistiek wat die gemiddeld (standaardafwykings), mediaan (en interkwartiel reeks (IKR)) en onderlinge verhoudings insluit. Die verskil in sitpostuurgedrag tussen die meting met die skoolstoel en dié met die prototipe is deur middel van die Wilcoxon-vergelykende pare ontleed.

Resultate: Die steekproef vir fase 1 het uit 689 leerders tussen 13 en 18 jaar bestaan. Uit dié groep het 65% tot 80% nie met die skoolstoele se afmetings ooreengestem nie. Vyf stoele wat in die handel beskikbaar is, se hoogte het goed met die leerders se afmetings vergelyk, maar 50% van die leerders kon op nie een van die stoele in hierdie groep se sitplekdiepte en -breedte inpas nie. Die prototipe se hoogte het met 97% van die leerders ooreengestem, en die sitplek se diepte en breedte met onderskeidelik 65% en 60% van die leerders.

Gevolgtrekkings: Hierdie navorsing het vir die eerste keer die onderlyf-antropometrie van veelrassige hoërskoolleerders in die Kaapse Metropool (Wes-Kaap, Suid-Afrika) ondersoek. Nóg die stoele wat in die skool se rekenaarlaboratorium gebruik word nóg verstelbare stoele wat in die handel te kry is, toon ’n aanvaarbare ooreenkoms met die antropometriese profiel van die groep plaaslike hoërskoolleerders. Die prototipe is gevolglik ontwikkel, en dít het die naaste met die leerders se antropometrie ooreengestem. Met die prototipe is ’n toename in posturale bewegings aangeteken, vir veral in die pelvis. Hierdie belowende resultate verg verdere navorsing om die effek van hierdie prototipe van ’n stoel op muskuloskeletale pyn in leerders te bepaal.

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LIST OF ABBREVIATIONS AND ACRONYMS

3D	Three-dimensional
BMI	Body mass index
BPL	Buttock-to-popliteal length
CASP	Critical Appraisal Skills Program
CPUT	Cape Peninsula University of Technology
CSV	Comma-separated values
EMDC's	Education management and development centres
EMG	Electromyography
HW	Hip width
ICT	Information communication technology
ID	Identification
IQR	Interquartile range
KB	Kate Beaton
KG-S	Karen Grimmer-Somers
Max.	Maximum
Min.	Minimum
MSD	Musculoskeletal disorder
MSE	Mean square error
PH	Popliteal height
RCT	Randomised controlled trial
SD	Seat depth; standard deviation
SH	Seat height
SPSS	Statistical Package for Social Sciences
SvN	Sjan-Mari van Niekerk
SW	Seat width

CHAPTER 1

Introduction

Computers have become increasingly accessible in developing countries over the last five years (Cheeseman-Day *et al*., 2005). The phenomenon of increased computer usage has also been noted globally, and it has been demonstrated that children and adolescents in the United States, Europe and Australia are using computers at an increased frequency and duration, as well as from an increasingly younger age (Jacobs & Baker, 2002; Saarni *et al*., 2007; Straker *et al*., 2002; Straker *et al.,* 2010). Computers are also frequently used for extended periods of time in schools (Straker & Pollock, 2005). In South Africa, the use of computers and the amount of time that is spent in front of desktop computers is increasing among high school learners in the Western Cape (Smith *et al.,* 2008). Prolonged and incorrect posture whilst using computers has been shown to be associated with spinal pain and the development of long-term poor postures in the long term (Harris & Straker, 2000).

The prevalence of spinal pain among high school learners has been shown to be high around the world, and to increase across the teenage years (Burton *et al*., 1996; Grimmer & Williams, 2000; Kovacs *et al*., 2003; Walker *et al.,* 2004; Watson *et al.,* 2002; Wedderkopp *et al*., 2001). Cross-sectional surveys conducted in different countries with children and adolescents between the ages of eight and 16 years reported one-month prevalence rates of up to 39%, and lifetime prevalence rates of up to 69.3% (Kovacs *et al*., 2003; Watson *et al*., 2002;

Wedderkopp *et al*., 2001). In South Africa, the prevalence of spinal pain among high school learners has been reported to be more than 70% in a cross-sectional study (Smith *et al*., 2009). The findings of this local study also demonstrated that South African high school learners who are seated at a computer workstation for about nine hours per week are significantly at risk of developing spinal pain, compared with learners who are seated for a shorter period of time (Smith *et al*., 2009).

Adolescent spinal pain has been blamed on a range of external and internal predictive and contributing factors, including prolonged sitting (Kumar, 1994; Bernard, 1997; Yeats, 1997). Prolonged sitting at school is different from sitting for extended periods at home (Sjolie, 2004). Sitting at home usually forms part of leisure activities, and, consequently, sitting position and duration can frequently be altered. Sitting at school requires a learner to remain in a seated position for specified time periods in order to complete academic tasks. The difference in sitting patterns may explain why prolonged sitting at school, and not at home, is a strong predictor of adolescent spinal pain (Sjolie, 2004). Prolonged sitting with poor postural alignment accentuates the problem, as asymmetric attenuation of compressive and tensile forces acting on the body leads to harmful shear or compressive forces, as well as hampers the body's natural ability to discard harmful waste products from the intervertebral disks (Adams & Dolan, 2005; Ariëns *et al*., 2001; Bernard *et al*., 1994; Mandal, 1981; Pope *et al*., 2002; Tittiranonda *et al*., 1999; Troussier, 1999). In addition, the incorrect alignment of body segments reduces the ability of the antigravity muscles to generate torque (Tittiranonda *et al.*, 1999; Troussier, 1999). The body's neuromuscular systems may, consequently, not respond optimally to such external forces as gravity (Tittiranonda *et al.*, 1999; Troussier, 1999). Abnormal physiological strain on the neuromuscular systems leads to repetitive strain and pain (Ariëns *et al.*, 2001; Bernard *et al.*, 1994; Mandal, 1981; Tittiranonda *et al.*, 1999; Troussier, 1999).

Sitting postural alignment is influenced by two primary factors. Firstly, anthropometric and genetic characteristics can influence habitual posture (Yeats, 1997), and, secondly, the dimensions and design features of school furniture may influence postural alignment (Miller, 2000; Parcells *et al*., 1999; Yeats, 1997). School furniture design should play an important role in fostering good postural alignment during the formative years, since children spend a large proportion of their sitting time at school (Panagiotopoulou *et al*., 2004). It is recommended that school chairs be adjustable to accommodate the anthropometrics of 90% of the school learner population, to ensure that seating facilitates good posture (Cotton *et al*., 2002). Poor sitting habits during childhood are potentially detrimental to adult health, as it is difficult to correct such habits in adulthood if poor patterns of behaviour have already been established (Yeats, 1997). Considering ergonomics principles, learner anthropometrics and school furniture design is, thus, essential when considering strategies to promote good adolescent posture.

In a study conducted in the Cape Metropole, the mean overall scores obtained from the 29 computer laboratories adhered to only 41.5% of the criteria of the 'Computer laboratory Workstation Assessment Checklist' (Smith, 2007). The chair used in computer laboratories scored the poorest and adhered to less than 30% of the basic ergonomic guidelines. The chair-specific problems included fixed height of the backrest and arm supports, as none of the chairs had any adjustable features (Smith, 2007). School learners are, therefore, generally unable to adjust the dimensions of computer laboratory chairs to match their anthropometry, and can, thus, not adjust the chair to match their specific anthropometric profile. Both poor postural alignment and avoidable spinal pain may therefore ensue.

The current findings present a window of opportunity for improving the ergonomic design of chairs used in computer laboratories in local South African schools. The criteria to which the school computer chair had to adhere to in order for it to be deemed ergonomically sound were as follows: 1) the chair had to have movable rolling coasters; 2) the surface of seat to floor had to be in the range of 380 mm to 510 mm; 3) the seat pan depth had to be in the range of 330 mm to 430 mm; 4) the back support's height had to be adjustable; 5) the back support's angle had to be adjustable; 6) arm supports had to be present; and 6) the arm support's height had to be adjustable. A full version of the 'Computer laboratory Workstation Assessment Checklist' is available in Addendum A).

International studies have consistently demonstrated that school chairs in developed and developing countries were mismatched to learners' anthropometry (Brewer *et al.*, 2009; Castellucci *et al*., 2010; Chung & Wong, 2007; Cotton *et al.*, 2002; Dianat *et al*., 2013; . García-Acosta &. Lange-Morales, 2007; Gouvali & Boudolos, 2006; Milanese & Grimmer, 2004; Oyewole *et al*., 2010; Panagiotopoulou *et al.*, 2004; Parcells *et al.*, 1999; Saarni *et al.*, 2007). A learner-furniture mismatch is defined as the incompatibility between the dimensions of a piece of furniture (in the present instance, a school chair) and the anthropometric dimensions of the learner (Chaffin & Andersson, 1991; Parcells *et al.*, 1999).

Consequently, the fatigue and discomfort experienced by learners may accentuate poor postural habits and increase reports of spinal pain related to sitting on chairs that are not of a good fit (Parcells *et al.*, 1999). For instance, it has been reported that too low a seat height (SH) may lead to increased angles of lumbar flexion during sitting and predispose the seated person to increased risk of lower-back pain (Milanese & Grimmer, 2004; Parcells *et al.*, 1999). Pheasant (1996) reported that, if the chair depth is greater than the buttock- to-popliteal length (BPL), the learner would be unable to utilise the backrest of the chair for lumbar spine support during sitting. If the seat depth (SD) is significantly less than the BPL, the learner's thighs would not be supported in the sitting posture (Pheasant, 1996), which might have a detrimental effect on blood circulation in the legs.

Taking such features into account, the learners in Smith's (2007) study are potentially being exposed to considerable risk factors for the development of, and potential increase in, the already high prevalence rate of spinal pain amongst high school learners in the Western Cape.

1.1 Overall project aims

The aims of the research reported in this thesis were:

- *to establish a lower-body anthropometric database of high school learners in the Cape Metropole area of the Western Cape, South Africa;*
- *to determine whether there is a chair available that can accommodate the anthropometric profile of high school learners in the Cape Metropole area of the Western Cape, South Africa;*
- *to recommend the ideal dimensions of a school computer chair to accommodate the range of anthropometrics in the high school learners concerned; and*
- *to develop and test a prototype chair in terms of its capacity to reduce sustained postures when sitting in front of a desktop computer.*

The study was conducted, and reported, in two phases (Figure 1.1).

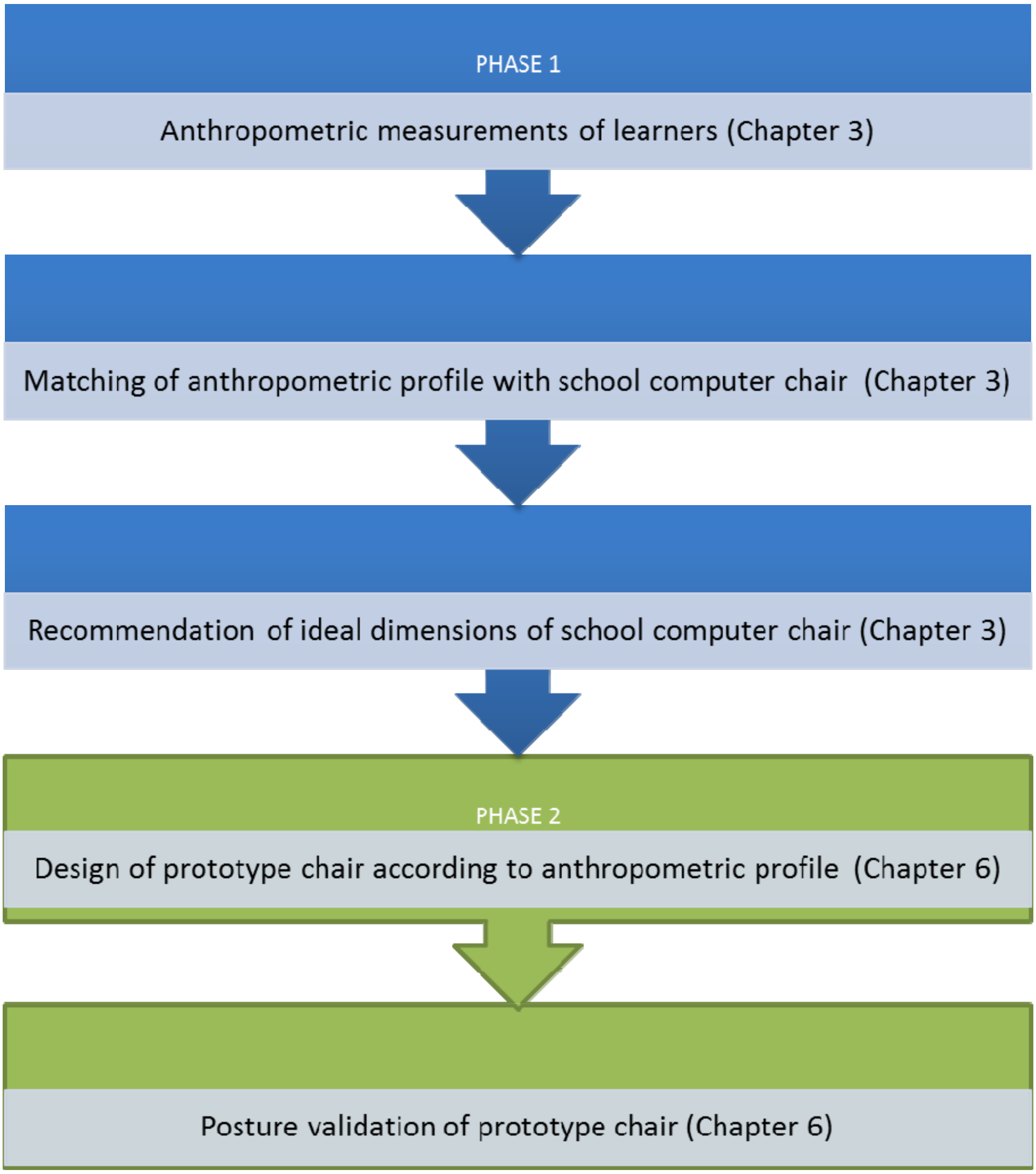


Figure 1.1: Organisational chart demonstrating the two phases of the study

1.2 Research questions

The research questions that applied in the present study were:

- *What is the lower-body anthropometric profile of high school learners in the Cape Metropole area of the Western Cape, South Africa?*
- *Does the 'usual' school computer chair provide an adequate fit to the anthropometric profile of the high school learners in the Cape Metropole area of the Western Cape, South Africa?*
- *Is there an affordable, adjustable commercially available chair that provides an adequate fit for the anthropometric profile of the high school learners in the Cape Metropole area of the Western Cape, South Africa?*
- *What should the dimensions of a school computer chair be, in order to accommodate the range of anthropometric profile of high school learners in the Cape Metropole area of the Western Cape, South Africa?*
- *Can a prototype chair be constructed simply and inexpensively that will fit a significant percentage of the pilot high school learners in the Cape Metropole area of the Western Cape, South Africa, participating in Phase two of the study?*
- *Does such a prototype chair provide the vehicle to reduce adolescent school learners' sustained postures when they are seated in front of a desktop computer?*

CHAPTER 2

Lower-body anthropometric profile of high school learners in the Cape Metropole area, Western Cape, South Africa.

2.1 Introduction

It could be argued, albeit a lack of evidence, that children in the Cape Metropole area of the Western Cape of South Africa today differ from children in the same area less than two decades ago. According to the latest census data (StatsSA, 2012), the Western Cape has the highest Coloured population in the country, constituting about 54% of the province's 3.9 million people. The Western Cape has 21% African/black people, 21% white people and 1% Indian/Asian people. During the apartheid era, children attended racially segregated (white, coloured and black) schools (Act No. 47, 1953), and intermarriage between the races was illegal (Act No 55, 1949). Races identified throughout the apartheid era in the Western Cape included Dutch, English, Indian, Malay, and Xhosa. Since the dismantling of the apartheid laws, the potential for significant changes to adolescent anthropometry through interracial marriages has largely been uncharted.

Today, children in South Africa, who come from a blend of ethnic backgrounds, all attend school together. The research focus in South Africa over the last two decades has (necessarily) been on the significant and costly issues of childhood disease and mortality. Given the limited understanding of multiracial children's weight-for-height profile and growth, it is difficult to estimate how big the current teenagers will grow, and to establish whether current furniture, clothing and workstation design principles are appropriate for them now, and whether they will be so for them in their adulthood.

The international literature suggests that, up to the onset of puberty, growth patterns of boys and girls are similar (Tanner *et al*., 1976). However, beyond ten years of age, gender-specific variations in growth lead to significant divergence in growth patterns between the two genders. Such divergence results from the effect of differences in the timing of puberty (Tanner *et al*., 1976). Girls commence their growth spurt, on average, two years before boys (Beunen *et al*., 2000), with the first phase of the growth spurt occurring, on average, between 13 and 15 years of age in boys and between 11 and 13 years of age in girls (Dimeglio, 2001). The second phase of growth, which is characterised by a deceleration in growth rate, occurs between 13 and 15½ years of age in girls and between 15 and 17½ years of age in boys, with the phase in question lasting approximately 2½ years (Dimeglio, 2001).

Anthropometry is integral to ergonomics and chair design. Taking into account that measurements such as popliteal height (PH), BPL, and hip width (HW) are essential when determining the dimensions of a chair that will be appropriate for all its users. To ensure the availability of a chair that provides adequate support for the potentially anthropometrically-diverse adolescents of the Cape Metropole area of the Western Cape, South Africa, it is important first to have an understanding of the lower body anthropometric profile of the adolescents concerned.

Current school furniture is typically purchased by school administrators who may not be aware of the importance of physiological and/or musculoskeletal effects of school furniture design and size on the learners using it (Parcells *et al.*, 1999). The general economic climate in South Africa is that of a developing nation. Government-owned schools are poorly resourced, and, thus, the biggest factors influencing the choice of purchase of school furniture are often the cost and durability of the furniture pieces concerned, and neither their ergonomic design nor the fit of the furniture to child users. Such considerations often lead to the purchase of furniture that is neither intended for the school environment nor for the learner population involved (Figure 2.1). Smith (2007) found the above to be the case in the high schools in Western Cape, South Africa, in relation to which the analysis of school computer workstations indicated that the chairs used in the computer laboratories in the Cape Metropole comply with fewer than a third of the basic ergonomic guidelines (discussed in detail in Chapter 1). The predominant concern with the school computer chair was found to be its lack of adjustability (Smith, 2007).

Figure 2.1: The two chairs currently used in school computer laboratories

The current systematic review of the literature asks the following three questions using a similar searching approach:

- *whether there is published information on the lower-body anthropometric profiles of high school learners who are based in the Cape Metropole area of the Western Cape, South Africa;*
- *how a mismatch between a chair and user is defined and described in the literature; and;*
- *what the physiological and/or musculoskeletal effects or potential effects of such a mismatch are.*

The present review addresses each review question separately, in terms of methods and results, and then combines the overall findings in a final summary. Figure 2.2 provides a graphical presentation of the layout of Chapter 2. At the beginning of each of the three sections, the same figure is presented to highlight the relevant section for ease of navigation through the chapter.

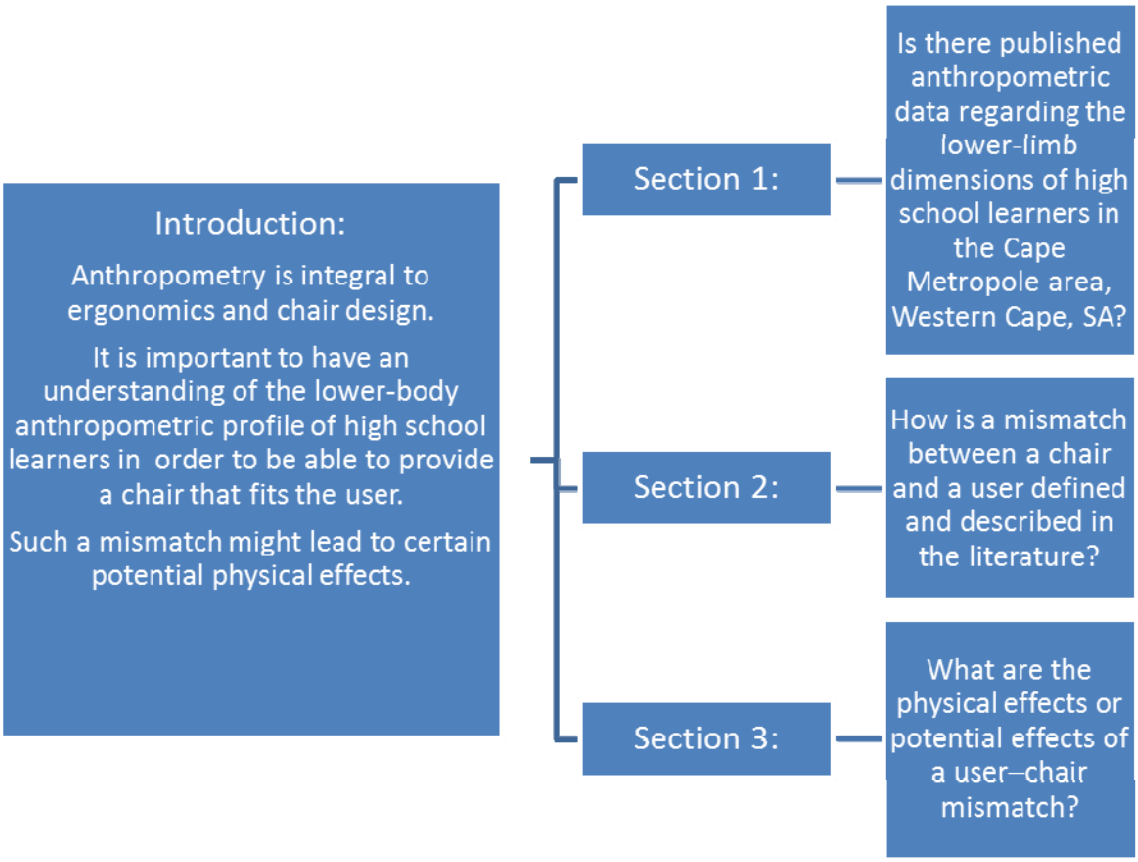
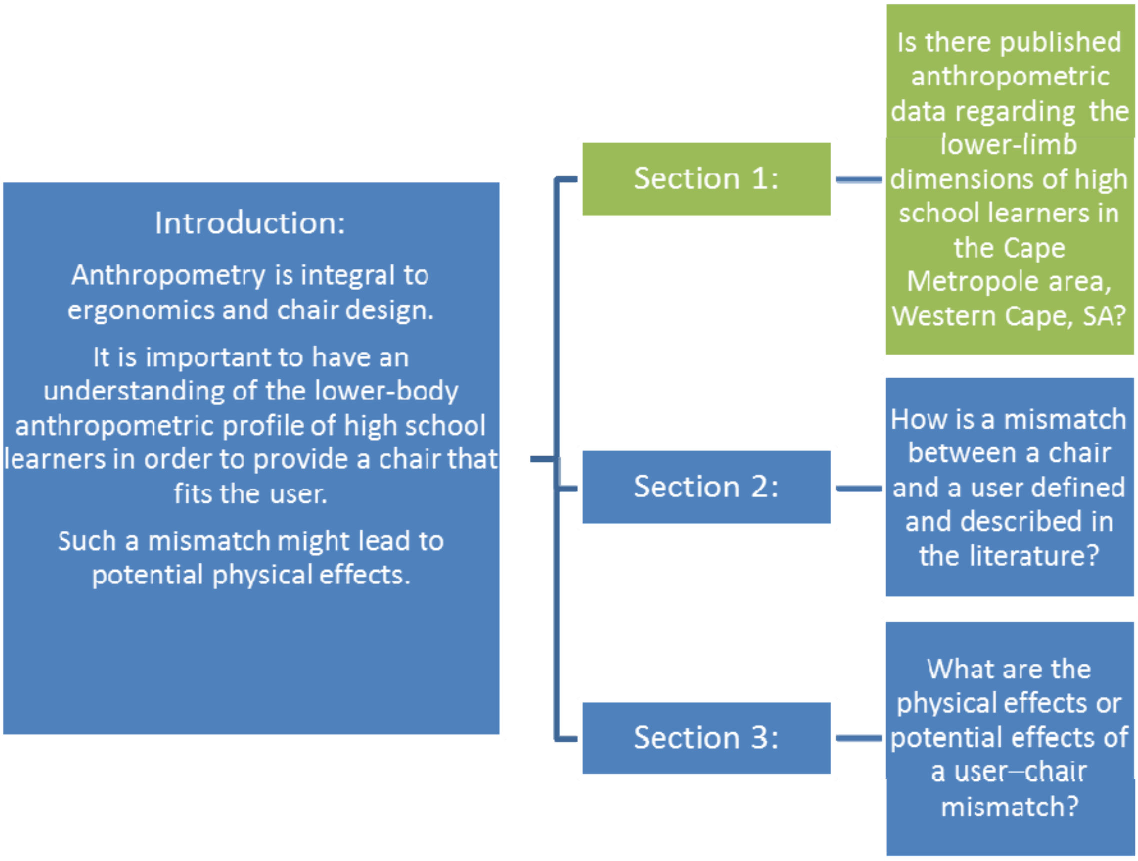


Figure 2.2: Graphical presentation of Chapter 2 layout

2.2 Section 1: Lower-body anthropometric data



2.2.1 Methodology

In Section 1 of this thesis, we aimed to establish whether there was a published anthropometric profile of the lower-body dimensions of the high school learner population of the Cape Metropole area of the Western Cape, South Africa, which could be used to inform chair choice and design. A comprehensive search of following relevant electronic library databases was undertaken, from inception of the databases up until June 2012: EBSCOhost: (Academic Search Premier; Australia/New Zealand Reference Centre; CINAHL; Ergonomics Abstracts; ERIC; Health Source [consumer and nursing/academic editions] MasterFILE Premier; SPORTdiscus); Pubmed; OVID: (AMED, EMBASE, MEDLINE); and SAGE.

A combination of search terms was used to identify observational studies in all the available databases (Table 2.1). Two reviewers (SvN and KB) independently screened the selected titles and abstracts for eligibility. Observational studies were the most relevant to the research question, because the question would be answered by prevalence data from population-based studies.

Table 2.1: Search terms and combinations used to search the databases

Keyword 1	Keyword 2	Keyword 3
anthropometry OR anthropometric profile OR anthropometric charts OR growth charts OR size OR body dimensions	teenagers OR adolescents OR high school learners	South Africa OR Western Cape of South Africa OR Cape Metropole

2.2.1.1 Inclusion criteria

Included in the review were observational studies found reporting lower-limb anthropometric information applying to 13- to 18-year-old school learners based in the Cape Metropole of the

Western Cape, South Africa. No date restrictions were applied, and only English-language articles were included. Full-text articles were retrieved for those studies that appeared to meet the inclusion criteria, and for those in which insufficient information was presented in the title, abstract and key words to determine eligibility

2.2.1.2 Exclusion criteria

Articles were excluded from the review if they were not available in full text in the English language. No date exclusions were applied. Articles reporting on only body mass index (BMI) and weight profiles were also excluded.

2.2.1.3 Independence of decision-making

Disagreements between the two reviewers were discussed and consensus was reached, where possible. When agreement could not be reached, a third reviewer (KG-S) was consulted for a resolution about the relevance of the article to the review.

2.2.1.4 Data extraction

One reviewer (SvN) extracted the data by using purpose-built data extraction form recording information on study design, population, age, gender and anthropometric profiles. Where data were found to be missing, first authors of the included studies would be contacted and additional information requested. A second reviewer (KB) would audit data extraction accuracy from 10% of the randomly selected articles.

2.2.2 Results

2.2.2.1 Study selection

Table 2.2 reports on the number of hits obtained per database. Both reviewers (SvN and KB) read the only apparently-relevant hit and established that Mokwena's (2003) writing took the form of a personal letter that was published in the *South African Journal of Clinical Nutrition*, in which the author mentioned being part of a survey that had taken place in the North West Province of South Africa in the year 2000. The survey only investigated full body length and weight, and neither measured, nor reported on, lower-body anthropometrics separately. Thus, there were no studies suitable for inclusion in the current review.

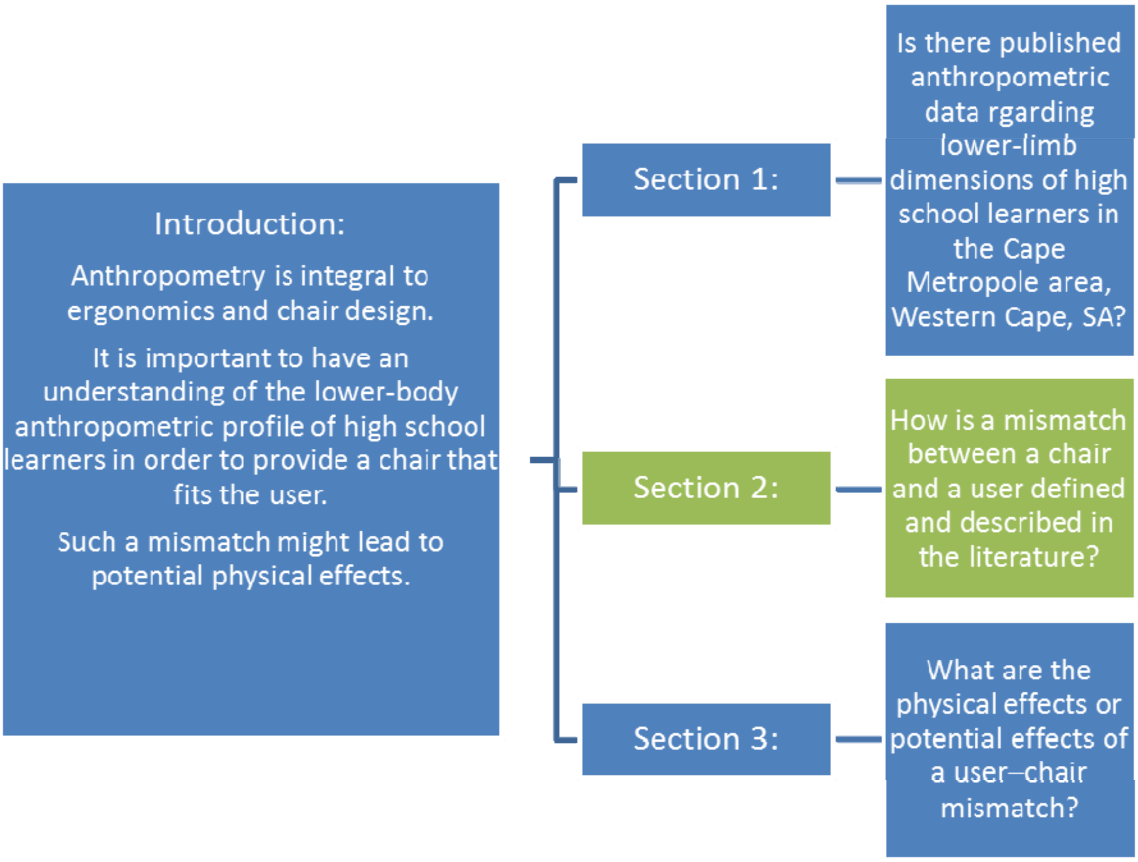
Table 2.2: Number of hits per database

Name of database	Search no.	Keywords used	No. of relevant hits
EBSCOhost: Academic Search Premier; Australia/New Zealand Reference Centre; CINAHL; Ergonomics Abstracts; ERIC; Health Source [consumer and nursing/academic editions] MasterFILE Premier; SPORTdiscus	1	1+2+3	24 (0)
Pubmed	1	1+2+3	57 (0)
OVID: AMED; EMBASE; MEDLINE	1	1+2+3	47 (1)
SAGE	1	1+2+3	0
Total number of hits			128
Excluded after review of the title and abstract (not relevant / duplicates)			127
Excluded after review of full paper			1
Total number of papers included			0

2.2.3 Summary

Apart from Mokwena (2003), who only determined the height-to-weight ratio (referring to the BMI) of teenagers in the Western Cape more than a decade ago, no published information was found on the current lower-body anthropometric profile of high school learners in the Cape Metropole area of the Western Cape of South Africa. Thus, there was no current, relevant detail on which to base furniture selection criteria for high school learners in the area surveyed.

2.3 Section 2: Definition of a mismatch



2.3.1 Methodology

In Section 2, the literature was consulted to determine how a mismatch between the anthropometric measurements of a high school learner in relation to the school chair dimensions could be defined and described. We performed a comprehensive search of relevant electronic library databases from inception of the study up until June 2012:

EBSCOhost: (Academic Search Premier; Australia/New Zealand Reference Centre; CINAHL; Ergonomics Abstracts; ERIC; Health Source [consumer and nursing/academic editions] MasterFILE Premier; SPORTdiscus); Pubmed; OVID: (AMED; EMBASE; MEDLINE); and SAGE.

A combination of search terms was used to identify observational studies from all the databases consulted (Table 2.3). Two reviewers (SvN and KB) independently screened the selected titles and abstracts for eligibility. Observational studies were the most relevant to the research question, because the question sought to obtain prevalence data, on which secondary analysis was conducted.

Table 2.3: Search terms and combinations used for searching the databases

Keyword 1	Keyword 2	Keyword 3	Keyword 4	Keyword 5
anthropometry OR 'anthropometric measures' OR 'anthropometric measurements' OR 'body measurements'	school chair OR school furniture	mismatch OR match OR fit	definition	'high school' OR adolescents OR teenagers

2.3.1.1 Inclusion criteria

Included in the review were observational studies reporting on the definition or prevalence of the anthropometric mismatch of high school learners in relation to their school chair dimensions. Studies from anywhere in the world was included.

2.3.1.2 Exclusion criteria

Articles were excluded if they were not in English, or if they were not available in full text. No date exclusions applied.

2.3.1.3 Independence of decision-making

Disagreements between the two reviewers were discussed, and consensus reached where possible. When agreement could not be reached, a third reviewer was consulted for a resolution about the relevance of the article to the review.

2.3.1.4 Methodological appraisal

The Critical Appraisal Skills Program (CASP) for Qualitative designs was adapted to appraise the eligible studies. Two reviewers assessed the selected studies and reached consensus on the final results. A third reviewer was consulted to adjudicate if there were any disagreements.

The adapted CASP consisted of a series of eight criteria assessing the rigour, credibility and relevance of the studies. A dichotomous score (yes/no) was used to assess all criteria and evidence supporting the response to each criterion was tabulated. A total score was not derived and the methodological quality of the included studies was narratively summarised.

The criteria were as follows:

- *Was there a clear statement of the aims of the research?*

- *Was the research design appropriate to address the aims of the research?*
- *Was the recruitment strategy appropriate to the aims of the research?*
- *Were the data collected in a way that addressed the research issue?*
- *Have ethical issues been taken into consideration?*
- *Was the data analysis sufficiently rigorous?*
- *Is there a clear statement of findings?*
- *How valuable is the research?*

2.3.1.5 Data extraction

One reviewer (SvN) extracted the data using a purpose-built data extraction form recording information on study design, population, age, gender and anthropometric profiles (Addendum B). If data were found to be missing, principal authors of the included studies were contacted and the additional information requested. A second reviewer (KB) audited the data extraction accuracy from 10% randomly selected articles. Consensus between the two reviewers was reached regarding the data extracted from the primary studies.

2.3.1.6 Data analysis

No statistical analysis was performed, as the aim of the targeted review was to ascertain which definitions were used to define a chair-learner misfit in the high school population.

2.3.2 Results

2.3.2.1 Study selection

Table 2.4 shows the study selection process that was followed. After exclusion of the duplicated references, both reviewers (SvN and KB) read 16 titles and abstracts. The most frequent reasons for exclusion were: the studies located did not report on the mismatch between furniture and body dimensions, and the studies used samples from a younger age group. Finally, six studies were included in the review (Castellucci *et al.*, 2010; Cotton *et al.*, 2002; Dianat *et al.*, 2013; Gouvali & Boudolos, 2006; Parcells *et al.*, 1999; Saarni *et al.*, 2007).

Table 2.4: Number of hits per database

Database	Search no.	Keywords used	No. of relevant hits
EBSCOhost:	1	1 + 2 + 3 + 4 + 5	0
Academic Search Premier; Australia/New Zealand Reference Centre; CINAHL; Ergonomics Abstracts; ERIC; Health Source (consumer and nursing/academic editions) MasterFILE Premier; SPORTdiscus	2	1 + 2 + 3 + 5	4
Pubmed	1	1 + 2 + 3 + 4 + 5	0
	2	1 + 2 + 3 + 5	11
OVID: AMED; EMBASE; MEDLINE	1	1 + 2 + 3 + 5	1
SAGE	1	1 + 2 + 3 + 5	0
Total number of hits			16
Excluded after review of the title and abstract (not relevant; duplicates)			4
Excluded after review full paper			6
Total number of papers included			**6**

2.3.2.2 Study characteristics

Table 2.5 reports on the characteristics of the studies included in this section of the review. Five of the six studies had a sample size of fewer than 300 learners (Castellucci *et al.*, 2010; Cotton *et al.*, 2002; Gouvali & Boudolos, 2006; Parcells *et al.*, 1999; Saarni *et al.*, 2007), with only Dianat *et al.* (2013) reporting on a large sample size (n=978 children). Only two studies (Dianat *et al.*, 2013; Gouvali & Boudolos 2006) examined the mismatch of learners older than 14 with furniture. Five of the six studies used the same definition for SD mismatch (where an SD mismatch is defined as the SD being either smaller than or equal to the BPL or when the SD is larger than or equal to 95% of the BPL) (Castellucci *et al.*, 2010; Cotton *et al.*, 2002; Dianat *et al.*, 2013; Gouvali & Boudolos 2006; Parcells *et al.*, 1999), and one study failed to report on the SD mismatch (Saarni *et al.*, 2007). Moreover, all the included studies used the same definition for SH mismatch (Castellucci *et al.*, 2010; Cotton *et al.*, 2002; Dianat *et al.*, 2013; Gouvali & Boudolos, 2006; Parcells *et al.*, 1999; Saarni *et al.*, 2007), using the equation:

$$(PH+3)\cos 30° \leq SH \leq (PH+3)\cos 5°$$

which converts to

$$0.8660(PH+3) \leq SH \leq 0.9962(PH+3)$$

(with the number three being the allowance for footwear).

The following equation is marginally different to $SH \geq 95\%$ or $\leq 88\%$ of PH, as demonstrated in the example:

1. $(PH)\cos 30° \leq SH \leq (PH)\cos 5°$

   $\Rightarrow (PH)\ 0.86 \leq SH \leq (PH)\ 0.99$

2. $SH \geq 88\%$ or $\leq 95\%$ of (PH)

   $\Rightarrow (PH)\ 0.88 \leq SH \leq (PH)\ 0.95$

Regarding mismatch between body dimensions and furniture, Saarni *et al.* (2007) subtracted the PH from chair height to define a mismatch. Only three of the included studies defined a mismatch between SD and HW, and all three studies used the same definition (Castellucci *et al.*, 2010; Dianat *et al.*, 2013; Gouvali & Boudolos, 2006).

The mismatch equations can be described as follows:

- *PH against SH: When the SH is larger than 95% of the PH or when the SH is 88% smaller than the PH (SH>95% or <88% of the PH)*
- *BPL against SD: When the SD is either smaller than or equal to the BPL or when the SD is larger than or equal to 95% of the BPL (SD is either ≤80% or ≥95% of the BPL)*
- *HW against SW: When 110% of the HW is smaller than or equal to the SW or when the SW is smaller than 130% of the HW (110% HW≤ SW≤ 130% HW)*

Table 2.5: Study characteristics

				Mismatch criteria		
Authors	**Country**	**Age groups**	**Sample size**	**PH against SH**	**BPL against SD**	**HW against SW**
Castellucci *et al.* (2010)	Chile	12–14 years	195 (94 boys, 101 girls)	(PH+3) cos30°≤SH≤(PH+3)cos5°	SD ≤80% or ≥95% of BPL	HW < SW (designated for the 95th percentile of HW distribution or for the largest HW)
Cotton *et al.* (2002)	USA	Grades 6–8	211 (106 boys and 105 girls)	SH>95% or <88% of PH	SD ≤80% or ≥95% of BPL Modified to: 0.80 BPL ≤SD ≤ 0.99 BPL	–
Dianat *et al.* (2013)	South-east Iran	15–18 years	978 (480 boys and 478 girls)	SH>95% or <88% of PH PH+3) or cos30°≤SH≤(PH+3)cos	SD ≤80% or ≥95% of BPL	110% HW≤ SW≤ 130% HW
Gouvali & Boudolos (2006)	Greece	6–18 years	274	SH>95% or <88% of PH	SD ≤80% or ≥95% of BPL Modified to: 0.80 BPL ≤SD ≤ 0.99 BPL	1.1H≤SW≤1.30H
Parcells *et al.* (1999)	USA	11–13 years	74 (37 boys and 37 girls	SH>95% or <88% of PH	SD ≤80% or ≥95% of BPL	–
Saarni *et al.* (2007)	Finland	12 and 14 years	101 (44 boys and 57 girls)	PH- SH	–	–

2.3.2.3 Methodological appraisal

Table 2.6 provides the dichotomous responses of the included studies for each of the CASP criterion.

Table 2.6: Response to CASP criteria

Study	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8
Castellucci *et al.* (2010)	✓	✓	×	?	✓	✓	✓	✓
Cotton *et al.* (2002)	✓	✓	×	?	✓	✓	✓	✓
Dianat *et al.* (2013)	✓	✓	✓	?	✓	✓	✓	✓
Gouvali & Boudolos (2006)	✓	✓	×	?	✓	✓	✓	✓
Parcells *et al.* (1999)	✓	✓	×	?	✓	✓	✓	✓
Saarni *et al.* (2007)	✓	✓	×	?	✓	✓	✓	✓

✓ = indicates “met criteria”

× = indicates “does not meet criteria”

? = indicates “unsure/unclear”

Table 2.7 provides justification for selected criteria (criterion 1, 3, 4 and 7).

Table 2.7: Justification for selected criteria

	Statement of the aims	**Recruitment strategy**	**Measurement tools**	**Statement of findings**
Castellucci *et al.* (2010)	To compare 3 different school furniture dimensions with the anthropometric characteristics	3 different schools	Chair: metal tape measure Anthropometrics: portable anthropometer	Seat height, should be considered in the design of classroom furniture.
Cotton *et al.* (2002)	To compare student body dimensions of children/adolescents to classroom desk dimensions.	8 different school systems	Chair: tape measure and angle finder. Anthropometrics : Stadiometer	Subjects did not fit chairs.
Dianat *et al.* (2013)	To provide information on learners' anthropometry to be used in the design of school furniture	randomly selected from high schools	Chair: wooden right angle and measuring tape. Anthropometrics: anthropometer, adjustable chair,	The results indicated a considerable mismatch between body dimensions and school furniture.
Gouvali & Boudolos (2006)	to examine the match between the dimensions of school desks and seats and the anthropo-metrics of learners	6 schools were selected	Chair: Not stated Anthropometrics: anthropometric chair	Seat height were bigger than the accepted limits for most children
Parcells *et al.* (1999)	To identify a mismatch between anthropometrics and the classroom furniture	convenience sample from 1 school district	Not stated	Seating arrangements in their classrooms are not conducive to learning.
Saarni *et al.* (2007)	To study how conventional desks and chairs at school match with the anthropometrics of learners	2 schools	Chair: plastic ruler, metal right angle, Anthropometrics: wooden measure board and digital scales	The results indicate that there is a mismatch between school furniture and the anthropometrics of school-children.

All studies incorporated a cross-sectional study design, although all except one study included a convenient sample. It is strongly advisable that the sample is randomly recruited to reduce selection bias thereby ensure that the findings can be generalised to the population (Joubert & Ehrlich 2007). Dianat *et al*. (2013) reported that the included sample was randomly selected, but failed to elaborate on the type of randomisation used and the randomisation method was also not stated.

A variety of tools were utilized in the measurement of the school furniture and anthropometric parameters of the school children. For this reason a comparison between studies was hindered. Furthermore, a discrepancy existed between the tools used to measure the school furniture and the anthropometric parameters of the school children. Since the aim of the studies were primarily to compare the match between the furniture and the anthropometrics of the children, this discrepancy between the choice of measurement tools may have resulted in systematic measurement error. In addition, the reliability of the tools utilized in the included studies was not reported. All studies stated that one consistent measurer was used throughout the study, but none of the studies commented on blinding or masking of the measurer. No information or data were provided in any of the included studies regarding the repeatability of the measurement procedure.

The included studies provided valuable information about data analyses approaches. Four of the studies (Castellucci *et al*., 2010; Dianat *et al*., 2013; Gouvali & Boudolos, 2006; Parcells *et a*l., 1999) presented the data into three categories. Cotton *et al*. (2002) described the data into two categories while Saarni *et al*. (2007) provided a descriptive summary of the data.

2.3.3 Summary

The current section of the literature review indicates that there are few differences in the definitions that have been used to describe a mismatch between the anthropometric measurements of high school learners in relation to school chair dimensions. The basic matching criteria as originally quoted by Bendix (1984 & 1985) were incorporated in all of the included studies although different anthropometric parameters were reported. It therefore appears that this is the only matching criteria currently recognized by researchers in this field. Overall, the included studies provided valuable information regarding the feasibility of utilising the mismatch criteria in a school setting.

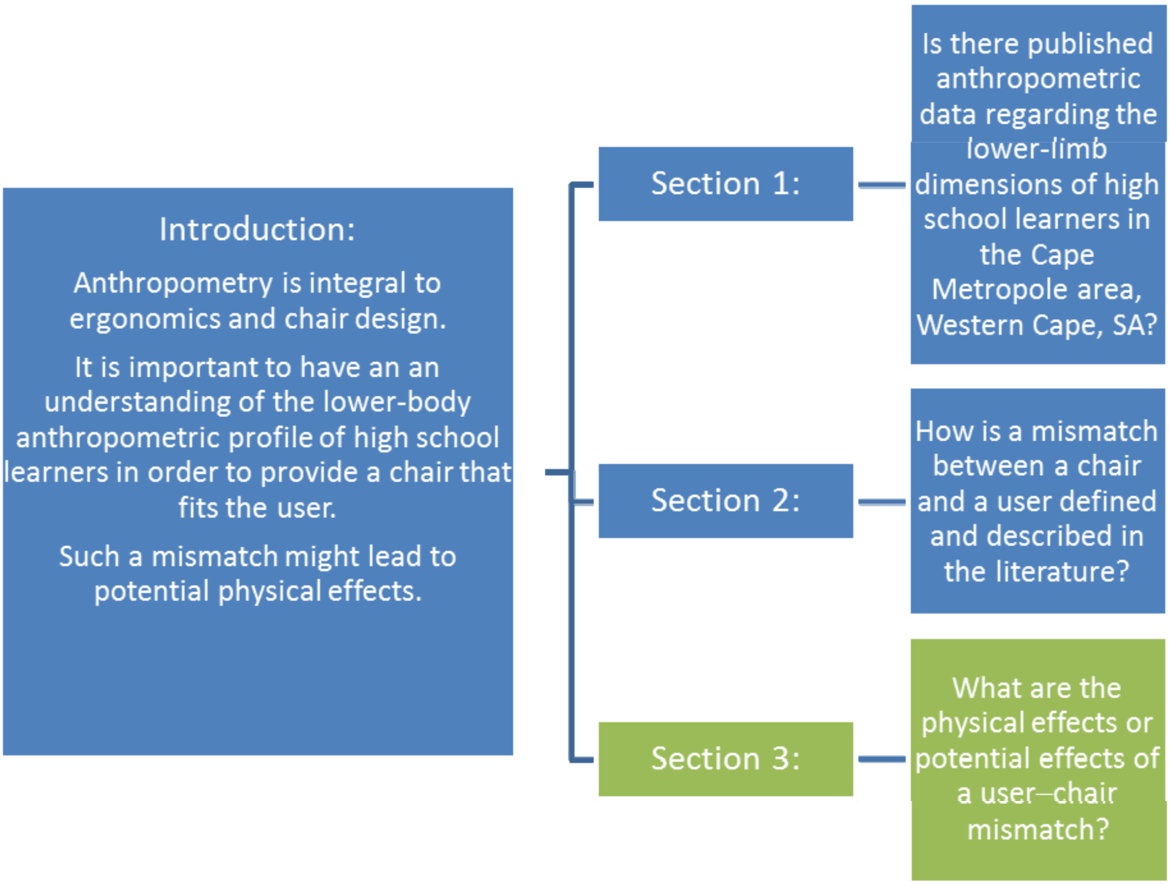
Thus, for purposes of the research reported in the present thesis, the following equations will be used to define a mismatch:

- *SH and PH mismatch: SH≤88% or ≥95% of PH;*
- *SD and BPL: SD ≤80% or ≥95% of BPL; and*
- *SD and HW: 110% HW≤ SW≤ 130% HW.*

This section of the review highlights the limited literature base reporting on the mismatch between anthropometric measures of high school learners and school chair dimensions. The literature largely focuses on the chair-learner mismatch in a population that is younger than 14 years old (Brewer *et al.*, 2009; Castelluci *et al.*, 2010; Chung & Wong, 2007; Cotton *et al.*, 2002; García-Acosta &. Lange-Morales, 2007; Milanese & Grimmer 2004; Oyewole *et al.*, 2010; Panagiotopoulou *et al.*, 2004; Parcells *et al.*, 1999; Saarni *et al.*, 2007).

2.1

2.4 Section 3: Effect of a user-chair mismatch



2.4.1 Methodology

In Section 3 we asked the question: “What is the physical effect of a mismatch between the anthropometric measurements of a school learner in relation to the school chair dimensions?” We performed a purposive literature search, seeking the seminal textbooks that inform the practice in the area of ergonomical chair design principles, in relation to the effect of poorly fitted chairs, in an attempt to answer the above question. The texts were cited in the literature identified in the earlier section, and were identified by ergonomist experts, as the lead researchers whose work has shaped the current understanding of ergonomics. Work from the following authors was included: Grandjean (1973), Oxford (1969) and Pheasant (1996).

2.4.2 Summary of the literature

2.4.2.1 Effect of a seat height mismatch

The literature shows that, if the seating surface is too high, the underside of the thigh becomes compressed, causing discomfort and restriction in blood circulation (Pheasant 1996). To compensate for the above, a seated person usually moves their buttocks forward on the chair seat (Grandjean, 1975; Oxford, 1969; Pheasant, 1996). The result can be the assumption of a slumped, kyphotic posture, due to lack of the effective use of the back. In addition, the feet lack proper contact with the floor surface (heels are off the floor), and the body stability is weakened (Grandjean, 1975; Oxford, 1969; Pheasant, 1996). In contrast, if the seat surface is too low, the knee flexion angle becomes small, the user’s weight is transferred to a small area at the ischial tuberosities, and there is a lack of pressure distribution over the posterior thighs (Pheasant, 1996). The sitter would then be required to assume a position of greater hip flexion than 90 degrees to accommodate the mismatch, which would increase the degree of lumbar flexion involved in sitting (Pheasant, 1996).

2.4.2.2 Effect of a seat depth mismatch

If the seat pan depth were greater than the BPL of the sitter, he/she would be unable to utilise the backrest of the seat to support the lumbar spine in sitting, and there might also be a tendency to increase the pressure over the posterior calf muscle (Pheasant, 1996). If the seat pan depth were significantly less than the BPL of the sitter, the thighs would not be supported in sitting (Pheasant, 1996).

2.4.2.3 Effect of a seat width mismatch

Although none of the authors whose work was consulted commented on the effect of a seat width (SW) mismatch, they did recommend that the SW should be sufficient to support ischial tuberosities, in order to achieve stability and to allow space for lateral movements (Pheasant, 1996). The SW should also be large enough to accommodate even those users with the largest hip breadth, in order to ensure clearance between the armrests (Pheasant, 1996). The recommendations above suggest that a 'too small' SW might lead to instability in someone sitting with unsupported ischial tuberosities, and that it might produce undue pressure on the lateral sides of the thighs, if armrests are present.

Research also shows that a 'too small' SW might result in unsteadiness and in mobility constraint (Evans, Courtney & Fok, 1988; Helander, 1997; Khalil, Abdel-Moty Rosomoff & Rosomoff, 1993; Occhipinti, Colombini, Molteni & Grieco, 1993; Orborne, 1996; Sanders & McCormick, 1993).

2.4.3 Summary

Social and economic changes that have occurred since apartheid was dismantled in 1992 and have possibly influenced the current school learners' body dimensions. Therefore, pre-1995 adolescent anthropometric data in South Africa, or data from other Western countries, might not be an accurate representation of the current South African situation. Current South African teenagers' anthropometry has not been described, and, therefore, there is no foundation on which to base the ergonomically-sound purchase of school furniture for computer laboratories in South African schools.

In a comprehensive systematic review of the literature, only two studies were found that described the mismatch of furniture to body dimensions, relevant to high school learners. The most common formulae provided for calculation of the mismatch of body dimensions to seat dimensions relevant to adolescents are:

- *SH and PH mismatch: SH≤88% or ≥95% of PH;*
- *SD and BPL: SD ≤80% or ≥95% of BPL; and*
- *SD and HW: 110% HW≤ SW≤ 130% HW.*

There is evidence that indicates that biomechanical imbalance and musculoskeletal symptoms can develop if a chair is mismatched with an adolescent learner.

CHAPTER 3

Anthropometric measurements

3.1 Introduction

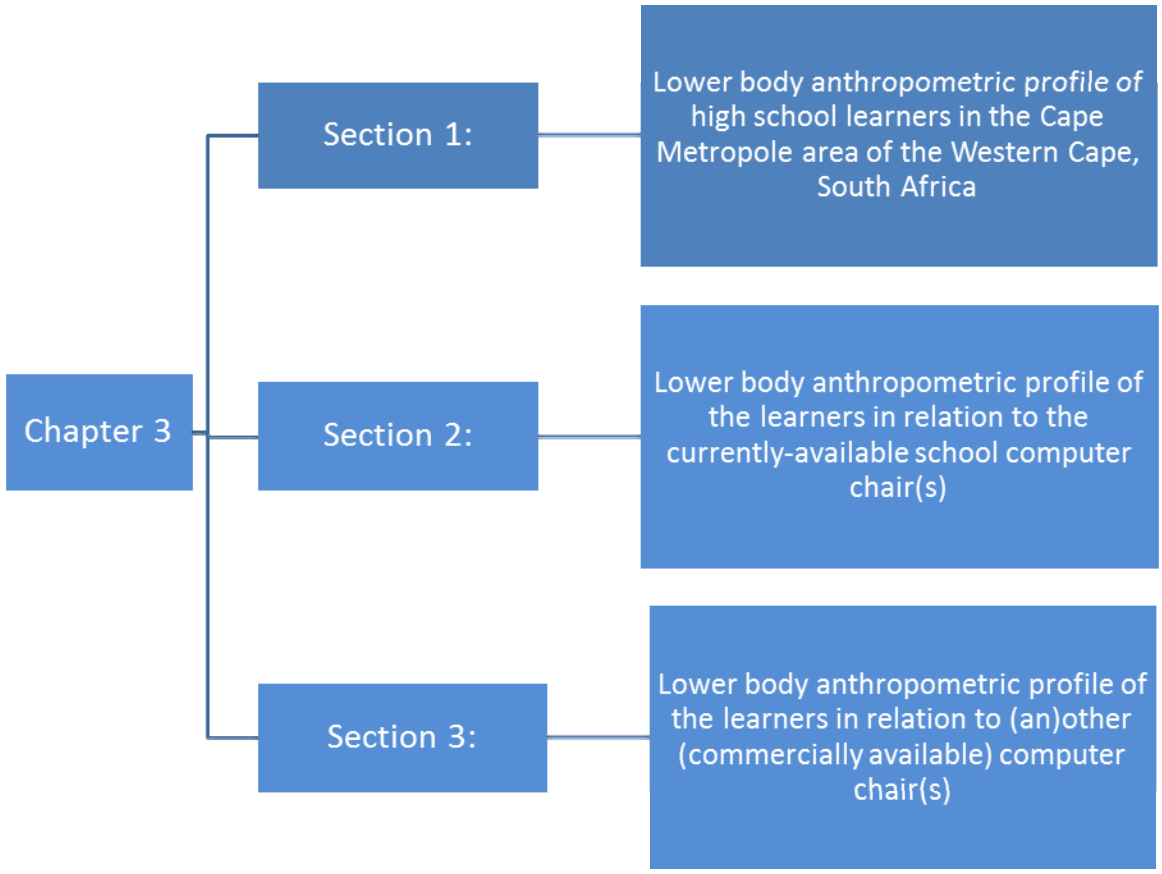
Due to the lack of published South African anthropometric lower-body profiles for adolescents (which was established in Chapter 2), it was necessary to establish an estimate of the anthropometric profile of high school learners in the Cape Metropole area of the Western Cape, South Africa, prior to examining the fit of adolescents to school furniture. The step concerned was a prerequisite that was undertaken prior to examining the match of adolescents' anthropometrics to school furniture. Establishing whether the specific group of learners fitted the standard school computer chair entailed identifying opportunities for determining whether there was a mismatch, and, if so, the extent of the mismatch concerned. If the mismatch were to be found to give rise to concern, the next step of the study would be to determine whether there were other available chairs that could better fit the anthropometric profile of the group of learners involved.

The current chapter will be presented in three separate sections (Figure 3.1).

In **Section 1**, the lower-body anthropometric profile of high school learners in the Cape Metropole area of the Western Cape, South Africa is reported on. Following on such reporting, the mismatch between the lower-body anthropometric profile of the learners in relation to the currently-available school computer chair(s) (**Section 2**) and commercially available chairs (**Section 3**) is determined.

Therefore, the specific sections of the current chapter are as follows:

- *Lower-body anthropometric profile of high school learners in the Cape Metropole area of the Western Cape, South Africa;*
- *Lower-body anthropometric profile of the learners in relation to the currently available school computer chair(s); and*
- *Lower-body anthropometric profile of the learners in relation to other (commercially available) computer chair(s).*



3.1 Section 1: The lower-body anthropometric profile of high school learners in the Cape Metropole area of the Western Cape, South Africa

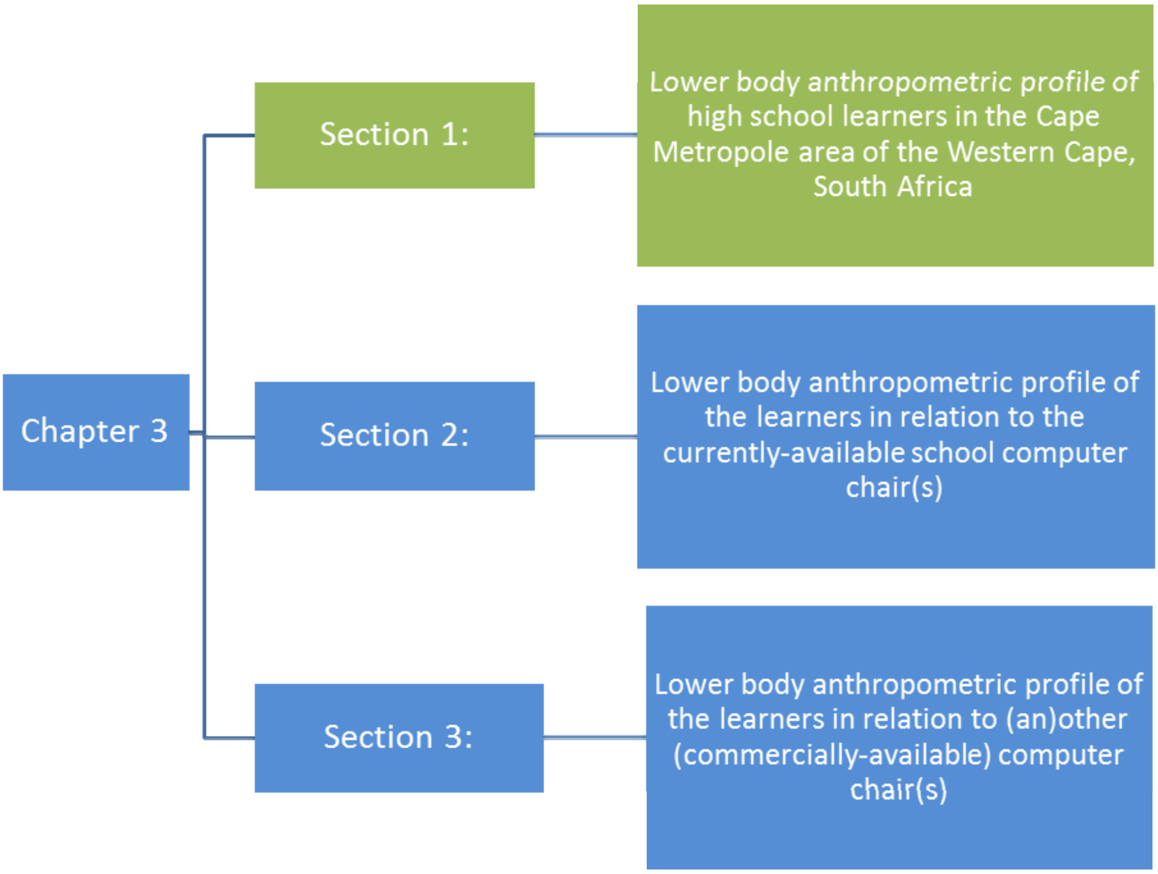


Figure 3.1: Illustration of the layout of Chapter 3

Section 1 aims at answering the following question: What is the anthropometric profile of high school learners aged 13 to 18 years in the Cape Metropole area of the Western Cape, South Africa?

To answer the above question, the anthropometric profile of 13- to 18-year-old learners in the Cape Metropole area of the Western Cape, South Africa was embarked upon by measuring the different relevant body dimensions. The body dimensions measured were as follows:

- *stature;*
- *weight;*
- *PH;*
- *BPL; and*
- *HW.*

The above-mentioned measures are important, because they are integral to the fit of a computer chair to the individual (Chapter 2).

3.1.1 Methodology

3.1.1.1 Study design

A cross-sectional observational study was conducted during August 2011. This study design was chosen to gain insight into the point-prevalence of the mismatch between the Cape Metropole high school learners' anthropometric profile and the chair(s) that are currently used in the school computer laboratory setting.

3.1.1.2 Sampling procedure

Four Education Management and Development Centres (EMDC's), which constitute the greater Cape Town school population (Figure 3.2), formed the basis from which the school learners were randomly sampled.

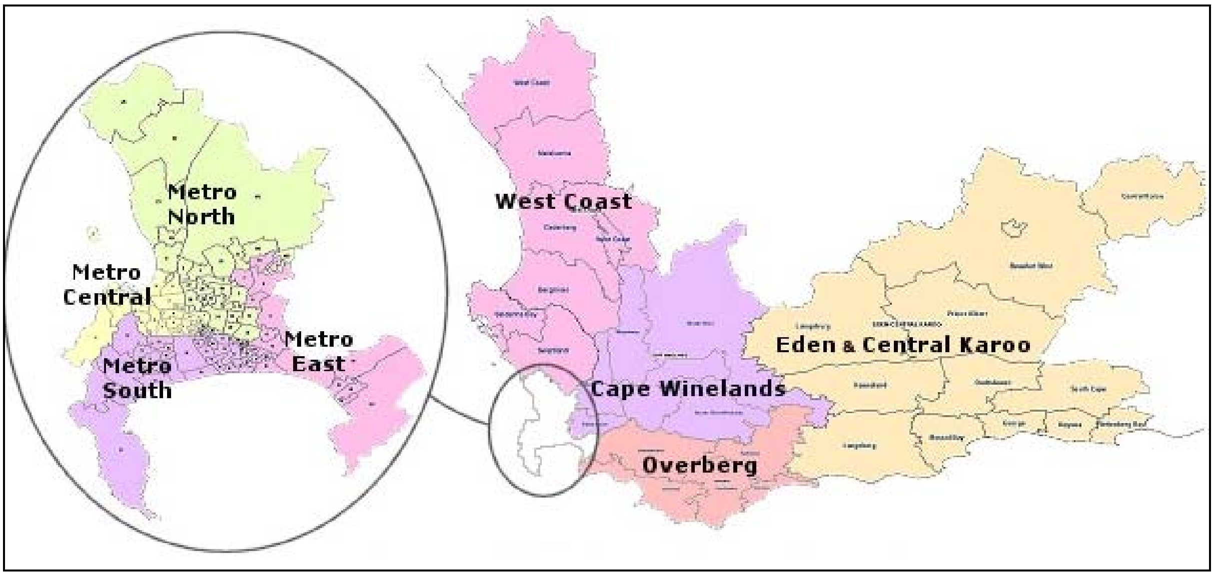


Figure 3.2: The four EMDCs concerned in the current study

Since, no lower body anthropometric data were currently available to use as reference for a sample size calculation, it was decided that a *post-hoc* power analysis would be calculated after data had been collected from the most robust sampling frame possible. The following procedure was followed to obtain a robust sampling frame. The input of a specialist statistician in the field of sampling methodologies was obtained, with the process described below being largely based on the advice made available thereby. The description is based on a possible sample of 1500 learners to ensure that a process for sampling was in place if a larger sample were needed after a mid-sample *post-hoc* power calculation was performed.

A list of the schools within each district was obtained, as were the details respecting the number of learners (Grades 8–12) in each school who took Computer Studies as a subject. The situation is graphically represented in Figure 3.3.

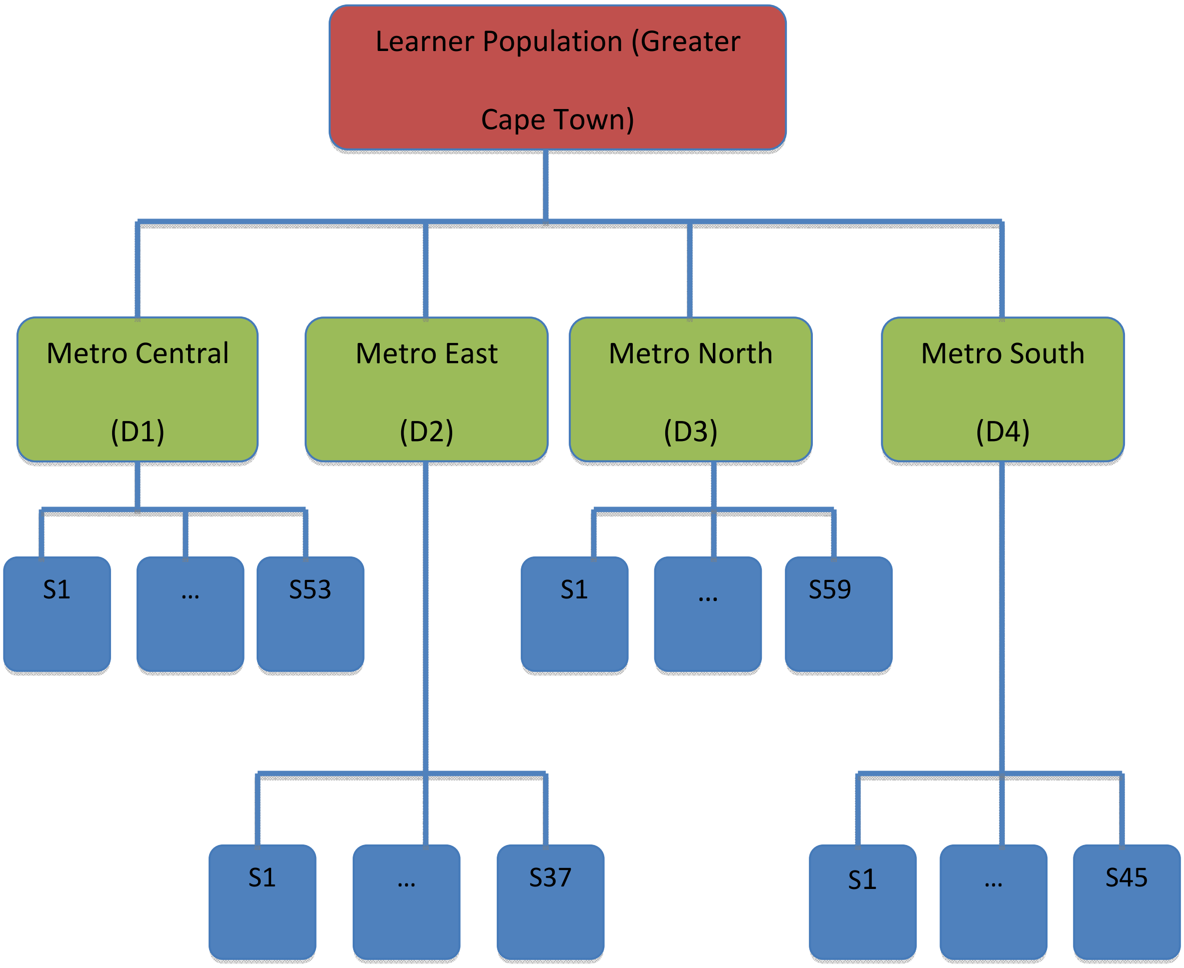


Figure 3.3: The Cape Town school population

The four different educational districts were regarded as strata, with the schools being regarded as clusters within each stratum. A stratified two-stage cluster sample was followed, using a method of proportional allocation. All learners between the ages of 13 and 18 years taking Computer Studies as a subject were eligible for inclusion.

More clusters were sought within each stratum, rather than increasing the number of learners within each cluster, so as to ensure that school representation remained the primary unit for randomisation. For the specified reason, from each of the chosen clusters (i.e. schools), 36 learners were randomly selected from the available Grade 8- to Grade 12-learners. The following table (Table 3.1) outlines the outcome of the sampling procedure.

Table 3.1: The outline of the sampling results

District	Population of schools (2009)	Population of learners (2009)	Proportional allocation	Number of schools with 30 learners per school	Weight per learner
Central	53	4 474	303	10	14.91
East	37	5 021	340	11	15.22
North	59	8 856	601	20	14.76
South	45	3 769	256	9	13.96
TOTAL	194	22 120	1 500	50	

The 36 learners per school comprised six learners per age group (13–18 years). For the randomly selected schools, three boys and three girls per age group were randomly selected from the group of learners for whom parental consent was obtained (all learners were invited to participate). The number of schools within the district, with 30 computer learners per school, indicated the number of schools sampled per district. However, since the above procedure is not that of simple random sampling, the weights of each unique sampled unit were not the same. The issue in question was considered when calculating descriptive statistics for the sample in general. A simplistic explanation of the weights used is that the weight for a district represents the number of learners in the total population that each learner sampled ‘represents’.

The schools in each district were sampled as follows (using the Metro Central district as an example): A list of all the schools within the specific district had already been obtained.

The list was sorted from smallest to largest school (i.r.t. Computer Studies learner numbers). For the sorted list, the cumulative number of learners was calculated. Table 3.2 illustrates the example of the Metro Central district.

Table 3.2: An example of the sampling process undertaken in relation to the Metro Central district

School	Number of learners taking Computer Studies (Gr 8–12)	Cumulative total
1	45	45
2	27	72
….	….	….
53	113	4 474

From Table 3.2, random numbers between 1 and 4 474 were generated. For example, if the random number was between 0 and 45, then School 1 was included in the sample. However, if the random number was between 45 and 72, then School 2 was selected for the sample, and so forth. The previous step was repeated until the desired number of schools for that specific district had been sampled.

In each school, the 36 required learners were chosen according to a simple random sampling procedure. If, for some reason, a sampled school had fewer than 36 learners from Grades 8 to 12 taking Computer Studies, then the details of the school immediately before the sampled school on the list were combined with the details of the sampled school, so that 36 learners in total were sampled from the two schools in question. The step concerned was taken provided that the school immediately before the sampled school was not already in the sample. In the unlikely event that such occurred, the details of the school after the sample school were combined with the details of the school with insufficient numbers.

3.1.1.3 Ethical approvals

The Committee for Human Research at Stellenbosch University and the Western Cape Department of Education approved the study. Individual schools, parents and subjects provided written informed consent permitting participation.

3.1.1.4 Subject recruitment and invitation

A letter of invitation was sent to each of the randomly-selected schools via post and e-mail. The letter (Addendum C) informed the school principal of the details of the research project, and invited them to participate in the study. The letter was followed up telephonically, and the principal was asked to specify an appropriate date and time on which to meet with the researcher.

A combined meeting with the Grades 8 to 12 learner classes was arranged and held at the school. The aims of the study were discussed, as were the tasks that would be expected of them, if they wished to participate in the study. They were also asked about their availability during the proposed data collection period.

During Phase 1, when anthropometric measurements were taken, the learners missed only one hour of school time. The most appropriate times for testing were agreed upon by the principal researcher and the school principal. The inclusion and exclusion criteria were explained. A consent form (Addendums D and E) was handed to all learners who had indicated their willingness to participate in the study. The consent forms were completed by the learner's parent, by the legal guardian concerned (Addendum D), or by the learner him/herself if the learner was 18 years old (Addendum E). The completed forms were collected two days later. An appointment was set up with each school on a convenient date for testing. A telephone call was made to the school's principal, a week prior to the chosen date, in order to confirm the appointment.

3.1.1.5 Study setting

The data collection for the anthropometric measurements of the learners took place in a normal classroom at each of the selected schools.

3.1.1.6 Role of research assistants

Seven trained research assistants were responsible for taking the anthropometric measurements of the participating learners. The principal researcher (SvN) was responsible for taking the measurements of the different computer chairs (school/commercial). The assistants underwent a training session which included training regarding the measurement procedure and a practical session. During the practical session, each assistant was required to measure each of the parameters three times to obtain a measure of repeatability (interand intra-rater repeatability). The raw data demonstrating the repeatability of the assistants is presented in Addendum F.

3.1.1.7 Data capturing procedure

The learners were greeted upon arrival by the principal researcher, who explained the logistical arrangement that had been made for the testing. All the anthropometric measurements, except for stature and weight, were taken with the learner in a seated position, with feet on the floor. The research assistants measured four learners simultaneously. For the taking of the measurements, five minutes per learner was necessary. Thus, with four learners being measured simultaneously, 40 minutes (amounting to one study period) was required per school. Stature was measured as the vertical distance from the floor to the top of the head (Parcells et al 1999). The learner was asked to stand erect, whilst looking straight ahead (Parcells et al 1999). For the remaining measurements the learners were instructed to sit in such a way that their thighs were in full contact with the seat, with their trunk upright (Gouvali & Boudolos, 2006). The learners' feet were bare and placed on an adjustable horizontal step, if necessary, to ensure postural positioning (Gouvali & Boudolos, 2006; Panagiotopoulou *et al.*, 2004).

Anthropometric measurements were taken by means of a measuring tape that was marked out in millimetres. Weight was measured with a standard bathroom scale, in grams. The following body dimensions were measured:

- *PH;*
- *BPL;*

- *HW;*
- *stature; and*
- *body weight.*

When using all vertical data (i.e. stature and PH), an allowance for footwear (25mm) was added to ensure that the relationship reflected the 'real-world' environment, as all measurements were taken in an unshod state, and all of the learners were required to wear shoes during school hours.

3.1.1.8 Statistical analysis

Data analysis, using SAS and MS Windows Excel, was used to compute the descriptive statistics (mean, standard deviation [SD], 5% and 95% percentiles, Shapiro-Wilks) required, so as to describe the variability of physical characteristics of the learners concerned. The post-hoc power analysis was calculated midway through the sample collection, when approximately 690 children had been collected, using a population sample calculator software (EpiInfo Version 10). The approach sought an estimated two-tail sample, in which at least ten in each subset (gender and age) fell between 0% and 5% and between 95% and 100%, assuming a normal distribution of the height data for age and gender. The calculation identified that sufficient power had already been reached, as, for an overall sample power of 95%, the total sample should have been in the order of 720, and, for 90% power, the sample should have been approximately 580. Therefore, the sample already collected was powered somewhere between 90% and 95%.

3.1.2 Results

3.1.2.1 Sample size

A total number of 20 schools participated in the study. One school, which initially agreed to participate in the study, withdrew during data capturing due to other school engagements on the day. Only five learners could be measured from the particular school. The number of schools per EMDC, the number of learners who participated per district, and the percentage weight of each district are indicated in Table 3.3.

Table 3.3: Number of participating schools and learners per EMDC

Districts	Participating schools	Participating learners	Percentage (%) weight
Metropole Central	4	113	20
Metropole East	5	180	25
Metropole North	8	288	40
Metropole South	3	108	15
Total	20	689	

The total consenting sample consisted of 689 learners (342 boys, 347 girls) aged between 13 and 18 years. The number of learners in each age group is described in Table 3.4 .

Table 3.4: Number of study participants

Gender	13 years	14 years	15 years	16 years	17 years	18 years	Total
Girls	54	52	64	57	59	61	347
Boys	49	57	63	59	56	58	342
Total	103	109	127	116	115	120	689

3.1.2.2 Anthropometric measurements

- Anthropometric profile

The mean and the 5th and 95th percentiles of the learners' anthropometric measures are reported in Table 3.5. The smallest 5th percentile value for the PH fell in the range of the 16-year-old girls, with the largest 95th percentile for the measurement falling in the range of the 18-year-old boys. The girls were found to range in height from 1 500 mm to 1 720 mm, whereas the boys were found to range in height from 1 407 mm to 1 900 mm. The difference in height range amongst the boys was more than double that of the girls (493 mm vs 180mm).

Table 3.5: Anthropometric range for age and gender

Age (years)	Gender	Height (mm)			Weight (kg)			PH (mm)			BPL (mm)			HW (mm)		
		Mean (mm)	5th %ile	95th %ile	Mean (g)	5th %ile	95th %ile	Mean (mm)	5th %ile	95th %ile	Mean (mm)	5th %ile	95th %ile	Mean (mm)	5th %ile	95th %ile
13	**M**	1644	1407	1780	547	352	732	442	420	492	510	390	628	336	277	400
13	**F**	1606	1490	1736	578	433	830	426	415	487	512	410	606	363	294	453
14	**M**	1662	1450	1790	604	385	860	446	430	505	506	440	595	349	285	435
14	**F**	1593	1500	1710	556	415	750	417	400	478	513	440	613	362	279	467
15	**M**	1691	1512	1830	569	438	767	445	420	510	517	430	610	340	275	424
15	**F**	1598	1510	1724	579	413	797	425	412	484	514	425	610	367	301	449
16	**M**	1689	1540	1839	585	428	896	447	425	510	513	441	625	360	300	459
16	**F**	1599	1476	1720	554	396	732	422	398	482	495	416	610	364	305	440
17	**M**	1697	1529	1860	608	416	926	451	435	510	521	429	638	353	282	458
17	**F**	1616	1496	1740	577	405	821	427	401	485	507	420	618	365	290	450
18	**M**	1711	1559	1900	599	417	807	452	434	527	509	435	592	354	279	436
18	**F**	1606	1490	1720	556	436	728	426	410	490	505	425	590	367	290	455

The anthropometric data for the total sample were normally distributed for all the anthropometric measurements. Table 3.6 provides the mean, the SD and the ρ-value for the subjects of the study, illustrating that the data were normally distributed for the entire group of learners.

Table 3.6: Indication of normal distributions per age groups for the male learners

	Height (mm)	Weight (kg)	PH (mm)	BPL (mm)	HW (mm)
Mean (SD)	1643.1 (96.7)	65.0 (14.5)	465 (30.6)	477.5 (60.8)	312.5 (51.8)
Median	1665	65	465	477.5	312.5
Mode	1600	65	440	510	350
ρ-Value	0.0638	0.0000	0.0000	0.0000	0.0000

Note: Shapiro-Will value with ρ value < 0.05 is regarded as a normal distribution.

- *The minimum and maximum percentiles for each measurement*

Table 3.7 illustrates that the minimum and maximum percentiles of the entire group vary between age and gender and do not follow the expected pattern, with the smallest 5th percentile falling in the 13-year-old male group and the largest 95th percentile in the 18-year-old male group.

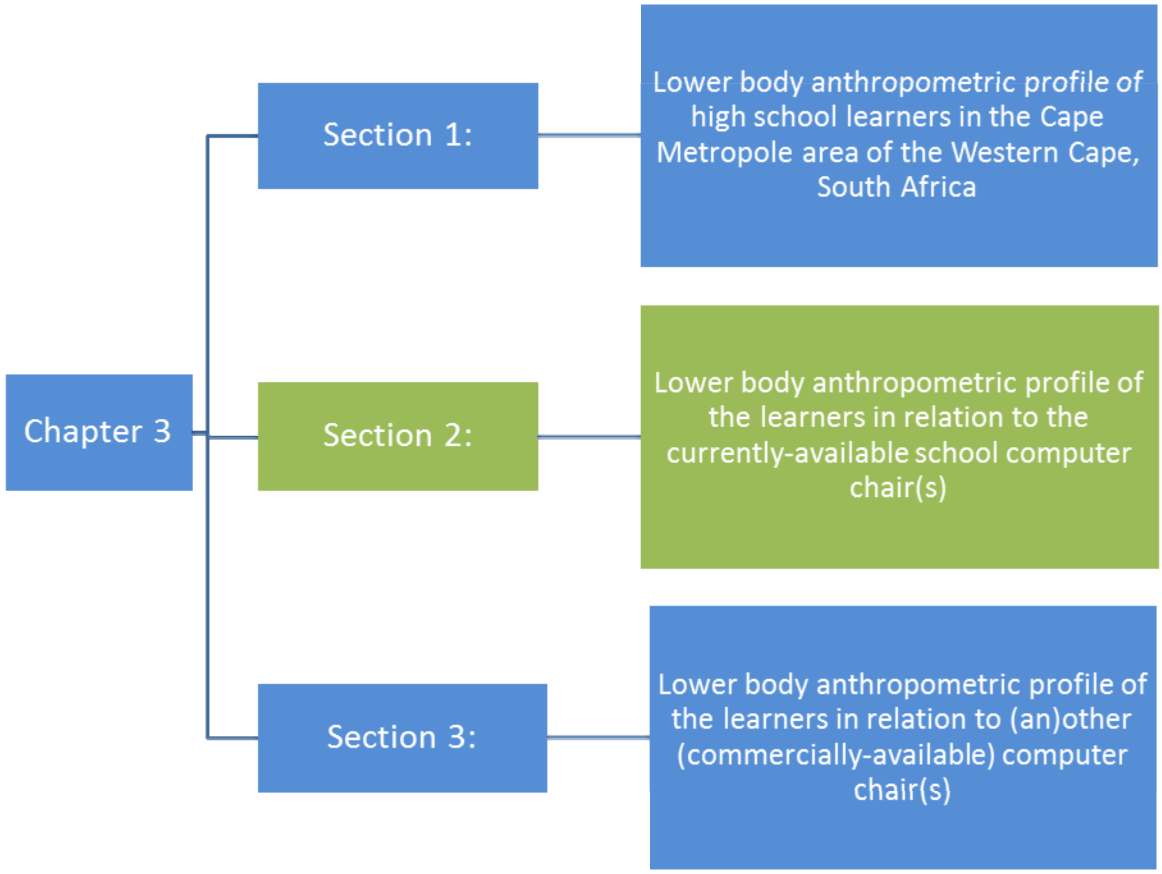
Table3.7: Fifth and 95th percentiles per anthropometric parameter

	Weight (kg)	Height (mm)	PH (mm)	BPL (mm)	HW (mm)
5th %ile	35.19	1407	398	390	275.25
Age/Gender	13/M	13/M	16/F	13/M	15/M
95th %ile	92.55	1900	526.5	638.25	466.5
Age/Gender	17/M	18/M	18/M	17/M	14/F

3.1.3 Summary

The anthropometric measures of high school learners in the Cape Metropole area of Cape Town, Western Cape, South Africa are variable in their anthropometric measurements, particularly within the gender-age groups. The sample proved to be normally distributed for each of the anthropometric measurements concerned. Demonstrating the vast variability existing within the multiracial group of adolescents, the 5th percentiles did not always fall within the 13-year-old male group, as had been expected, and, similarly, the 95^{th} percentile did not fall within the 18- year-old male group for all of the measurements. Therefore, it was of utmost importance to collect data from the specific population of interest and not to extrapolate data from other studies that focused on the anthropometric measurements of learners based in other regions of South Africa or in a different country.

3.2 Section 2: Anthropometric profile of the learners in relation to the school computer chair(s)



Over the last five years in South Africa, there has been increasing application of information communication technology (ICT) in terms of skills training and curriculum delivery in high schools. In the Western Cape of South Africa (Smith *et al.*, 2009), the Education Department equipped all schools with at least one computer laboratory per school. Nowadays, learners spend a considerable amount of time in school computer laboratories. The consistent usage of computers in schools warrants investigation into the ICT-related risk factors for the development of spinal pain in school learners.

The school computer laboratory chair is the least ergonomic aspect of school computer laboratory workstations in the Cape Metropole (Smith, 2007). The analysis of school computer workstations indicated that the chairs used in the computer laboratories in the Cape Metropole complied with less than a third of the basic ergonomic guidelines. The chair-specific shortcomings of school computer workstations included the fixed height of the backrests and arm-supports, as none of the chairs had any adjustable features (Smith, 2007). The school learners concerned were, therefore, unable to adjust the dimensions of the school chairs to match their anthropometry, consequently possibly leading to poor postural alignment.

The question was thus raised: How well do the dimensions of the computer chairs currently used in schools match the anthropometric measurements of high school learners in the Cape Metropole area of the Western Cape, South Africa?

3.2.1 Methodology

3.2.1.1 Study design

A secondary data analysis was undertaken to compare the school computer chair dimensions to the range of learners' anthropometric measurements.

3.2.1.2 Procedure

All the available types of school computer chairs were measured at each of the participating schools. The principal researcher measured the dimensions of the school computer chairs at the same time as the assistants were obtaining the learners' anthropometric measurements. The chair dimensions were measured with a metal measuring tape (Panagiotopoulou *et al.*, 2004).

The following dimensions of the school computer chair were measured:

- ***Seat height**: The distance from the highest point at the front of the seat to the floor (Gouvali & Boudolos, 2006; Panagiotopoulou et al., 2004).*
- ***Seat depth**: The distance from the back of the surface of the seat to its front (Gouvali & Boudolos, 2006; Panagiotopoulou et al., 2004).*
- ***Seat width**: The distance from the left side of the seat to its right (Gouvali & Boudolos, 2006).*

A mismatch was defined as the incompatibility between the dimensions of the school computer chair and the anthropometric dimensions of the learners concerned (Chaffin & Anderson, 1991; Parcells *et al.*, 1999). The chair dimensions with the corresponding matching criteria are presented in Table 3.8.

Table 3.8: Chair dimensions and matching criteria

Dimension	Mismatching criteria	Reference
PH and SW	SH should not be > 95% or < 88% of the PH. SH > 95% or < 88% of PH	Parcells *et al.*, 1999
BPL and SD	SD was either > 95% or < 80% of the BPL SD ≤ 80% or ≥ 95% of BPL	Parcells *et al.*, 1999
HW and SW	SW should be at least 10%, and at the most 30%, larger than the HW. 110% HW ≤ SW≤ 130% HW	Gouvali & Boudolos, 2006

3.2.1.3 Statistical analysis

Data analysis was undertaken using the Statistical Package for Social Sciences (SPSS) for MS Windows 8.0. The 5^{th} and 95^{th} percentile of the anthropometric measurements were determined for each age group and gender. The smallest 5^{th} percentile and the largest 95^{th} percentile that were noted in the subgroup analysis were then matched with the corresponding chair seat dimension, according to the standard equations listed in Table 3.8.

3.2.2 Results

One of two types of computer chairs was used in all 20 of the randomly-selected schools. Figure 3.4 illustrates the two types of chairs used in the school computer laboratories.

Figure 3.4: The two chairs used in school computer laboratories

Table 3.9 reports on the sizes of the two chairs used. The two chairs were very similar in size, with Chair 1 being 10 mm shorter than Chair 2. Chair 1 was also 10 mm narrower than was Chair 2.

Table 3.9: Dimensions of chairs used in school computer laboratory

	SH (mm)	SW (mm)	Seat length (mm)
Chair 1	440	460	370
Chair 2	450	470	360

Figure 3.5 demonstrates the percentage of learners who did not match the two school computer chairs' seat dimensions. Around 65% of the learners did not match the SH for Chair 1, and more than 75% did not match the SH of Chair 2. The SD match was worse in

Chair 2, with just over 80% of the learners not matching the dimension, compared to 75% of the learners not matching the dimension for Chair 1.

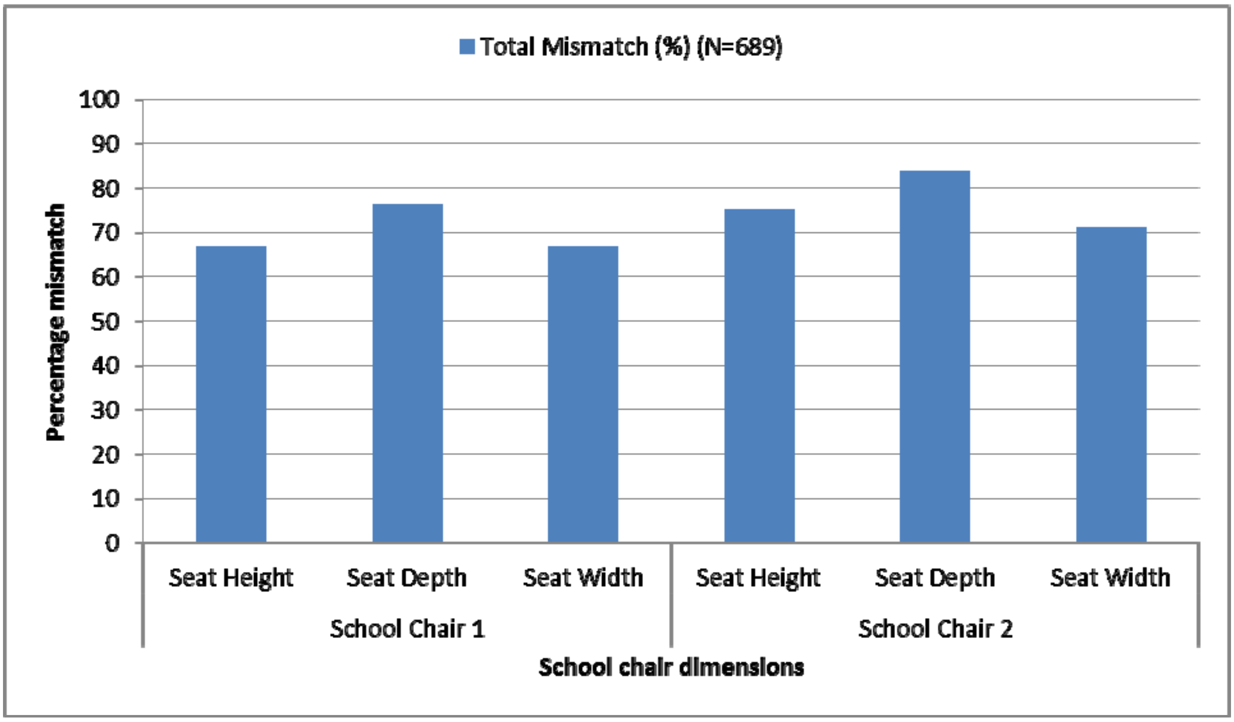


Figure 3.5: Percentage of learners whose measurements did not match the school chair

Figure 3.6 illustrates the percentage of girls and boys who did not match the dimensions of the two school chairs. Of the girls, 80% did not match the chair height of school chair 1 and just over 50% of the boys did not match the chair height of school chair 1. Of the girls, 90% were either too short or too tall for the SH of school chair 2, with 60% of the boys not matching the SH of this chair.

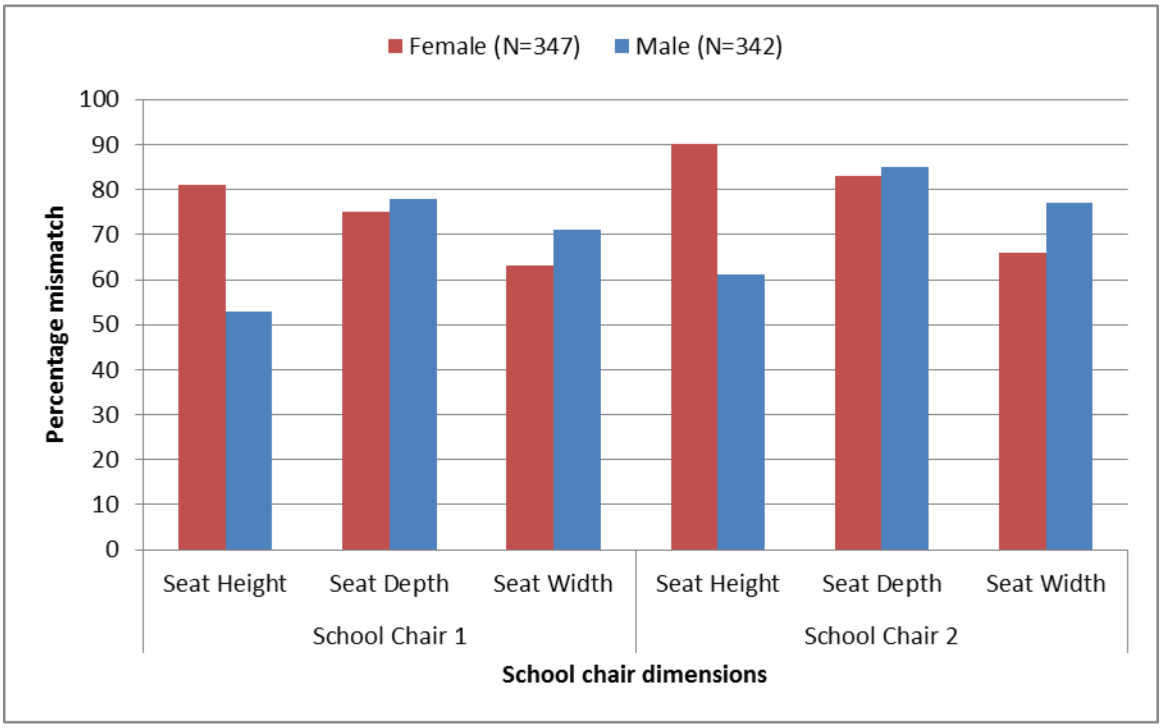


Figure 3.6: The percentage of boys and girls whose measurements did not match their chair dimensions

Table 3.10 illustrates the percentage of learners who did not match the chairs' dimensions, according to the learners' age. School chair 2 provided the worst match for all age groups in all three of the chair dimensions. Of the learners, from 70% (14-year-olds) to 82% (13-year-olds) did not fit the chair height of school chair 2, compared to 63% (17-year-olds) to 71% (18-year-olds) in school chair 1.

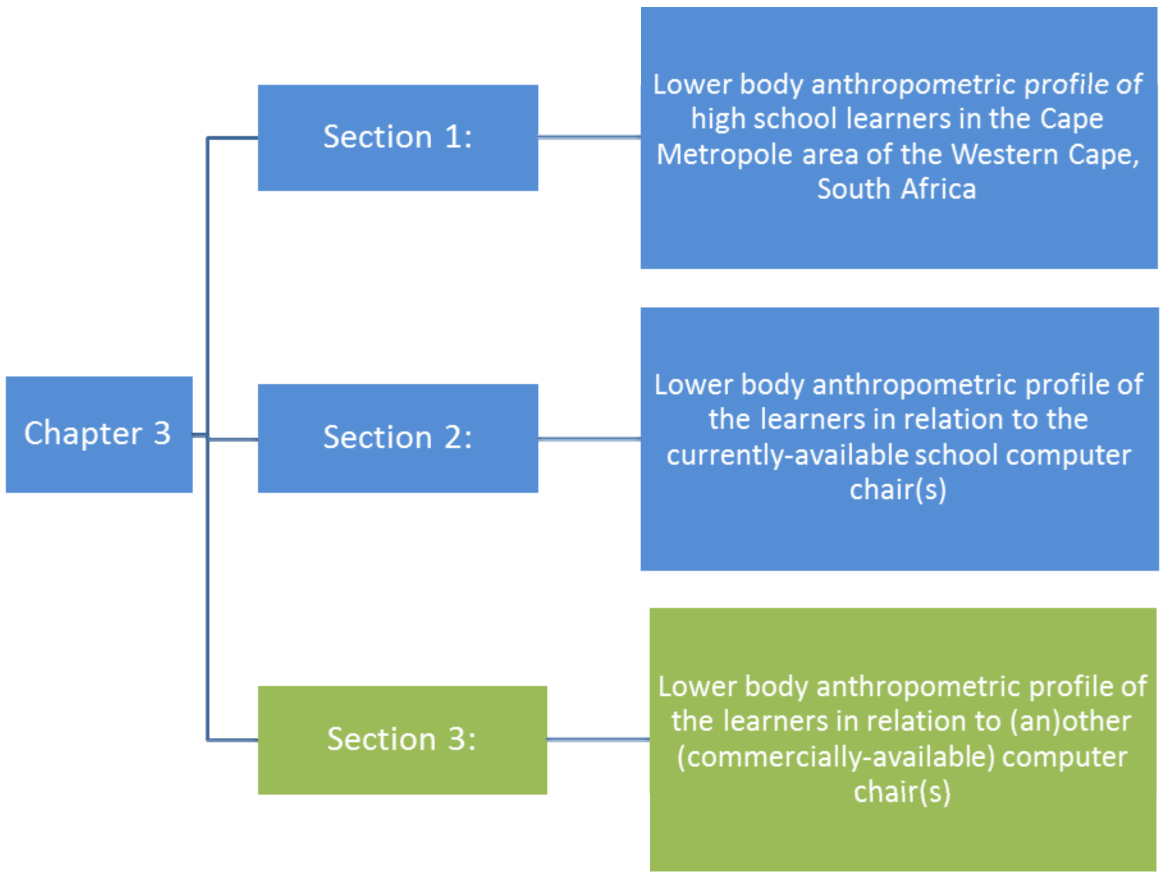
Table 3.10: The percentage of learners who did not match their chair dimensions, according to age groups

	School chair 1			School chair 2		
Age (years)	**SH (%)**	**SD (%)**	**SW (%)**	**SH (%)**	**SD (%)**	**SW (%)**
13	65	78	63	82	82	74
14	66	83	69	70	88	71
15	70	78	69	76	84	72
16	65	72	67	71	84	72
17	63	75	68	74	82	69
18	71	74	65	80	83	71

3.2.3 Summary

From the above results, it was evident that there was a large mismatch between the dimensions of the high school learners in the Cape Metropole area of the Western Cape, South Africa and the dimensions of the school computer chairs that they regularly used. The finding raised the question of whether there were any other chairs (such as other commercially available computer chairs) that would provide a better match for the anthropometric profile of the group of learners concerned.

3.3 Section 3: The anthropometric profile of high school learners in relation to adjustable commercially available computer chair(s)



A concerning proportion of school learners, worldwide, were found to fail to find a school chair that fitted their individual anthropometric profile (Brewer *et al.*, 2009; Castellucci *et al.*, 2010; Chung & Wong, 2007; Cotton *et al.*, 2002; Dianat *et al.*, 2013; García-Acosta &. Lange-Morales, 2007; Gouvali & Boudolos, 2006; Milanese & Grimmer, 2004; Oyewole *et al.*, 2010; Panagiotopoulou *et al.*, 2004; Parcells *et al.*, 1999; Saarni *et al.*, 2007). We established in Section 2 that the anthropometrics of a concerning number of learners in the Cape Metropole were found not to match the usual school chair dimensions according to accepted criteria for chair height, depth and width. Thus, most secondary school learners, at the time of the current study, were found to be seated in chairs that were too short and/or too shallow for their body dimensions. Learners' anthropometric dimensions are highly variable in the adolescent population within and between year groups (Section 1). It is important that the chairs used in high school computer laboratories have the appropriate dimensions with which learners can interact in order to adjust their chair dimensions optimally according to their individual anthropometric profile (Pheasant, 1996).

The large variability and subsequent anthropometric profile and school computer chair mismatch of high school learners in the Cape Metropole area of the Western Cape of South Africa clearly warranted an investigation into the availability of more appropriate, commercially available chairs that could be recommended for school computer laboratories. The chairs recommended for school computer laboratories should be adjustable, affordable and allow relevant adjustments to match the anthropometrics of a significant percentage of learners, irrespective of their age, gender and school grade.

Therefore, Section 3 aimed to answer the following question: How well do the dimensions of adjustable, commercially available computer chair(s) match the linear anthropometric measurements of high school learners in the Cape Metropole area of the Western Cape, South Africa?

3.3.1

3.3.1 Methodology

3.3.1.1 Study design

A secondary data analysis was undertaken to compare the dimensions of the affordable adjustable commercially available computer chair(s) to the range of anthropometric measurements obtained.

3.3.1.2 Procedure

An extensive Internet and phone-book search was conducted by the principal researcher to find adjustable, commercially available chairs appropriate for school computer room use in the Western Cape, South Africa. After consultation with a representative of the Khanya project, which is responsible for equipping all schools in the Western Cape with computer laboratories, it was advised that a chair should not cost more than R500, to make it viable for the schools to purchase the chair if it should provide a better fit to the learners' anthropometric profile than the current school computer chair. Even such cost might have been prohibitive if 30 to 40 chairs were required per school computer room.

The following inclusion criteria applied:

- *any commercially available chair that was adjustable to accommodate any anthropometric feature, and that was appropriate for computer laboratory use; and*
- *chairs that were being sold for R500 or less each.*

Chairs were excluded if they were on promotion for R500 or less each on the day of data collection.

The principal researcher measured the included adjustable, commercially available chairs. The chair dimensions were measured with a metal measuring tape (Panagiotopoulou *et al.*, 2004). The following dimensions of the school computer chair were measured:

- ***Seat height****: The distance from the highest point at the front of the seat to the floor (Gouvali & Boudolos, 2006; Panagiotopoulou et al., 2004).*
- ***Seat depth****: The distance from the back of the surface of the seat to its front (Gouvali & Boudolos, 2006; Panagiotopoulou et al., 2004).*
- ***Seat width****: The distance from the left side of the seat to its right (Gouvali & Boudolos, 2006).*

A mismatch was defined as the incompatibility between the dimensions of the school computer chair and the anthropometric dimensions of the learners (Chaffin & Anderson, 1991; Parcells *et al.*, 1999). The mismatch criteria were outlined in Table 3.8 above.

3.3.1.3 Statistical analysis

Descriptive statistics were used to analyse the anthropometric measures of each learner, which were compared to the relative furniture measures, according to the matching criteria described in Chapter 2 page 25 in order to identify a match or mismatch between the specific learner and the furniture he/she had been assigned to use.

3.3.2 Results

From the 26 chair suppliers and manufactures identified, who were relevant to the current study, eight chairs in total were found to meet the inclusion criteria. Chairs were mostly excluded because of them costing more than R500 each. Figure 3.7 illustrates the eight commercially available chairs that formed part of the current part of the study.

Chair 1	**Chair 2**
	
Chair 3	**Chair 4**
	

Chair 5	**Chair 6**
	
Chair 7	**Chair 8**
	

Figure 3.7: The eight commercially available chairs included in the study

Table 3.11 illustrates the size and adjustability measurements of the eight commercially available chairs. None of the chairs had adjustable SW or SD, but all were adjustable in height.

Table 3.11: Size of the commercially available chairs

	SH (mm)	SW (mm)	SD (mm)
Chair 1	385–520	450	430
Chair 2	395–520	440	355
Chair 3	385–510	420	445
Chair 4	440–565	430	410
Chair 5	380–490	395	365
Chair 6	370–490	390	395
Chair 7	440–530	455	430
Chair 8	440–530	520	500

The percentage of learners who mismatched the commercial chairs' dimensions is reported in Figure 3.8. Although chairs C1, C2, C3, C5 and C6 offered a good match for SH, none of the chairs provided an adequate SD and SW to fit more than 50% of the learners concerned.

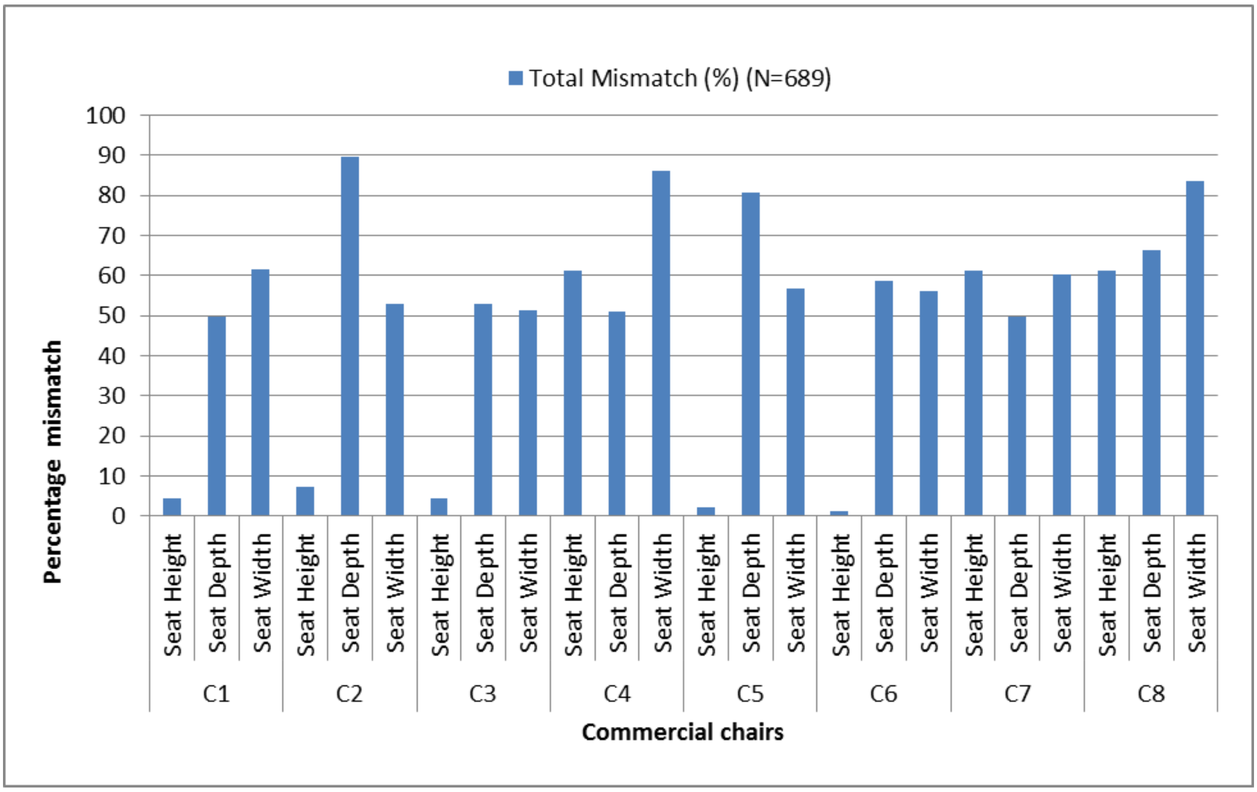


Figure 3.8: Percentage of learners who mismatched the commercially available chairs' dimensions

3.3.2.1 Ideal school computer chair dimensions

Due to the physical impact of a chair that does not fit the users' anthropometric profile (Chapter 2), it is important to ensure that a chair fits about 90% of the high school learners from the local South African population identified. The ideal school chair dimensions are based on the 5th and 95th percentile of each of the three anthropometric measurements that are important for matching the chair to the user (PH, BPL, HW). Table 3.12 reports on the ideal dimensions for a school computer chair that would match 90% of the high school learners in the Cape Metropole area, Western Cape, South Africa.

Table 3.12: Ideal school computer chair dimensions

Dimension	Min. (mm)	Max. (mm)
SH	389	445
SW	473	473
SD	476	476

3.4 Summary

Neither the computer chairs used at school nor affordable, commercially available computer chairs offered an acceptable fit for all the anthropometric measurements of learners aged between 13 and 18 years, attending randomly-selected high schools in the Cape Metropole area. The findings of the current study indicate that, even if the Western Cape Education Department or individual schools wanted to improve the chair profile of the computer laboratories, they would find it hard to do so, as an affordable commercial chair that matches the learners' anthropometric measurements was not found to be currently available.

Consequently, there is an urgent need for a computer chair that is specifically designed to adjust to the anthropometric profile of high school learners, so that their postures are protected whilst they are learning.

CHAPTER 4

An overview of the literature

4.1 Setting the scene

For the last three decades, there has been debate in the literature regarding ergonomic chair designs that support sitting postures in the best manner possible (Corlett and Clark, 1995 (First published in 1986); Mandal, 1982; Molenbroek *et al*., 2003; Nag *et al*., 2009; Pheasant, 1986 (newest addition 1996). The majority of the research has been conducted on adults (Breen *et al*., 2007). Debate has ranged from the best type of chair design, the best type of posture that should be supported on a chair, and the association between sitting posture and musculoskeletal disorders (MSDs) and pain (Corlett, 1995; Mandal, 1982; Molenbroek *et al.*, 2003; Nag *et al.*, 2009; Pheasant, 1996; Straker & Mathiassen, 2009; Straker *et al.*, 2010).

The dictionary definition of ergonomics as “the scientific study of human beings in relation to their working environments” has been reworded by Pheasant (1996) as the following definition: “Ergonomics is the application of scientific information about human beings to the problems of design”. Thus, the basis of ergonomic design is to take the specific user into account, for instance when designing a chair. However, in the school environment, which is regarded as the child’s ‘work’ environment (Pheasant, 1996), the above-mentioned principle of ergonomic design is generally not followed. In fact, the exact opposite is taking place in

South African schools, with school learners being forced to use furniture in computer laboratories that was neither designed according to their physical and workplace needs, nor to their anthropometric profile (Smith, 2007).

The mismatch between school furniture and school learners is a major concern in the Cape Metropole area of the Western Cape, South Africa, where an alarming number of learners (about 70%) do not fit the school computer chair dimensions, as was reported in Chapter 3 of this thesis. The finding of a high occurrence of mismatch came as no surprise, as the chairs used in the school computer laboratories were rigid, plastic garden chairs designed for recreational use in the adult population, and not for the multiracial, variably- shaped population of adolescents comprising the local South African group of high school learners. Chapter 2 of the present thesis discussed the physical effect of sitting on a chair that is either too big or too small for the user, and the potential that having to sit on such a chair has for influencing musculoskeletal and spinal symptoms.

The Cape Metropole adolescents have been reported as experiencing a high-point prevalence of spinal symptoms, with around 70% of the group complaining of spinal pain (Smith *et al.*, 2009). As a result, some 16 000 adolescents from an estimated population of 22 000 high school learners in the Cape Metropole area could have been suffering from spinal pain at the very moment at which the current study was conducted. Taking into account that the occurrence of adolescent spinal pain has been established as a predictive factor for spinal pain in adults, by seating learners on poor chairs, schools could be helping to ensure their learners a possible lifetime of spinal pain (Bernard, 1997).

The South African economy was already crippled by an extremely high unemployment rate of 25.2% in the first quarter of 2012 (StatsSA, 2012), with newly-graduated high school learners being part of the problem. As many as 1, 393 million youths (15–24 years) are expected to be unemployed in 2013 (StatsSA, 2012). The use of computers and prolonged sitting are increasingly common in current employment requirements. If young adults are sent out into an extremely competitive workforce with an already established propensity for spinal pain resulting from their school-going days, schools could be contributing inadvertently to young peoples' bleak chances of finding employment. South Africa is also plagued by many infectious diseases that threaten mortality (such as TB and HIV/Aids), and it can ill afford an epidemic of preventable adolescent and adult spinal pain resulting from increased hours of computer use during which they are subjected to inappropriate workstation design. Adhering to Pheasant 's (1996) definition of ergonomics is, therefore, of utmost importance. In the school setting, the focus should be on designing school chairs for appropriate fit of as many school learners as possible. Hence, the present chapter focuses on sitting biomechanics and ergonomic chair design principles.

Key researchers in the field generally agree regarding the purpose of a chair, which is to provide adequate support in order to help ensure a comfortable sitting posture (Brewer *et al.*, 2009; Castellucci *et al.*, 2010; Chung & Wong 2007; Cotton *et al.*, 2002; Dianat *et al.*, 2013; García-Acosta &. Lange-Morales, 2007; Gouvali & Boudolos, 2006; Milanese & Grimmer, 2004; Oyewole *et al.*, 2010; Panagiotopoulou *et al.*, 2004; Parcells *et al.*, 1999; Pheasant, 1996; Saarni *et al.*, 2007). Pheasant's proposed purposes for a chair include:

- *providing the user with sitting comfort over a period of time;*

- *being physiologically satisfactory, in that physiological stresses (i.e. spinal load; muscular or neurological tension; blood circulation) are minimised; and*
- *appropriateness to the task or activity to be performed.*

For a chair to fulfil the above-stated purposes, key design principles must be followed. The basic principles concerned are discussed in detail later on in the current chapter.

While the key researchers in the area of chair design (Brewer *et al.*, 2009; Castellucci *et al.*, 2010; Chung & Wong 2007; Cotton *et al.*, 2002; Dianat *et al.*, 2013; García-Acosta &. Lange-Morales, 2007; Gouvali & Boudolos, 2006; Milanese & Grimmer, 2004; Oyewole *et al.*, 2010; Panagiotopoulou *et al.*, 2004; Parcells *et al.*, 1999; Pheasant, 1996; Saarni *et al.*, 2007) discuss appropriate school furniture for children, the area of adolescent school furniture appears to have been the most poorly researched (Dianat *et al.*, 2013; Gouvali & Boudolos, 2006). At present, there is insufficient knowledge of the interactions between 'the humans in schools and the systems comprising school environments' to claim that we have an adequately 'fundamental understanding' of 'Ergonomics in Schools' (Legg *et al.*, 2006). The above is probably due to the issues of adolescent growth and to the different requirements for school chairs that are used in different environments (such as in computer laboratories, libraries, and classrooms). It is important to remember that one cannot merely extrapolate research conducted on an adult population to that of an adolescent population. Adolescents require their own area of research, in terms of furniture fit related to their rapidly-changing anthropometry (Sotoyama *et al*., 2002; Breen *et al.*, 2007).

Despite the seating design principles advocated by the key authors in the field, very few intervention studies have been conducted regarding the best type of chairs to be used in schools, and how well the chairs concerned fit young people through their adolescent growth years (Koskelo *et al*., 2007). Therefore, a number of the findings from the research reported in this thesis represent new knowledge, and provide a platform for future research to be undertaken into the best chair for supporting the different postures of adolescents in relation to school furniture. The extent to which a chair achieves the above-mentioned objectives is dependent on various anthropometric and biomechanical factors. The anthropometric factors influencing chair design were discussed in Chapter 2. The present chapter now explores the current understanding of the biomechanics of sitting, and what is considered as an 'ideal' posture.

4.2 Sitting posture

The definition of what constitutes a good seated posture is the subject of considerable debate in the literature. Corlett (2006) explains that the ergonomics of sitting has been a subject for discussion since well before the term 'ergonomics' first originated. Oyewole *et al.* (2010) presented a brief review of 19th-century writing that demonstrated a belief in the need to sit erect, with a straight back. The idea was reinforced in schools and elsewhere by the use of backboards on chairs to help the seated person maintain the ideal posture. Sitters used chairs with vertical backs and horizontal seats, which were usually 46cm off the floor. The belief of the requirement of a straight back for any person who is seated on a horizontal seat is still implicit in descriptions of 'correct' sitting. Corlett then goes further to explain that, in the 20th century, the understanding of the consequences of adopting a poor sitting position increased. This notion was probably driven by the increase in the number of seated workplaces and in recognition of the prevalence of back pain among the adult and school learner population.

However, the conventional sitting posture remains idealised as that which is characterised by an erect back and a horizontal thigh. To achieve such a posture requires that the thighs rotate through 90 degrees, while in actual fact only about 70% of thigh rotation towards the horizontal occurs at the hip joint. After a hip angle of 60 degrees is reached, further increase in the angle concerned is opposed by the tension of the hamstrings. The hamstring muscles run along the back of the thigh from just below the back of the knee to the pelvis. When the muscles involved stretch, they exert a pull on the pelvis, which causes it to rotate backwards, hence the movement in question is completed by a 30-degree backwards tilt of the pelvis.

The sacrum, which is central to the pelvis and to which the spine is connected, also rotates backwards, which causes the lumbar curve to flatten, resulting in what is commonly known as a 'slumped' posture (Bridger, 1988; Keegan, 1953; Pheasant, 1996). Sitting posture and, in particular, a 'slumped' sitting posture increases the amount of stress that is placed on the spinal structures (Keegan, 1953; Szeto *et al*.,2002; Vergara & Page, 2002). 'Slumping' forward causes an increase in the forces that are generated by the erector spinae and other contributing trunk muscles in order to support the trunk (Corlett, 2006), and, subsequently, increases the pressure on the lumbar intervertebral discs (Andersson *et al*., 1974; Horst & Brinckmann, 1981; Keegan, 1953).

If the muscles of the back are active, they apply pressure to the spinal discs. Small and frequent variations in the pressure are beneficial, since the discs gain their nutrients from such pressure changes (Van Deursen *et al*., 2001; Van Dieën *et al*., 2001). However, if the pressure is held for a long period, the discs, which creep under load, experience a gradually increasing convexity around the rim, which, over time, may cause them to rupture or to place abnormal pressure on the nerves in the spinal column. Hence, the workplace design must permit the postural changes that are necessary to allow recovery of disc height without inhibiting work activities.

However, as Fostervold (2003) suggests, "considerable effort would be expended in maintaining this position, and its validity for real work situations is questioned". Mandal (1997) further notes that such an erect posture could only be held for one to two minutes at a time, leading him to question its suitability for human function. Thus, rather than just the traditional seated posture with an upright trunk and thighs that are perpendicular to the trunk, as described by Corlett (2006), an array of seated postures is now considered acceptable, including forward- and backward-inclined positions (Mandal, 1982; Nag *et al.*, 2009). In a review of guidelines for adult computer workstations, Cook and Burgess-Limerick (2003) concluded that the array of seated postures that can be adopted (back-leaning, upright, forward-leaning), and an ability to vary postures and to adjust furniture easily to facilitate the adoption of any of a range of postures is desirable. The posture adopted while sitting at a computer should not only offer comfort, but should also serve as a good model for young children.

Static postures of the head-neck complex, particularly sustained periods of neck flexion, are significant contributing factors to physical load and subsequent reports of musculoskeletal pain, increased muscle activity and, therefore, the development of MSDs (Evans & Patterson, 2000). The adoption of such postures is, however, common among computer users (Grieco *et al*., 1998; Hedge, McCrobie *et al*., 1995).

4.3 Adolescent sitting posture, computer use and sustained posture

The high school learners in the Cape Metropole area, Western Cape, South Africa spent 3 to 5 hours, on average. Per day working at a desktop computer at school, with a typical school lesson lasting 40 to 90 minutes. During a Computer Studies lesson, learners tend to be involved in computer-related tasks for the majority of time, as well as in non-computer-related activities, such as listening to the teacher, reading from a textbook and taking notes (Smith, 2007). The findings mentioned are similar to those that have been made in relation to school learners' studies that have been conducted in developed countries (Grimes & Legg, 2004; Murphy *et al.*, 2004). The studies concerned noted that the adoption of a slouched posture for a prolonged period whilst using the computer was the norm and that the opportunity for postural changes was often limited, particularly if the sitting posture was fixed.

Significant health risks associated with computer use among adults have been reported (Gerr *et al*.,2006; Marcus *et al*., 2002), with the adoption of an awkward or a non-neutral working posture being a commonly-cited risk factor for pain (Gerr *et al.*, 2006; Hünting & Grandjean, 1981; Karlqvist *et al*., 1994; Kilbom *et al*.,1986; Punnett *et al*., 1991).

Furthermore, computer-based tasks have commonly been found to involve sustained low-level muscle activity in the trapezius muscle (Kitahara *et al*., 2000; Turville *et al*., 1998; Waersted & Westgaard, 1997; Zennaro *et al*., 2004), which may result in local muscle strain, peripheral nerve compression and inflammation, and reduced vascular circulation (Forde *et al*., 2002; Visser & Van Dieën, 2006). Lack of variation in tasks and postures has been suggested as being a generic risk factor in the development of MSDs of the neck, shoulder and back (Berqvist *et al.*, 1995; Forde *et al.*, 2002; Straker *et al*., 2006; Waersted & Westgaard, 1991; Winkel & Mathiassen, 1994). Furthermore, the adoption of a prolonged posture overloads the intervertebral discs, which can obstruct micronutritional exchange (Adams *et al*., 1996; McMillan *et al*., 1996) and lead to disc degeneration (Corlett, 2006). The posture adopted while sitting at a computer should not only offer comfort, but should also present a good model for young children to take through to adolescence and adulthood.

As children's muscles tend to tire more rapidly than those of adults do during static muscle work, it is important to introduce regular postural change, which is considered one method of preventing neck and low-back pain (De Looze *et al.*, 2003). Freudenthal, Van Riel, Molenbroek & Snijders (1991) and Yeats (1997) have gone so far as to state that the correct sitting posture should allow for dynamic behaviour, with many small postural changes. Pheasant (1996) explains that muscle tissue responds badly to prolonged static mechanical loading, and that, when the chemical balance within the muscle is disturbed, metabolic waste products tend to accumulate, leading to muscle stress and fatigue. Therefore, Clark and Corlett (1995) and Pheasant (1996) advocate that the sitter should adopt several different postures throughout a task to avoid the fatigue, and subsequent tissue stressors that are associated with maintaining a static posture. Stresses on spinal tissues could be reduced by allowing for variation in postures that prevent static load on the spine (Saarni *et al.*, 2007). It is natural for learners in classrooms to change their posture frequently, and no single posture constitutes an ideal sitting position (Karvonen *et al*., 1962). Being able to change posture is a characteristic of a comfortable posture (De Loose *et al.*, 2003; Hira, 1980; Mandal, 1981), and, thus, youngsters in schools need to be supported in adopting sitting postures on furniture that will help them to do what they do naturally.

The notion of encouraging postural movement whilst sitting is supported by the evidence-based recommendations provided by Straker *et al.* (2010). Straker *et al.* (2010) embarked on reviewing the evidence relating to physical aspects of the child–computer interaction in order to provide child specific evidence-based guidelines. Straker *et al.* (2010) selected a narrative review approach due the variable nature of the available evidence. This form of review however leaves room for error in study selection since a systematic search strategy is was not developed and the quality of the selected studies is not critiqued. Straker *et al.* (2010) provided the following recommendations for healthy computer use for school learners:

- *The chair should be an easily-adjustable component of the workstation set-up, keeping in mind that the children concerned are likely to be expected to adopt a seated posture for much of their 'working' day. Chair size, therefore, should suit the child's size.*
- *The seating should aim to encourage movement as much as possible.*

- *For computer tasks, the chair should be able to be placed close to the edge of the desk, so that input devices can be reached and forearm support can be achieved on the desk surface.*
- *The children concerned should be encouraged to evaluate their sitting position and to take advantage of any adjustability or other supports.*
- *The seat pan height should allow the child's feet to rest flat on the floor.*
- *The lack of a backrest is acceptable to encourage movement, but, if one is provided, it should be adjustable to fit the child's lumbar spine.*
- *Armrests should be avoided, unless they fit the child and desk well.*
- *The seat style should support a range of reasonable postures.*

Specific workstation dimensions and parameters have been shown to affect posture, muscle activity and musculoskeletal discomfort or disorders in both adults and children (Trevelyan & Legg, 2006). The selection and adjustment of an appropriate chair for computer-based work is an important component of workstation optimisation. Since any posture that exerts undue stress can lead to damage (particularly if it is held for long periods of time, such as may arise during computer use at school), the school computer chair should adhere to the best ergonomic design principles, in order to minimise avoidable loads on the spine of the adolescent user. When examining how the loads arise, design requirements for school chairs become clearer (Pheasant, 1996).

4.4 Chair design principles

According to Oyewole *et al.* (2010), *"the use of furniture has been traced back to the Stone Age, where 'handy' men created chairs and tables from stones and rocks. In the ancient civilizations, the chair was one of the first types of furniture, which was created in order to convey status, kingship and authority. Archaeologists have discovered images of early furniture of ancient civilizations, especially in Ancient Egypt. The chair and table design changed very little for several thousand years. The chair was typically pictured with a low seat and slightly reclining back as seen in the thrones and folding stools of the Egyptian Pharaohs."*

Design principles for chairs used at desks have been a topic of discussion since the late 1960s in the developed world. During this time, the current leaders in the field of ergonomically-designed chairs and workstations emerged. The chair design principles of Corlett and Clark (1995), Grandjean (1973), Oxford (1969), and Pheasant (1996) as well as the reasoning behind their principles, are discussed in the present chapter under the following section headings: 'Seat height'; 'Seat depth'; 'Seat width'; 'Backrest'; 'Armrests'; and 'Seat angle'.

4.4.1 Seat height

The height of a seat plays an important role in the posture that a user assumes when sitting. When a school learner sits on a seat that is too low, the learner is inclined to slouch (Grandjean, 1973; Oxford, 1969; Pheasant, 1996). Pheasant (1996) claims that a too-high seat setting leads to even greater problems than the former, in terms of standing up and sitting down, due to the distance through which the centre of gravity must travel, and due to the user requiring more legroom to execute the manoeuvre. When a seat is too high (i.e. above the PH of the user), the pressure on the posterior thigh increases (Grandjean, 1973; Oxford, 1969; Pheasant, 1996). Oxford (1969) suggests an optimal SH of 445 mm, with Grandjean (1973) recommending 450 mm. Pheasant (1996) suggests that the optimal SH is close to the PH of the user.

Reflecting on the findings discussed in Chapter 3, 60% to 73% of the high school learners in the Cape Metropole area, Western Cape, South Africa sit on chairs that are too high. As the sitting postures of the local learners had never before been measured, we can only assume that, based on the above-mentioned literature, the school children concerned are potentially exposed to musculoskeletal injury. According to the data presented in Chapter 3, the optimal SH for the South African group of learners surveyed would have been between 389 and 445mm.

4.4.2 Seat depth

A seat pan that is too long suggests that the seated child would not comfortably be able to lean against the backrest without resultant pressure behind the knees or slumping (Pheasant, 1996). If the depth were to be increased beyond the BPL, the user would not be able to use the backrest effectively, leading Pheasant to recommend a depth of 435 mm (based on adult female dimensions). Oxford (1969) suggests that the depth of an educational chair should be 368 mm, according to the anthropometric data set used in their study.

The suggested dimension would also fit the BPL of the high school learners discussed in Chapter 3. The chairs on which the learners concerned in the current study were found to be currently sitting in the computer laboratory were found to be too shallow for the majority of the learners, exposing the learners involved to possible vascular circulation problems. According to the measurements obtained, the optimal SD for the South African group of high school learners would be 476 mm.

4.4.3 Seat width

The SW should be sufficient to support ischial tuberosities, in order to achieve pelvic stability and so as to allow sufficient space for lateral movements (Corlett & Clark, 1995; Pheasant, 1996). In order to allow for the above, the SW should be large enough to accommodate even those users with the largest hip breadth, also ensuring adequate clearance between the armrests (Evans *et al.*, 1988; Helander, 1997; Orborne, 1996; Pheasant, 1996; Sanders & McCormick, 1993). According to the anthropometric profile of the high school learners who formed part of the data set for this thesis (Chapter 3), the ideal SW should be 473 mm.

4.4.4 Backrest

The use of a backrest on a chair continues to be controversial. Grandjean (1973) recommended a backrest of 20 cm high, with the lower edge about 20 cm from the seat surface, and making an angle of 100 degrees with the seat surface. Pheasant (1996) suggests that the higher the backrest, the more effect there would be in supporting the weight of the trunk. Pheasant discusses three different settings of backrests: the ‘low-level backrest’, which supports only the lumbar region; the ‘medium-level backrest’, for full shoulder support, or the ‘high-level backrest’, which provides support for the neck and head.

In an experimental setting, the use of backrests on a chair has been shown to reduce the load distributed at the seat (Nag *et al.*, 2009) and is thereby believed to reduce spinal loading. Leaning against a backrest can also assist with the retention of the lumbar curve during sitting (Corlett & Clark, 1995). Seated postures without a backrest have been reported to increase load within the spinal discs to a level that may restrict physiological ‘nourishing’ of the discs in adults (Colombini *et al.*, 1986). However, observations of children working in school settings have shown that children often work without using a backrest, even if one is present (Breen *et al.*, 2007; Ciccarelli, Straker, Mathiassen & Pollock, 2007 Murphy, Buckle & Stubbs, 2004).

In addition, Koskelo *et al.* (2007) found that children who used a saddle-style seat with no backrest for two years were found to have improved trunk muscle strength, better sitting and standing postures, and less musculoskeletal discomfort than a control group, who used traditional school chairs with backrests. Breen *et al.* (2007) also reported that children who did not have a backrest tended to adopt better postures than did those with a backrest. Geldhof, De Clercq, De Bourdeaudhuij and Cardon (2007) reported that 8- to 12-year-old children used a backrest for 36% of the time and Cardon, De Clercq, De Bourdeaudhuij & Breithecker (2004) observed use of a backrest for 30% of the lesson time.

The lack of a backrest, therefore, appears to be acceptable to encourage ‘usual’ postural adjustments and body movements, although, if one is provided, it should be adjustable to fit the child’s lumbar spine (Straker *et al.*, 2010). Whilst it appears that a suitable backrest can reduce loading on the lower trunk, a chair without a backrest might encourage more trunk activity and general movement (Cardon *et al.*, 2004). If a backrest is present on the chair, it should be adjustable in both the horizontal and the vertical direction.

4.4.5 Armrests

Similarly to backrests, armrests may give additional postural support, reducing the spinal load. The use of armrests can also aid the sitter in standing up and in sitting down (Nag *et al.*, 2009; Pheasant, 1996). Delisle *et al*. (2006) suggest that alternating forearm support from the desk surface and from chair armrests could be of benefit by introducing the possibility of postural variation. However, the use of armrests for children’s seating has not yet undergone any scientific investigation, so that their efficacy and ideal positioning, with reference to body dimensions, is unknown. Fixed armrests that are either too big or too high could be expected to constrain posture, particularly that of the upper limb, and may prohibit the chair being positioned close enough to the work table to permit appropriate forearm support on the desk, and to allow for the child’s relatively small reach when using input devices. Armrests should also be adjustable anteriorly, posteriorly and laterally, as well as in height, in order to ensure an appropriate position for providing support. Whilst it is likely that armrests that are optimally positioned may provide the benefits that are documented for adults, it may, in the present instance, be wiser to provide chairs without armrests, given the difficulty that prevails in ensuring an appropriate armrest position.

Doing so may have the additional advantage of allowing for greater postural variability for children (Straker *et al.*, 2010).

4.4.6 Seat angle

The seat angle or slope has an influence on the amount of hip flexion that occurs whilst sitting. Grandjean (1973) recommends a seat slope of three degrees downwards tilt towards the back, for workers who sit mostly in an upright position. In contrast, Mandal (1981) and Pheasant (1996) suggest that a chair without a backrest should be tilted forward between 5 and 10 degrees in order to accommodate forward-bending postures, which are assumed during writing tasks, and to help maintain a normal lumbar lordosis. Mandal came to this conclusion after he embarked on evaluating the effect a forward tilting seat has on the forward bending of the back, he conducted an experiment to document the results. To record the changes in the flexion of the various parts of the body, the anatomical points were marked at the knee-joints, hip-joints, 4th lumbar disc and shoulder joints. The participant was seated at a fixed height for the seat and work surface, but the feet were placed incrementally in three different positions in order to simulate different work heights, and the seat and work surface were tilted. Firstly the subject was positioned at the conventional right angle of the chair, whereupon the chair seat and work surface were tilted incrementally and the position of the feet lowered to simulate an increase in the chair and work surface heights. Fifty photographs of each of the 3 positions were taken during a period of 10 days to record the changes in the degree of flexion in the lumber area and hips. Mandal found that when the subject was seated in the final position with the chair in a forward tilted position and with the feet lowered, simulating a high seat height and work surface, the hip-joint and back flexion was greatly reduced, preserving lumber lordosisis.

Mandal found that this sitting position was similar to the natural resting position where the muscles are relaxed and the body is in a "perfect posture".

Aagaard-Hensen & Storr-Paulsen (1995) found that approximately 43% of classroom time was spent in a backward-leaning position, whereas 57% was spent leaning forwards, for example when the learner concerned was either reading or writing. Thus, a combination of backward and forward tilt should accommodate both the design principles and the sitting activities in school covered above.

4.5 Summary

Taking all the above-mentioned recommendations into consideration, several clear guiding principles were obtained that should be adopted when assessing and designing a chair for high school learners in the Cape Metropole area, Western Cape, South Africa to use in computer classes in school:

- *The SH, SD and SW should fit the anthropometric range of the learners concerned.*
- *Neither armrest nor backrest is required.*
- *A chair should allow the learner to move freely either into an anterior or into a posterior pelvic tilt, according to the schoolwork activity involved.*
- *A chair should aid the learner to make frequent postural adjustments, whilst sitting.*

The key summary points of the above review are as follows:

- *No 'Ideal' sitting posture exists for adults or children.*
- *There is considerable debate amongst the key researchers in the field of ergonomics regarding the most appropriate chair design for supporting working postures.*
- *Static, prolonged posture is associated with the development of MSDs.*

- *Using seated furniture that encourages a range of sitting postures is important.*
- *Chairs that are designed for use during work should be designed for the user to do their work, in the workplace, in a healthy, safe, comfortable and efficient manner.*

CHAPTER 5

The effectiveness of conducting a chair intervention in the workplace to reduce musculoskeletal symptoms: A systematic review

Prolonged sitting at suboptimal workstations is associated with musculoskeletal dysfunction (Aarås *et al*., 2001; Amick *et al*., 2003; Pillastrini *et al*., 2010; Robertson *et al*., 2009; Ijmker, *et al*., 2007). Musculoskeletal dysfunction generally presents as pain or discomfort around the cervical, shoulder, and lumbar regions. A range of modifiable and non-modifiable risk factors has been associated with the above-mentioned symptoms.

Non-modifiable risk factors are genetic predisposition, structural spinal deformities or disorders, and female gender (Aarås *et al.*, 2001; Helander, 1997). The modifiable factors include body alignment (posture), the nature and duration of task and job demands, as well as physical features of the work (Aarås et al., 2001; Helander, 1997). Commitment from supervisors and employees is essential for assessing and modifying, where appropriate, the mutable risk factors concerned. Careful capital investment is also necessary in order to optimise the ergonomic design of workstations in an attempt to reduce the influence of postural perturbations and stressors that may be associated with the development of musculoskeletal symptoms.

Workstation modifications frequently address the height, angle and positioning of the work surface and/or chair (Aarås *et al.*, 2001; Lewis *et al*., 2001; Nelson & Silverstein, 1998). Since the chair has a direct influence on body alignment (posture), individuals suffering from musculoskeletal symptoms related to prolonged sitting are often advised to alter the chair of their workstations as the first stage of adjusting a workstation (Aarås *et al.*, 2001; Lewis *et al.*, 2001; Nelson & Silverstein, 1998). Changing the chair is also the most pragmatic action, because alterations of the work surface may be limited by physical space constraints, and an adjustable work surface is not always economically viable. Therefore, modifying the workstation's chair is often the most feasible and cost-efficient initial step that can be taken to ascertain whether the design and organisation of a workstation is associated with musculoskeletal symptoms.

In selecting an appropriate chair, the adjustability of the SH and the seat pan depth, in conjunction with the anthropometrics of the user, should be taken into consideration (Gouvali & Boudolos, 2006; Panagiotopoulou *et al.*, 2004). A mismatch in the dimensions of a work chair has long been proposed to impact on the ability of the postural muscles to support the body, which could also lead to abnormal stresses and strains on the individual's neuromuscular system, producing pain (Ariëns *et al.*, 2001; Tittiranonda *et al.*, 1999; Troussier, 1999). The use of chairs that have design features to minimise such effects, and which can be adjusted to an individual's anthropometry, can be beneficial in the prevention of spinal pain.

Musculoskeletal dysfunction associated with repetitive seated tasks in the workplace typically accounts for about 30% of the reasons for absenteeism in the US (Whysall *et al.*, 2006). In the Unites States, the loss of productivity has been reported as amounting to about US $7.4bn during 2004 and in Australia the indirect cost of back pain resulted in AUD 8.1 billion during 2001 (Walker *et al*., 2004; Ricci *et al*., 2006). However, whilst reducing absenteeism is an appropriate management goal in making the workplace a more comfortable work environment, employers require sound evidence for the benefits that will flow from a (often significant) financial investment to alter workstations to a more ergonomic fit for their employees.

The aim of the current chapter is to review and to appraise the current evidence base for the effectiveness of a chair intervention in the workplace that is aimed at reducing musculoskeletal symptoms.

5.1 Methodology

5.1.1 Search strategy

The following medical electronic databases were searched since inception of the study untill March 2011: Pubmed; Cinahl; Pedro; ProQuest; Scopus; and PhysioFocus. The same search terms (Table 5.1) were used in all the databases; pearling and hand searches were also conducted. Two reviewers (SH and SvN) independently screened the selected titles and abstracts for eligibility.

Table 5.1: Search terms and combinations used for searching the databases

Keyword 1	Keyword 2	Keyword 3

'Ergonomic intervention' OR chair	'musculoskeletal symptoms'	ergonomics OR 'Seated work'

5.1.1 Inclusion criteria

Articles were deemed eligible for inclusion in the current study if they met all the following inclusion criteria:

- *postulation that the chair had an influence on biomechanics;*
- *studies of children or adults in predominantly-seated occupations;*
- *any trial with pre- and post-testing, including controlled, randomised or single-subject design; and*
- *outcome measures that included consideration of neuromuskuloskeletal and/or postural alignment comfort.*

5.1.2 Exclusion criteria

Articles were excluded if they were not in English. No date exclusions applied.

5.1.3 Article criteria

No date restrictions were applied, and only English-text articles were included. Full-text articles were retrieved for those studies that appeared to meet the inclusion and exclusion criteria, and for those in which insufficient information was presented in the title, abstract and key words to determine eligibility.

5.1.4 Independence of decision-making

Disagreements between the two reviewers were discussed until consensus was reached. When agreement could not be reached, a third reviewer (QAL) was consulted to finalise a resolution about the relevance of the article.

5.1.5 Risk of biased assessment

The risk of bias in the included studies was assessed using six criteria recommended by the Cochrane Back Review Group (as outlined in *The Cochrane Handbook* [Higgins & Green, 2008]). The criteria were scored ’yes’, ’no’ or ‘unclear’, and were reported on in the *Risk of Bias* tables. A trial with low risk of bias was defined as a trial that met, at minimum, criteria 1 (randomisation), 2 (allocation concealment), and 5 (outcome assessor blinding). Two review authors (SvN, SH) independently assessed a selection of trials for risk of bias and reached consensus on the final results. A third review author (QAL) randomly assessed the risk of bias in the studies chosen.

5.1.6 Data extraction

One reviewer (SH) extracted all required data using a purpose-built data extraction form, which collected information on study design, population and outcomes (Addendum B). If data were missing, the corresponding authors of the studies were contacted for additional information. A second reviewer (SvN) audited the data extraction of all the included studies.

5.2 Results

5.2.1 Study selection

The library search resulted in the finding of two references in Pubmed, 10 in Cinahl, 1 in Pedro, 6 in Google Scholar and 0 in ProQuest. The pearling of the reference lists of relevant articles produced 3 additional articles that matched the inclusion criteria. After the exclusion of duplicated references (*n*=2), both reviewers (SvN and SH) read the 18 remaining titles and abstracts. Thirteen papers were subsequently excluded, for reasons including that the studies did not report pre-/post-measurement, or that the chair was not the chief concern for intervention. Five studies were subsequently included in the present review (Amick III *et al.*, 2003; Gadge & Innes, 2007; Herbert, Dropkin, Warren, Sivin, Doucette, Kellogg, Bardin, Kass & Zoloth, 2001; Rempel, Wang, Janowitz, Harrison, Yu & Ritz, 2007; Wang, Ritz, Janowitz, Harrison, Yu, Chan & Rempel, 2008) (Table 5.2).

Table 5.2. Number of hits per database

Database	**Search no.**	**Keywords used**	**No. of relevant hits**
Pubmed	1	1 + 2 + 3	2
CINAHL	1	1 + 2 + 3	10
Pedro	1	1 + 2 + 3	1
ProQuest	1		0
Google Scholar	1	1 + 2 + 3	6
Secondary Search (hand searching)	1		3
Total number of hits			22
Excluded after review of the title, abstract and full paper (not relevant; duplicates)			17
Total number of papers included			**5**

5.2.2 Risk of biased assessment

Overall, there was a moderate risk of bias in the body of evidence obtained. The most likely source of bias was in allocation concealment and generation of the random sequence. The areas in Figure 5.1 that are marked with a '?' or that comprise a blank space indicate that the reviewers were not able to determine whether the criterion was met by the study concerned. The blank areas in Figure 5.1 indicate that the reviewers were not able to determine whether allocation concealment was performed.

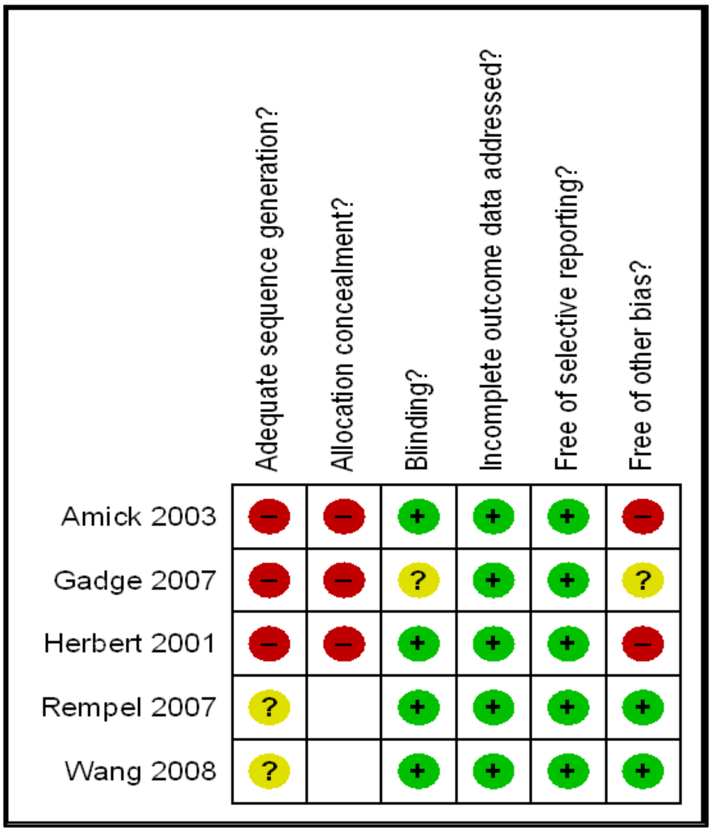


Figure 5.1: Methodological quality summary: review of authors' judgements about each methodological quality item for each included study

5.2.3 Study characteristics

Table 5.3 reports the characteristics of the included studies, of which the number of participants varied from 4 to 293. Three studies were randomised controlled trials (RCTs) (Amick III *et al.*, 2003; Rempel *et al.*, 2007;Wang *et al.*, 2008), one was a pre-/post-test intervention study (Herbert *et al.*, 2001), and one was a single case, multiple baseline (A-B-A-B) study (Gadge & Innes, 2007). Three studies were conducted in a garment factory (Herbert *et al.*, 2001; Rempel *et al.*, 2007; Wang *et al.*, 2008) (with one study generating two papers), one was conducted in an office environment (Amick III *et al.*, 2003) and another with university learners (Gadge & Innes, 2007). Two of the papers included were from the same funded trial (the Los Angeles Garment Study), but reported on different subgroups in the trial. Wang *et al.* (2008) reported on symptom change in the garment worker subject group of initial pain/discomfort in the low-back/hip regions and with Rempel *et al.* (2007) reporting on the subgroup with pre-intervention cervical/shoulder symptoms. Although the two groups might have had some overlap, the sampling frame was not reported in detail.

Table 5.3: Selected studies: summary of studies in order of level of evidence, with extracted data

Author (ref)	Country	Design	*n*	Population	Intervention	Measures	Outcomes	Conclusions	Notes
Wang *et al.*, 2008	USA	RCT	293 (subset of Rempel 2007, with lower ρ) Group *n*= (111;84;98)	Sewing-machine operators with back /hip pain	Gp 1: control; Gp 2: curved pan chair; Gp 3: flat seat pan chair (all received misc. items; chairs hgt-adjustable)	Pre- and post-intervention monthly for 4/12: pain symptoms – intensity (1–5) and frequency	Mean pain improv't gp 2 vs. 1: 0.25 (95% CI: 0.16, 0.34); Gp3 vs 1: 0.43 (0.34–0.51) per month.	Adjustable swivel chairs offer advantage (reduction in LB /hip pain) for workers in seated/UL occupations; flat pan superior to curved?	Obtain means and SD for pain scores for each group (presented graphically in Fig 5A) at 4/12 f/u
Rempel *et al.*, 2007	USA	RCT	277 (subset with upper ρ); Group *n*= (105;72;100)	Sewing-machine operators with neck/shoulder pain	Gp 1: control; Gp 2: curved pan chair; Gp 3: flat seat pan chair (all received misc. items; chairs hgt-adjustable)	Pre- and post-intervention monthly for 4/12: pain symptoms – intensity (1–5) and frequency	Mean pain improv't gp 2 vs. 1: 0.34 (95% CI: 0.28, 0.41); Gp3 vs. 1: 0.14 (0.07–0.22) per month	Adjustable swivel chairs offer advantage (reduction in Cx/ shoulder pain) for workers in seated/UL occupations; curved pan	Obtain means and SD for pain scores for each group (presented graphically in Fig. 5A) at 4/12 f/u

								superior to flat?	
Amick III *et al.*, 2003	USA	RCT (assigned according to office location)	192 (87;52;53)	Office workers (>4hrs per day at computer; >6hrs per day sitting)	Gp1: adjustable chair + training; Gp2: training only; Gp3: no intervention	Pre- (2 × monthly) and post-intervention (3 × over 1 year). Musculo-skeletal symptoms – 1. growth over workday; 2. average amt of pain over workday	Symptom growth over workday: Gp 1< gp 2/3 at 12/12 f/u (ρ=0.012). Avg. pain levels: reduced for both Gp 1 + 2, compared to Gp 3	Highly adjustable chairs. plus training resulted in less pain at end of day and reduced average amt of pain (largest reduction in neck/shoulder, followed by in upper and lower back)	Cannot separate chair as sole intervention, but clear that chair + info. is superior to info. alone or nothing.
Herbert *et al.*, 2001	USA	Pre- and post-test	36	Garment workers (occupied with 'spooling' task), female	Adjustable chairs and training in their use	MS symptom survey prior to and 6/12 after introduction. Joint position in sitting via video (subgroup	Baseline pain reported by 89% of group; post-intervention 63.9% (ρ=0.007). Reduction in severity at	Reduction in no. of people with pain and in severity overall at upper limb anatomical sites. Inconclusive posture	

						only). Upper limbs only.	10/11 anatomic sites after intervention Only modest declines in awkward posture (small n)	change findings.	
Gadge & Innes, 2007	Australi a	Single case, multiple baseline (ABAB)	4	University learners (seated 'most of the time')	Standard office chair (adjustable) vs. 'saddle' seat	(dis)Comfort (VAS); Productivity (typing task – speed and accuracy); Posture (videotape) Multiple measures across 4 phases.	Discomfort in lower back increased over time in both chairs but less so in the saddle; discomfort was significantly worse in lower limbs in saddle chair; Productivity no change;	Some benefits for lower back discomfort and posture in saddle, but also for other issues (lower limb discomfort).	

							Greater trunk to thigh angles in saddle.		

5.2.4 Study outcomes

All included studies reported a reduction after the workplace intervention in the amount of musculoskeletal pain suffered (Amick III *et al.*, 2003; Gadge & Innes, 2007; Herbert *et al.*, 2001; Rempel *et al.*, 2007; Wang *et al.*, 2008). The chair intervention was adjustable in all five included studies. In addition, there were variations to the chair intervention, including pan versus flat seat (Rempel *et al.*, 2007; Wang *et al.*, 2008) or saddle seat (Gadge & Innes, 2007). Training in the use of the adjustable features was also reported in the included studies. All participants adjusted their own seats, to fit their individual profiles, on the day of the start of the intervention. Different body sites for decreased pain were reported in each study: back/hip pain (Wang *et al.*, 2008); neck/shoulder pain (Rempel *et al.*, 2007); musculoskeletal symptoms anywhere in the body (Amick III *et al.*, 2003) (with reports of the greatest reduction in pain occurring in the neck/shoulder, followed by in the upper and lower back); upper limb only (Herbert *et al.*, 2001); and lumbar spine discomfort (Gadge & Innes, 2007). The only study that investigated productivity outcomes (Gadge & Innes, 2007) found no significant differences present. Similarly, the two studies that assessed elements of posture (such as thigh angles) also found modest to no differences with the chair interventions (Gadge & Innes, 2007; Herbert *et al.*, 2001).

5.3 Data analysis

Due to the heterogeneity of the included studies, in terms of population, intervention and outcomes, it was not possible to perform a meta-analysis on the data obtained. The only exception occurred in the research on garment workers, with Rempel *et al.* (2007) and

Wang *et al.* (2008) having the same intervention and overall population, but reporting different subgroups and outcomes. As such, a sensitivity analysis could also not be performed.

5.4 Clinical interpretation

All five included studies offered some evidence of the effectiveness of chair interventions to improve musculoskeletal discomfort in workers who sit for prolonged periods. Since the study quality was moderate, the findings could generally be trusted to inform practice. However, a high degree of clinical heterogeneity existed between studies, which precluded the making of specific recommendations regarding chair design or workplace interventions. The need for education as part of the intervention was reinforced in the review, since it was integral to each study.

As the studies reported different body areas regarding where the pain was experienced, it was not possible to be more specific about which kinds of musculoskeletal pain benefitted most from the chair intervention. The most common element of the chair interventions was having an adjustable-height feature. All the chairs were adjusted according to each individual at the commencement of the study, which reduced the amount of sitting-related musculoskeletal symptom experienced. Electromyography (EMG) studies illustrate that the use of a chair, which is height-adjustable and which has an adjustable backrest and armrests, can reduce the muscle activity of the neck, shoulder and back muscles, and also decreases the amount of intervertebral disc pressure experienced (Harrison *et al*., 1999; Leivseth & Drerup, 1997; Van Deursen *et al*., 2000). The adjustability of such a chair can, thus, be associated with the positive effects on the function of the musculoskeletal system that were found in the current review. The second most common feature was that the participants in the above-mentioned interventions received training in the use of the chair intervention (on how to adjust the chair appropriately).

Other features of the interventions varied, including pan versus flat seating – there is some suggestion that pan seating may be better in reducing upper body pain, whilst flat seating may be superior for lower body pain. The findings concerned require confirmation in further research. Saddle seating also seemed to have differential effects on back versus lower limb comfort – again the matter requires further careful investigation before any clinical recommendations can be made in such respect.

The articles included in the current systematic review considered the experiences of sewing-machine operators (three papers from two studies), with the remaining studies reporting on office workers and university learners. The scant evidence involving office workers is of concern, considering the (often significant) investment that is made in ergonomic chairs by companies in order to improve the functionality and utility of workstations, and in order to reduce the amount of absenteeism resulting from postural-related discomfort. No studies, conducted on children or adolescents were found. Research on the effect of a chair in an adolescent population is urgently required, since there are reports of increasing trends of musculoskeletal symptoms among youth (Cho, Hwang & Chen, 2003; Herbert *et al.*, 2001; Niemi *et al.*, 1996).

The key methodological shortcomings in the included studies were absent or unclear randomisation procedures and concealed allocation. Such issues may have introduced selection bias, possibly resulting in higher estimates of association (which were reported as odds ratios). Despite the concerns mentioned, the studies had only a moderate risk of bias, thus concerns about the evidence base for the question related more to the small number of studies that were found to be available. The above precluded making conclusive recommendations pertaining to the specific effects of any chair intervention.

Moreover, because of the focus on individual worker groups (sewing machinists [two studies], office workers [one study], university learners [one study]), it was also not possible to generalise study findings more broadly to other worker groups. The authors of the reviewed articles failed to mention whether confounding factors, such as gender, had been controlled for, as the allocation procedures were not mentioned. A further methodological issue in the evidence base presented in the current review was that two papers (Rempel *et al.*, 2007; Wang *et al.*, 2008) used the same overall population to report two different subgroups (based on two regions of pain). The subgroups concerned were treated, as two separate studies in the current research, assuming that the pain regions involved in each study were independent events. The making of such an assumption might not have been correct. The study by Gadge and Innes (2007) on office workers was the only publication found to include productivity as an outcome measure. The study sample was very small (n=4) and the types of outcomes – namely typing speed and errors – were not relevant to all seated workers. It is an assumption that ergonomic intervention correlates with productivity (Generalis & Mylonakis, 2007). However, the current review finding offers no supporting evidence for the making of positive gains in productivity, and the factor should be incorporated as an outcome in future research.

Although all five included studies conducted follow-up assessments of symptoms, the longest follow-up period was one year (Amick III *et al.*, 2003). The finding obtained indicates the existence of a research gap regarding the effectiveness of a chair intervention that has long-term benefits. The gap particularly relates to musculoskeletal symptoms, as well as to (currently unmeasured) issues of recurrence of symptoms, and to consequent costs of care. The need also exists to compare the features of an adjustable chair between different chair designs, so as to determine the essential features that are related to a reduction in musculoskeletal symptoms. Persistence in occupational pain is acknowledged as being multifactorial, with risk profiles relating to psychosocial factors dominating the literature (Bongers, Ijmker, Van den Heuvel & Blatter, 2006). We believe that studies that consider the long-term effects of ergonomic workstation intervention should be conducted in future, and that the anticipated studies should take into account such factors as larger samples over longer time periods, with standardised interventions, using randomised and controlled allocation, and the overt control of confounding during analysis.

5.5 Conclusion

The findings of the systematic review indicate consistent support for the effectiveness of a chair intervention to improve musculoskeletal symptoms among workers who are required to sit for prolonged periods. The small number of available studies, the methodological biases involved and the small number of different occupational groups tested, impact on the interpretation and strength of the available evidence. The review findings indicate cautious support for the effect of a chair intervention in reducing musculoskeletal discomfort, in particular suggesting that adjustable chairs, accompanied by appropriate user training, are the most promising. Further research is required into the effectiveness of ergonomic chairs for other workstation users, and into the long-term benefits of the use of ergonomic workstations, particularly with respect to the prevention of musculoskeletal symptoms and symptom recurrence.

5.6 Summary

The current review highlights that clinicians can cautiously support, or advocate for, the provision of adjustable chairs in the workplace and can offer appropriate training in how to adjust and manage posture whilst seated. The monitoring of pain reduction / increased comfort ratings will confirm effectiveness in individual cases. Further urgent research is required to clarify the relationship between environmental features (such as chairs), poor posture and symptoms, as currently the relationships concerned are merely inferred.

CHAPTER 6

Design of a prototype chair and anthropometric and posture validation

No agreed quantitative basis exists upon which to define the nature of an 'ideal' posture. Postures have commonly been qualitatively described according to spinal curves at the skin surface. In standing, 'ideal' spinal posture has been described as a slight lordosis at the lumbar and slight kyphosis at the thoracic, regions (Kendall *et al*., 1983). The 'ideal' posture is believed to ''involve a minimal amount of stress and strain and ... [to be] ... conducive to maximal efficiency in the use of the body'' (Kendall *et al*., 1952). Normally, the lumbar spine has a lordotic curve when at rest (standing, supine, or prone lying) (Bogduk, 1997:53), but with only a qualitative description of 'ideal' or 'acceptable' lumbar lordosis when it is observed at the skin surface, it is difficult to compare or to reproduce the spinal curves concerned.

The same situation occurs in relation to the description of the sitting posture. Textbooks on musculoskeletal assessment that have been published since 2000 are used as a basis for the providing of ergonomic advice, but they lack consensus about optimal spinal curves in sitting and about the stresses that are placed on surrounding musculoskeletal structures in optimal sitting. Qualitative descriptions and figures from textbooks appear to advocate different spinal curve combinations as the 'ideal' sitting posture. Firstly, a flat lower thoracic and lumbar posture has been advocated (Magee, 2006), or a flat lumbar posture with backrest support, arguing that lordotic sitting postures demand too much muscle activity and therefore, a back support is required to lessen the amount of muscle work required (Kendall, 2005). Secondly, spinal curves that are similar to the standing 'ideal' of a thoracic kyphosis with lumbar lordosis have been advocated by some authors (Lee, 2003; O'Sullivan, 2004), whereas others suggest a lumbar lordosis without the detail of a lower thoracic curve (Bullock & Bullock-Saxton, 2000; Sahrmann, 2005). As yet, the spinal curves in the three upright postures have not yet been quantitatively defined.

Scannell and McGill (2003) taught subjects to sit in the clinical 'ideal' posture, which entails sitting with a slight lordosis at the lumbar spine, as described for standing. The subjects were given a 12-week exercise programme for improving their physical range of motion and their neuromuscular control to enable them to sit in the described posture. Despite the advice and intervention provided, all subjects were found still to sit in a more flexed lumbar position than they had held during standing. O'Sullivan *et al.*, (2006b) found that all of the subjects had little or no ability to maintain a lumbar lordosis when they sat for one hour (with the mean lumbar angle being calculated from surface angles at L1 and S1 spinal levels). In the same study, subjects were given prior training to adopt two different lumbar-lordosed sitting postures, with surface angles measured at lower thoracic (with angles at T6 and T12) and lumbar regions (with angles at T12 and S2) (O'Sullivan *et al.*, 2006b). The first posture that they had to adopt was lordotic in both the lower thoracic and lumbar regions. The other posture was similar to the standing 'ideal', with a kyphotic lower thoracic angle, and a lordotic lumbar angle. The studies concerned provide evidence that trained subjects could sit with a lordotic lumbar posture during five second trials (O'Sullivan *et al.*, 2006b), but could not maintain a lordotic sitting posture for extended periods of time (Scannell & McGill, 2003). The finding raises the question of whether the poorly-defined 'ideal' sitting postures are realistic and/or achievable.

Thus, it has been suggested that it may be more appropriate to interpret posture data relative to an individual's resting posture, instead of comparing posture to an 'ideal'. A resting posture, which is seen as the sitter's 'normal' sitting position, which was assumed after at least five minutes of testing, might be the most efficient body position. The body may therefore use a load optimisation algorithm to assume a posture that minimises overall stress on both active and passive tissues (Genaldy & Houshyar, 1989). Moving between different postures whilst sitting is suggested to be 'ideal', rather than sitting in one static posture.

With the focus shifting from one 'ideal' sitting posture to regarding frequent postural changes whist sitting as 'ideal', in the research reported in this thesis, the focus was placed on the capacity of a chair to aid the user in altering his/her sitting posture with as little resistance as possible, rather than on trying to design a chair that supports one elusive 'ideal' posture for all users.

As was established in the earlier chapters of this thesis, school chairs should match the anthropometric profile of the user when using a computer (Chapter 3). Not only is a good furniture match important, but also high school learners should be encouraged to avoid static postures whilst undertaking relatively static activities (such as using a desktop computer) (Chapter 4). Both of the factors concerned have been linked to the development of spinal pain amongst adolescents (Aarås *et al.*, 2001; Amick III *et al.*, 2003; Milanese & Grimmer, 2004; IJmker *et al.*, 2007; Parcells *et al.*, 1999; Pillastrini *et al.*, 2010; Robertson *et al.*, 2009). At the time at which the present research was undertaken, such a chair was not available to the high school learners in the Cape Metropole area of the Western Cape, South Africa, thus exposing them to factors that might lead to spinal pain, both at the time of their schooling, and later, in the adult workplace. Chapter 6 reported that a chair intervention has the potential to reduce musculoskeletal symptoms in adults (Amick III *et al.*, 2003; Gadge & Innes, 2007; Herbert *et al.*, 2001; Rempel *et al.*, 2007; Wang *et al.*, 2008). Although such intervention studies have not been conducted on adolescents, it might be assumed that a similar effect would be detected in adolescents where such a chair is made available, as the learners included in the current study were sitting on less than optimal chairs (Chapter 3).

Consequently, a prototype school computer chair was designed (the prototype 'Dynamic' chair). Adhering to the design principles discussed in Chapter 4, the newly-designed chair is adjustable, so as to fit the diverse range of size existing among the high school learners. It provides both an anterior and a posterior slope to accommodate the sitting postures assumed during learning activities, in order to allow the user to change his/her posture frequently while sitting.

The current chapter is divided into the following two sections, allowing for separate discussion of the relevant issues:

Section 1: Design and anthropometric validation of the prototype 'Dynamic' chair

Section 2: Posture validation of the prototype 'Dynamic' chair.

6.1 Section 1: Design and anthropometric validation of the prototype 'Dynamic' chair

Section 1 discusses the design process of the prototype chair and how the anthropometric fit of the prototype 'Dynamic' chair compares to the school chair used in the computer laboratories, as well as to affordable, commercially available chairs.

6.1.1 Research question

Does a prototype chair, which is designed in terms of agreed ergonomic principles, provide an adequate fit to accommodate the postural needs of high school learners in the Cape Metropole area of the Western Cape, South Africa?

6.1.2 Methodology

6.1.2.1 Rationale behind the chair design

The dimensions of the prototype 'Dynamic' chair were determined, based on the recommended dimensions reported in Chapter 3 (SH 389–445mm; SW 473mm; SD 476mm). Due to the project's budgetary constraints, available materials had to be used, and could not be especially manufactured. For this reason, different parts of different existing chairs were used for making up the prototype 'Dynamic' chair. It was determined that the SH was the most important dimension that should fit the user. The SH determines the angle of the knees and hips, which, in turn, influences the pelvic angle, which determines the amount of lumbar flexion present (Pheasant, 1996). The position of the pelvis and, subsequently, of the lumbar spinal angle plays an important role in the development of low-back pain (Falla, O'Leary, Fagan & Jull, 2007; O'Sullivan, Grahamslaw, Kendell, Lapenskie, Möller & Richards, 2002; O'Sullivan, Dankaerts, Burnett, Farrell, Jefford, Naylor & O'Sullivan, 2006a; O'Sullivan *et al.*, 2006b). Emphasis was therefore placed on ensuring an appropriate seat high fit, and less focus was placed on the SW and SD dimensions.

Based on the design principles discussed in Chapter 4, the prototype 'Dynamic' chair had neither armrests nor a backrest. As was discussed in Chapter 4, the concern with an SD that is too big is that the user cannot utilise the backrest appropriately. As the prototype 'Dynamic' chair lacked a backrest, concerns regarding whether the SD of the prototype chair was too large for the user, were reduced. None of the learners was therefore deemed to be too small for the SD dimension concerned. The same principle applied for the SW, as no concern was raised in the previous research as to the effect of a too big SW, but only in relation to a too small SW.

Previously, it was established that there was no consensus regarding an 'ideal' sitting posture (Chapter 4). However, a number of researchers have advocated that a 'correct' sitting posture should allow for dynamic behaviour with many postural changes, rather than for the assumption of one 'ideal' posture (Corlett & Clark, 1995; De Looze *et al.*, 2003; Freudenthal *et al.*, 1991; Pheasant, 1996; Yeats, 1997). Thus, the decision was made to design a chair with a dynamic seat. We hypothesised that if the seat were dynamic and able to tilt in all directions, it would potentially allow the learner to adjust his/her sitting posture without effort. The multi-directional tilt degree was based on Mandal's (1981) recommendation that a chair seat should have a slope of between five and ten degrees (Chapter 4).

A mechanical designer at the Mechanical Engineering Department of Stellenbosch University was provided with the optimum chair dimensions (Chapter 3), as well as with the above-mentioned design guidelines. The mechanical designer was asked to use parts from existing chairs to assemble the prototype chair, in order to fit the required dimensions as closely as possible. As mentioned earlier, emphasis was placed on the SH dimension as being the most important factor required to fit the predetermined optimum dimensions.

6.1.3 Results

6.1.3.1 Prototype 'Dynamic' chair dimensions

The dimensions of the prototype chair compared to the 'ideal' dimensions, as were described in Chapter 3, are reported in Table 6.1. The prototype 'Dynamic' chair has a larger height-adjustable range than does the 'ideal' chair. The SD and SW are respectively 43 mm and 76 mm, smaller than the optimal dimensions.

Table 6.1: Dimensions of the prototype 'Dynamic' chair

Dimension	Min. (mm)	Max. (mm)
Ideal chair		
SH	389	445
SD	473	473
SW	476	476
Prototype 'Dynamic' chair		
SH	350	510
SD	430	430
SW	400	400

Figure 6.1 shows an image of the prototype 'Dynamic' chair. As the chair is only a prototype version (used for testing purposes), no attention had yet, at the time of the current study, been given to aesthetics or material.

Figure 6.1: The prototype 'Dynamic' chair

The mechanical designer conceptualised a dynamic mechanism for the seat using a four-spring-based system with 0.87 daN/mm tension. This spring-based system allowed up to nine degrees of movement in any direction (Figure 6.2). Nine degrees was the maximum amount of tilt that the spring system allowed, with the range concerned falling within Mandal's recommendation of 5 to 10 degrees (Mandal, 1982).

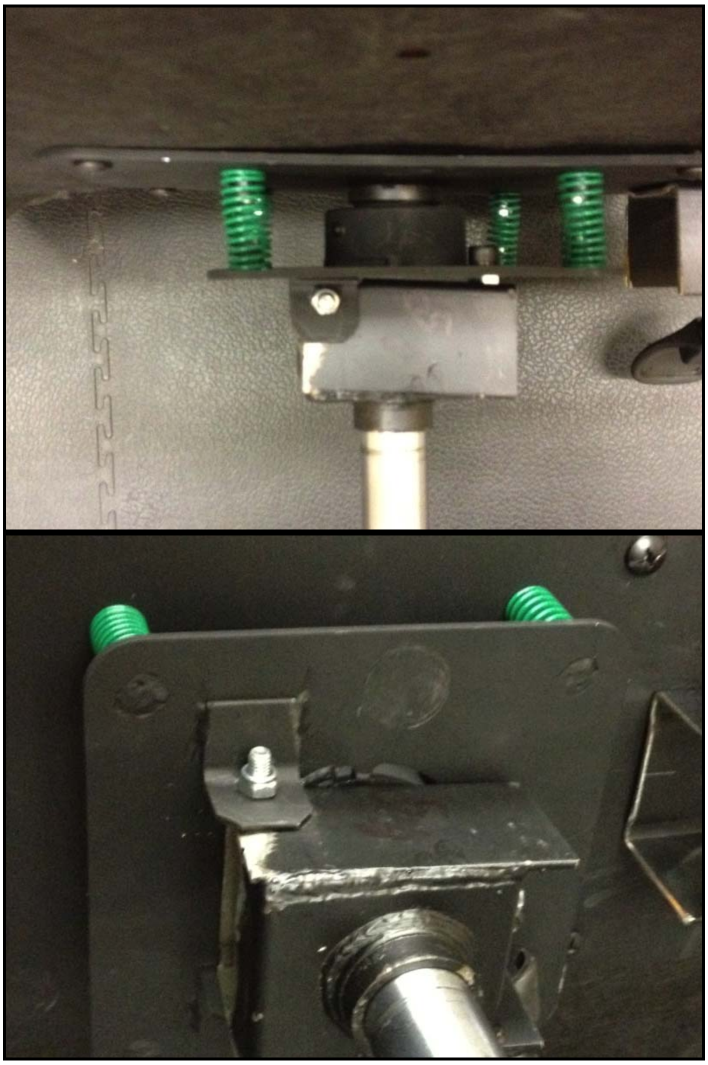


Figure 6.2: Dynamic spring-based mechanism of the prototype 'Dynamic' chair

6.1.3.2 *Comparison between learner body anthropometric profile and chair dimensions of the prototype 'Dynamic' chair*

Figure 6.3 illustrates the percentage of learners, that were measured during Phase 1 (as described in Chapter 3) and who matched the prototype 'Dynamic' chair seat dimensions. Nearly all of the learners matched the SH (97%) and more than 65% of learners matched the SD dimension, with just over 60% of the learners matching the SW dimensions.

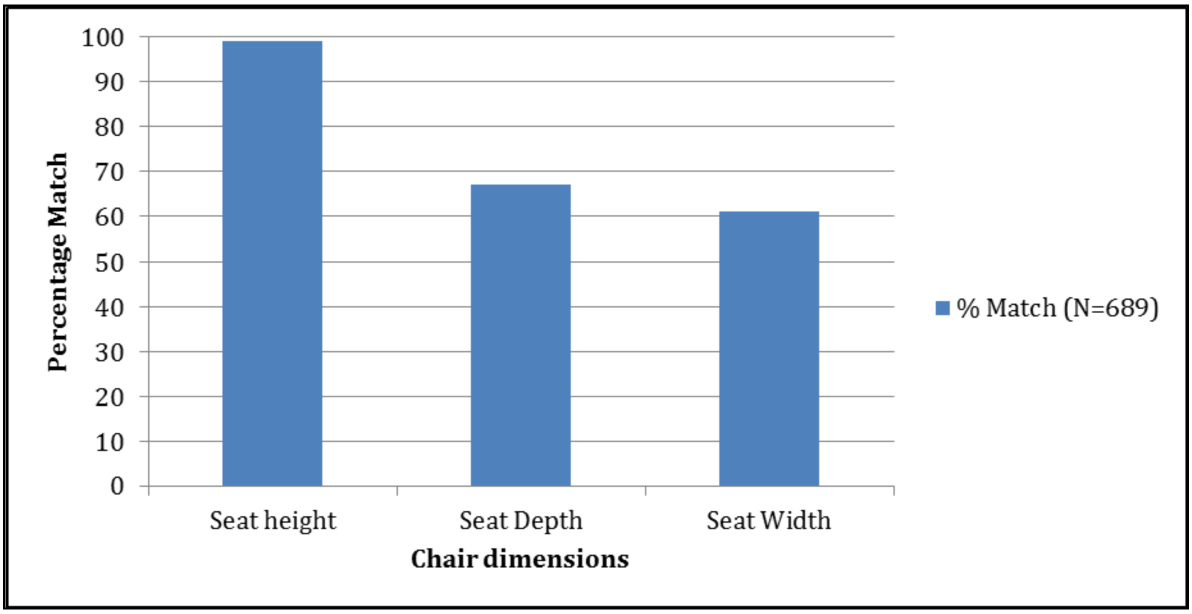
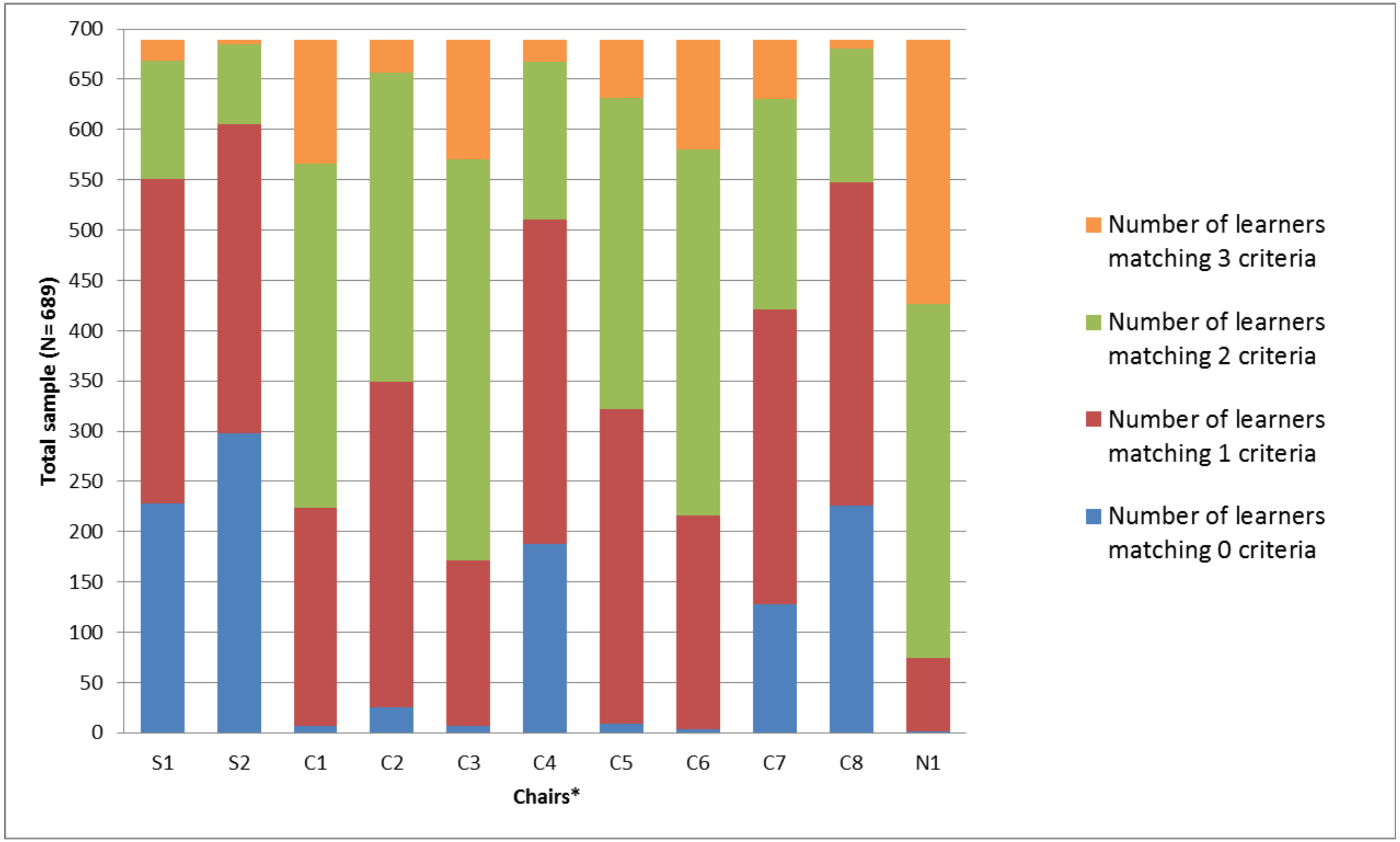


Figure 6.3: % learners matching the prototype 'Dynamic' chair dimensions

Figure 6.4 illustrates the number of learners who matched 0, 1, 2 or 3 of the chair dimensions. The prototype 'Dynamic' chair (N1) matched all three matching criteria for almost one-third of the sample, with nearly 90% of the learners matching two dimensions of the prototype 'Dynamic' chair.



*Key: S1: School chair 1; S2: School chair 2; C1–8: Commercial chairs 1–8; N1: Prototype chair.

Figure 6.4: The number (n=689) of learners who matched none (0), one (1), two (2), or all three (3) of the matching criteria

6.1.4 Summary

The prototype 'Dynamic' chair's height range was found to fit almost 100% of the learners in the Cape Metropole area, Western Cape, South Africa. The height of the chair has the biggest impact on sitting posture, thus the dimension was considered to be the most important one when designing a prototype chair. The prototype 'Dynamic' chair provides a better match with regards to all three dimensions of the chair than does any school computer chair or affordable, commercially-available chair. When comparing the number of matching criteria met, the prototype 'Dynamic' chair was found to outperform all of the other measured commercially available chairs that were described in Chapter 3.

The better 'fit' of the prototype chair was proposed to be due to the adolescents' anthropometric profile, because the seat is adjustable and provided a dynamic environment, which might encourage postural changes during sitting. The next step was to validate the sitting posture of learners using the prototype 'Dynamic' chair, in order to ascertain whether using the chair increased the number of postural changes made during sitting, compared to the number made while the learners sat in the chair that was being used at the time of the study in school computer laboratories.

6.2 Section 2: Posture validation of the prototype 'Dynamic' chair

In section 2, the three-dimensional (3D) sitting posture is discussed, as is the frequency of postural changes made, in the form of a comparison of the current school chair to the prototype 'Dynamic' chair.

6.2.1 Research Question

The current section aims to answer the following research question: Compared with the usual static, non-adjustable school chair, does the prototype 'Dynamic' chair increase the number of postural changes made by high school learners in the Cape Metropole, Western Cape, South Africa, whilst sitting at a desktop computer workstation? An attempt was made to answer the question by describing the postural effects of sitting on the prototype 'Dynamic' chair over a period of time, compared to the chair used in computer laboratories in high schools in the Western Cape.

6.2.2 Methodology

6.2.2.1 Study design

A pilot repeated-measures observational study was conducted.

6.2.2.2 Validation sampling process

Twelve conveniently selected learners, from a conveniently selected school from the group of schools that took part in Phase 1 (Chapter 3) of the current study, were invited to take part in Phase 2 testing. Two learners per age group were selected (13–18 years). Informed consent from the parents or guardian involved (Addendum D), as well as assent (Addendum E), were obtained prior to testing.

6.2.2.3 Ethical approvals

The Committee for Human Research at Stellenbosch University and the Western Cape Department of Education approved the study. Individual schools, parents and subjects provided their written informed consent to participate in the study.

6.2.2.4 Subject recruitment and invitation

A letter of details and objectives was sent to the conveniently-selected school via e-mail. The letter (Addendum C) informed the school principal of the details of this part of the research project, and invited them to participate in Phase 2 of the study. The letter was followed up telephonically, and the principal was asked for an appropriate date and time to meet with the researcher.

A combined meeting with the Grades 8 to 12 learner classes was held. The aims of the current phase of the study were discussed, as were the tasks that would be expected of them, if they wished to participate in the study. They were also asked about their availability during the testing period. Learners missed four hours of schooling during this phase of the study. The most appropriate times for testing were mutually agreed upon by the principal researcher and the school principal. The inclusion and exclusion criteria were explained. A consent form (Addendums C and D) was handed to all learners who had indicated their willingness to participate in the study. The consent forms were completed by the learner's parent or legal guardian (Addendum D), or by the learner him/herself (Addendum E), if the learner was 18 years old. The completed consent/assent forms were collected two days later. An additional appointment was set up with each school at a convenient date for testing. A telephone call was made to the school's principal, a week prior to the chosen date, in order to confirm the appointment.

6.2.2.5 Study setting

The data collection for the 3D posture measurements of the learners took place at Stellenbosch University's FNB Motion Analysis Laboratory. Learners were transported via university-provided transport services to and from the study setting.

6.2.2.6 Instrumentation

The VICON Motion Analysis (Ltd) (Oxford, UK) system is a 3D system that is used in a wide variety of ergonomics and human factor applications, where it is used for both digital and optical motion measurement and analysis. The VICON allows the researcher to work in real time, by facilitating immediate visualisation of the data being captured. It also allows offline recording for later analysis. (http://www.vicon.com). The VICON has demonstrated high accuracy and reliability (Ehara *et al*., 1997) and also demonstrated to have less than a 1.5-degree error (Richards, 1999).

For the current study, the eight-camera T-20 VICON MX system running NEXUS 1.7 software was used. The laboratory set-up is illustrated in Figure 6.5.

Figure 6.5: Laboratory set-up.

The T10 is a motion-capturing system with a unique combination of high-speed accuracy and resolution. The system has a resolution of 1-mega pixels and captures 10-bit grey scale images using 1120 × 896 pixels, with the ability to capture speeds of up to 250 frames per second. Retro-reflective markers (Figure 6.6) with a diameter of 9.5 mm were used.

Figure 6.6: The T10 infrared camera and retro-reflective markers used in the current study.

- *School chair*

The rigid plastic chair that was being used at the time of the current study in school computer laboratories was a 'one-size-fits-all' type chair (with the same size chair being used for the entire high school population [as outlined in Chapter 3]). For testing purposes, the back and armrest of the current school chair were removed to mimic the prototype chair. Figure 6.7 illustrates an image of the chair used for posture testing.

Figure 6.7: The school chair used for posture testing

6.2.2.7 Data-capturing procedures

The learners were welcomed by the principal researcher and familiarised with the laboratory and the testing procedures to be followed. Four learners were tested per day, with testing taking place over three days. The testing took one hour per learner, including:

VICON-specific anthropometric measurements; marker placement; subject calibration; data capturing in the school chair; and rest and data capturing in the prototype ‘Dynamic’ chair.

Dynamic calibration was performed according to standard laboratory protocol, with the laboratory technician walking through the capturing volume, while moving the T-wand (Figure 6.8) in scooping movements. The ability of the cameras to detect movement within the capturing volume was then calculated by the software. System-marker orientation was undertaken using a standard VICON T-wand. To test the ability of the cameras to detect accurately the orientation of the markers to one another and within the capturing volume, the T-wand was placed on a 3D Bertec forceplate (Bertec Corporation Ltd), which was synchronised with the VICON motion analysis system.

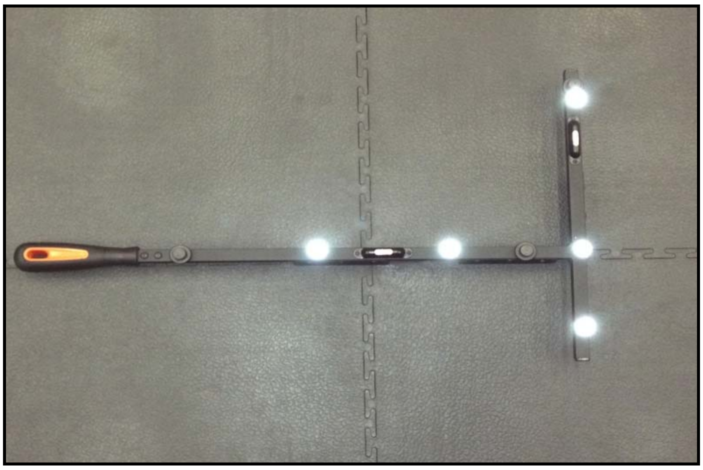


Figure 6.8: The T-wand

- *Anthropometric measurements and marker placement*

The standard full-body Plug-In Gait model was used, as the model provided the angle output sought in the current study. The Plug-In Gait model had not yet been validated for sitting, but, due to its established validity for standing, and the likely transferability of the model to sitting, the same model was used.

A trained Motion Analysis Laboratory technician was responsible for the marker placement and for the essential VICON-specific anthropometric measurements. The technician was specifically trained in placing VICON markers by using a standardized VICON marker placement protocol. The VICON-specific anthropometric measurements that were obtained were: height; weight; shoulder off-set; elbow diameter; wrist diameter; hand thickness; inter-asis distance; and knee and ankle diameter. The markers, which were not removed between chair conditions, could not have introduced marker-placement error. Standard infrared reflective markers (of 21-mm diameter) were placed on standard anatomical landmarks, using VICON-specific double-sided tape.

The girls were tested in provided tight-fitting sport tops and shorts, and the boys were tested in shorts only. Wearing the provided clothing was necessary in order to obtain accurate marker placement and visibility of the markers.

- *Sitting posture measurement procedure*

Following marker placement, a static calibration of the learner was done, with the learner assuming a T-pose (Figure 6.9) on the force plate, following standard laboratory protocol.

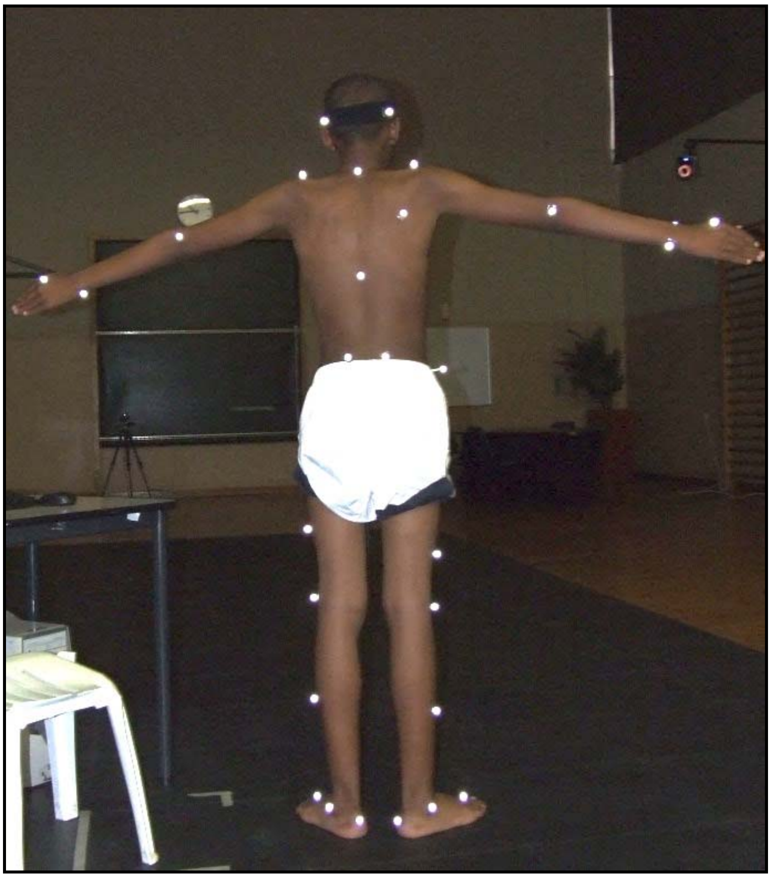


Figure 6.9: A learner standing in a T-pose

A trained laboratory technician reconstructed each calibration trial, in order to produce 3D reconstructions of the markers used. The reconstructed 3D markers were associated with marker labels from a generic Full-body Plug-In Gait labelling model. The association allowed the technician to label the markers manually and an image of the subject was created. In order for the Plug-in Gait model to calculate the key parameters, a general marker set model, contained in the VICON skeleton template, was calibrated to the VICON Skeleton file created for each subject. All trials were reconstructed to view the image of the subjects, and were subsequently rechecked for accuracy of the labelling of the anatomical marker positions.

Following the static calibration, dynamic trial capturing commenced. The learner was instructed to sit on the modified school computer chair, assuming the posture that he/she would normally obtain during a computer lesson at school. Each learner was given the same typing and mouse activity task to complete whilst the posture capturing was taking place, in order to ensure that the learners performed similar actions whilst being captured in both chairs (Szeto *et al.*, 2002). Learners were reassured that the task was not being evaluated, and that the answers were not being read, in an attempt to reduce anxiety in regards to task performance. The learners were also instructed that, if they finished with the list of tasks before the end of the posture capture that they should start at the top of the list again, until the posture capturing was complete.

The task consisted of answering the following questions and doing the following typing and mouse activities (with all activities being done in Microsoft Word, unless otherwise specified):

- *What is your name?*
- *When is your birthday?*
- *Where do you stay?*
- *How many brothers and sisters do you have?*
- *List the names of all your siblings.*
- *Write a paragraph on what you would like to do after you have finished Grade 12.*
- *Open 'Excel', and type in the names of all the cities in South Africa that start with the letter C. Each name must be typed in a new cell.*
- *Type out a list of the names of all your friends.*

- *Write a short paragraph about what you did during the most recent past holiday.*
- *Open 'Paint' and draw a house.*
- *What is your favourite school subject, and why?*
- *Open 'Excel' and type out the names of all the animals that start with the letter 'B'. Each name must be typed in a new cell.*

Foot position during sitting influences the knee angle, which, in turn, influences the hamstring length, which impacts on the pelvic position (Pheasant, 1996). Therefore, the learners were instructed to keep both feet in the same position on the floor at all times whilst typing, to ensure that detected movement at the pelvis is a primary movement due to actual pelvic movement, and not a secondary movement due to the movement of the learner's feet. The instruction was provided for testing on both chairs.

Data capturing of the trial took place over a period of 15 minutes that was split up into three sections of five minutes each. The five-minute sections were captured back-to-back (without a break). The procedure concerned, which was followed due to the immense size of the captured files, helped to ensure that the files were small enough for the VICON computer to process. Due to the risk of losing marker visibility at the beginning and end of captures, as markers become occluded by body parts or furniture, it was decided that it would be more efficient if data were captured for 15 minutes, so that not less than 10 minutes' data were available. Reported by other researchers as being sufficient for the purpose, 10 minutes' worth of sitting data has been found to allow the learner to become familiar with the surroundings and also, with the typing tasks required (Murphy *et al*., 2002; Straker *et al.*, 2008).

After the first 15 minutes of posture capturing was completed, the learner was requested to relax for 15 minutes without removing the markers. The period of so-called 'relaxation' was incorporated so as to prevent the effect of fatigue from influencing the posture outcome of the second testing condition. After the resting period concerned, the learner was asked to sit on the prototype 'Dynamic' chair. The principal researcher adjusted the chair height according to the PH of each learner (Straker *et al.*, 2008). The same testing procedure was then followed for the prototype 'Dynamic' chair as for the school computer chair.

After all data for posture was captured for both chair conditions, the markers were removed. Learners were free to watch an age-appropriate movie provided in the laboratory, whilst the next learner was being tested. The following learner's marker placement and the first round of data capturing took place during the resting period of the previous learner. Table 6.2 outlines the data- capturing procedure followed.

Table 6.2: Outline of data-capturing procedure

	15 min	15 min	15 min	15 min	15 min	15 min	15 min	15 min	15 min	15 min	15 min
Learner 1	Anthro + Markers	School chair	Rest	Prototype chair	Movie	Movie	Movie	Movie	Movie	Movie	Movie
Learner 2	Movie	Anthro + Markers	School chair	Rest	Prototype chair	Movie	Movie	Movie	Movie	Movie	Movie
Learner 3	Movie	Movie	Anthro + Markers	School chair	Rest	Prototype chair	Movie	Movie	Movie	Movie	Movie
Learner 4	Movie	Movie	Movie	Anthro + Markers	School chair	Rest	Prototype chair	Movie	Movie	Movie	Movie

The biomechanical data were processed using Nexus Version 1.7, with the full-body Plug-In Gait model being used to calculate the 3D kinematic data. A trained laboratory technician performed the data processing. Sometimes, gaps occurred in the captured data due to markers temporarily being obscured and, thus, not detected by the two minimally-required cameras. The gaps were, by preference, filled by means of the Pattern fill option in the VICON Nexus (1.1.7) software, which was patterned to a marker on the same rigid body segment (e.g. right wrist A & right wrist B, or ankle & heel). The pattern fill function was that of a spline fill that was corrected at discontinuities therein, in order to follow the pattern of the 2nd marker. After all the data were processed, the data were exported to Microsoft Excel for analysis.

- *Choice of angles for analysis*

The 3D sitting posture analysis was focused on the frequency of movement induced by the dynamic nature of the chair, and not on the sitting posture *per se*. The analysis focused on the pelvic, thoracic and head angles, as the angles concerned were classified as absolute angles, and were therefore orientated according to the laboratory coordinate system. The neck and spine angles were relative angles, which meant that the angles were dependent on the positions of the absolute angles. It was, therefore, difficult to compare the changes in relative angles between the testing sessions, as a change in a relative angle might actually have been due to a change in the absolute angle, and not due to actual movement in that specific relative angle. A description of the angles concerned is reported in Table 6.3.

Table 6.3: Description of measured angles

Angle	Description
Head angle	The angle between the head and the laboratory coordinate system
Thoracic angle	The angle between the thorax and the laboratory coordinate system
Pelvic angle	The angle between the pelvis and the laboratory coordinate system

The cervical and trunk angles (head and thoracic angles, as defined by VICON, are strongly associated with the position of the visual display, as well as the activity involved (i.e. whether it is computer-based or paper-based) (Straker *et al.*, 2008).

6.2.2.8 Data acquisition and processing

Data were acquired for each subject for both the prototype 'Dynamic' chair and for the school chair in two separate trials. Due to marker visibility problems, each capture per subject did not necessarily have the same end duration of data, as captures were trimmed so that the durations for both chairs were the same, per subject. Therefore, the capture period per learner differed.

The data were captured at 30 Hz, in order to deal with the data limitations of the VICON Nexus capture system. The longer the capture time, and the higher the frequency, the greater was the amount of processing time and the computer storage space required for the capture. A previous pilot test revealed that a contiguous capture of 15 minutes at both 50

Hz and 30 Hz would overload the processing system. A decision was then made to capture the 15-minute trial at 30 Hz in three back-to-back five-minute captures. The captures concerned were then processed and the data exported, and then spliced to form the output of the full 15-minute trial. According to signal processing theory, capturing at a sampling frequency of 30 Hz relates that the maximum frequency movement that can be captured is 15 Hz (Nyquist frequency is half the capture frequency). A smoothing filter function was applied to the data within VICON Nexus. A mean square error (MSE) of 10 was used. The function is part of the standard VICON Nexus software.

Raw data were exported as comma-separated values (CSV) files from the VICON Nexus program. The exported data were anatomical angles, as calculated in the VICON Nexus program, using the Plug-in Gait model. The 3D angles of interest for the study included the pelvic, thorax and head angles. The three dimensions were denoted as X, Y and Z planes. The X-axis represented the sagittal plane (the anterior/posterior tilt of the pelvis, or the flexion/extension of the head of the thorax); the Y-axis represented in the frontal plane (abduction/adduction) and the Z-axis represented the transverse plane (Figure 6.10).

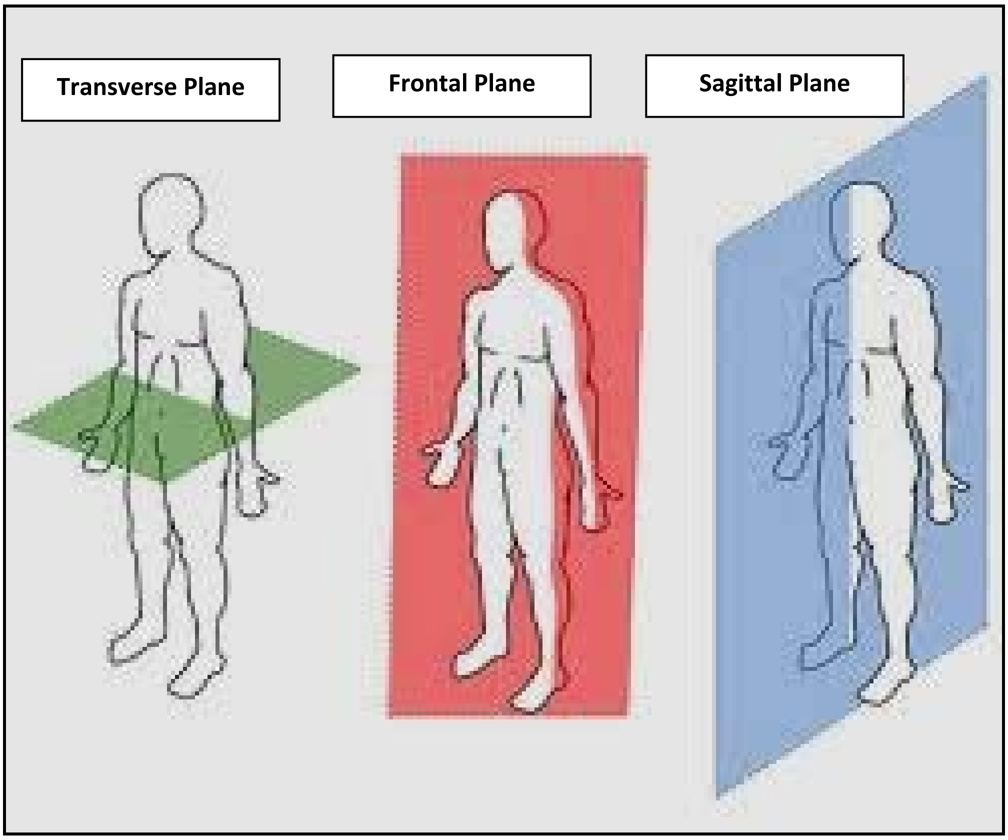


Figure 6. 10: The three movement planes

6.2.3 Statistical procedures and results

The statistical procedures are presented with the relevant results in the result section, for ease of reading.

The statistical procedures and results are reported in the following subsections:

- *Sample demographics;*
- *Basic descriptive analysis of sitting postural behaviour;*
- *Descriptive analysis of the number of postural changes; and*
- *Count ratio of the number of postural changes and the range of movement (in terms of interquartile range [IQR]).*

6.2.3.1 Sample demographics

- *Statistical procedure: Sample demographics*

Firstly, the basic demographical information of the pilot sample was reported, in terms of gender, age and anthropometry. The learners' anthropometric profile was then matched with the dimensions of the prototype 'Dynamic' chair and of the school chair.

- *Results: Sample demographics*

Twelve learners participated in the pilot study. The data of only eleven learners could be analysed, since the data set of one learner (S08) had to be discarded, due to the poor visibility of some of the markers required by the Plug-In Gait model. As a result, the VICON Nexus software could not calculate the kinematics for the learner concerned. For ease of identifying the learners according to their subject IDs, the numbering of the IDs was not changed, with subject number 8's (S08's) information merely being omitted.

The sample consisted of five boys and six girls. Table 6.4 provides information on the age distribution and the gender of the included sample, as well as the anthropometric profile of each of the learners. The learners' stature ranged from 1 415 mm to 1 850 mm.

Table 6.4: Demographics of the sample

Subject ID	Age (yrs)	Gender	Height (mm)	Weight (g)	PH (mm)	BPL (mm)	HW (mm)
S01	17	Female	1495	556	445	460	365
S02	18	Female	1521	493	415	445	335
S03	16	Female	1734	1330	460	480	300
S04	18	Male	1817	893	475	485	330
S05	16	Female	1515	393	420	425	315
S06	13	Male	1415	463	420	440	300
S07	17	Male	1800	959	470	480	420
S09	15	Male	1850	651	505	520	385
S10	13	Female	1740	549	495	535	290
S11	14	Male	1780	598	490	500	360
S12	15	Female	1578	456	475	485	345

Figure 6.11 demonstrates the number of pilot learners who matched the prototype ‘Dynamic’ chair’s and the school chair’s dimensions, according to the matching criteria discussed in Chapter 2 (Table 8). All 11 learners fitted both the SH and the SW dimensions, and eight of the learners fit the SD dimensions of the prototype chair. Only 5 learners fit the SH and SD dimensions of the school chair.

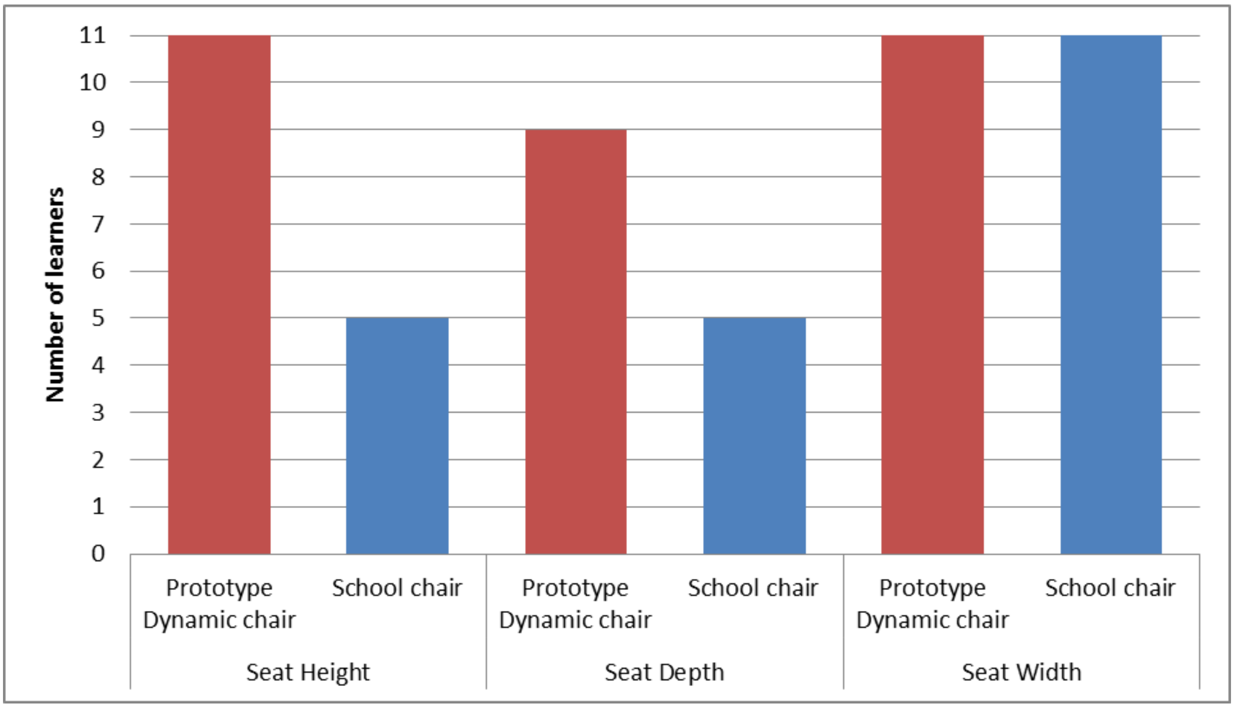


Figure 6.11: The number of learners who matched the dimensions of the prototype 'Dynamic' chair, compared to the school chair

6.2.3.2 Basic descriptive analysis of sitting postural behaviour

- *Statistical procedure: Sitting postural behaviour*

Currently, publications reporting on 3D adolescent sitting posture typically report a measure of central tendency (e.g. mean) and variability (e.g. SD) (Straker *et al.*, 2008). Straker *et al.* (2008) specifically reported the mean and SD of the sagittal plane angles during the final two minutes of the 10-minute capture. The rationale for using such a method is the notion that individuals normally settle into their habitual positions towards the end of a data-capture session (Straker *et al.*, 2008).

To summarise the data descriptively, the median and IQR were determined as measures of central tendency and variability for the last two minutes of the data capture session, which lasted up to 15 minutes. Doing so enabled the exploration of whether a measure of central tendency (i.e. mean/median) in the final two minutes was representative of the true/habitual sitting postural behaviour for the entire data capture duration. The median and the IQR were tabulated (for the final two minutes) for each subject and for the chair condition.

As an additional measure of variation in sitting behaviour, the median for each minute for the full duration of the capture was calculated. The difference between the smallest (min.) median value and the largest (max.) median value was calculated for each subject. The median could therefore be found anywhere within the range presented. Figure 6.12 illustrates how the above-mentioned statistical procedure was accomplished. The method was employed to illustrate how the median of the final two minutes could be different to the median of the entire capture duration.

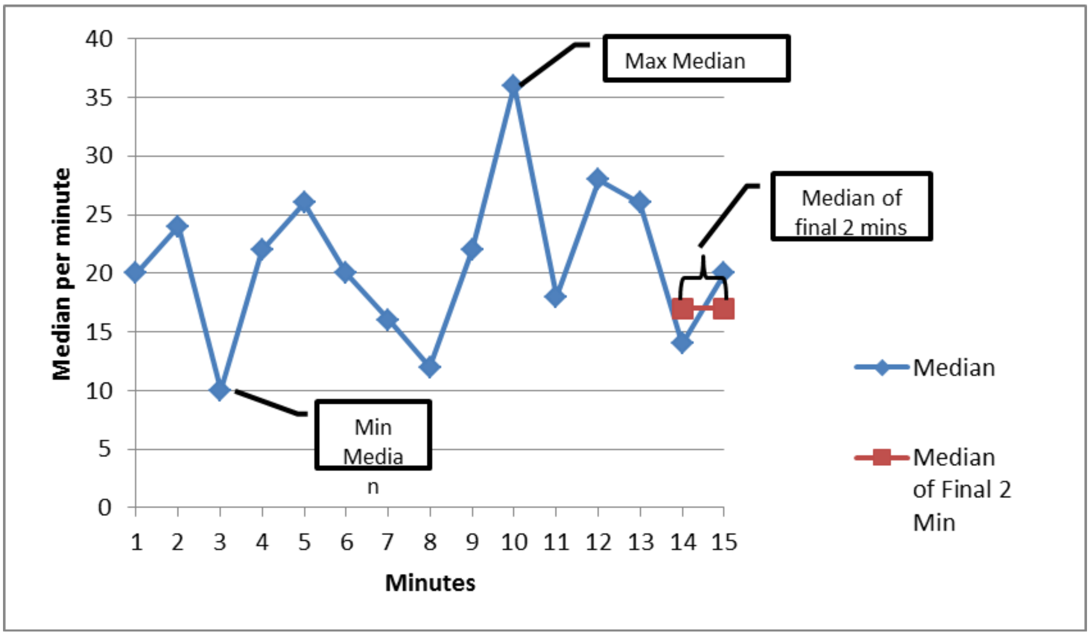


Figure 6.12: The sitting posture behaviour analysis

The next step taken was to illustrate the median angles and IQR for each minute of the capture duration, as an indication of the variability in the median angle and the IQR per minute. Box plots were created for both chair conditions to illustrate the data obtained.

- *Results: Sitting postural behaviour*

The median and the IQR of the final two minutes of capture were reported. In addition, the per minute minimum and maximum median for the full testing duration for the pelvic, thoracic and head angles in the sagittal plane, on both the prototype 'Dynamic' chair (Table 6.5) and the school chair (Table 6.6) were reported respectively, for the subject with the smallest and the largest difference in minimum and maximum medians. Since only the data of two subjects are reported in Table 6.6, the full data set for all subjects included in this study is provided in Addendum G. It should be noted that a negative value indicates a posterior pelvic tilt or head/thoracic extension, and a positive value indicates the opposite direction.

Table 6.5 reports on the subjects with the largest and smallest difference in median for the prototype 'Dynamic' chair. Subject S02 consistently demonstrated having the largest difference in medians for all three angles, with the most pronounced difference being the head angle (93.2 degrees). Subject S06 presented with the smallest difference in median for both the pelvic and thoracic angles. The smallest difference in median was found for the pelvic angle, with a difference of 1.4 degrees.

Table 6.5: The largest and smallest difference in median for the prototype 'Dynamic' chair

Prototype 'Dynamic' chair					
Median difference classification	**Subject ID**	**Median (IQR)**	**Min. median**	**Max. median**	**Median difference**
Pelvic tilt					
Largest	S02	3.2° (11.4°)	-2.0°	15.5°	17.5°
Smallest	S06	-0.1° (1.4°)	-0.9°	0.5°	1.4°
Thoracic flexion/extension					
Largest	S02	-4.4° (9.6°)	-14.7°	17.8°	32.4°
Smallest	S06	-1.8° (2.6°)	-2.8°	-0.5°	2.4°
Head flexion/extension					
Largest	S02	2.5° (7,3°)	-44.7°	48.5°	93.2°
Smallest	S12	0.8° (7.3°)	-43.7°	-41.5°	2.2°

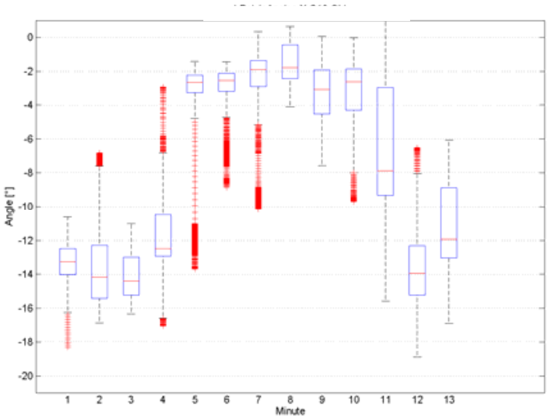
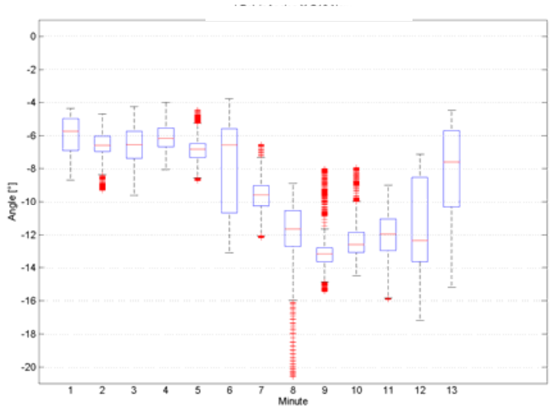
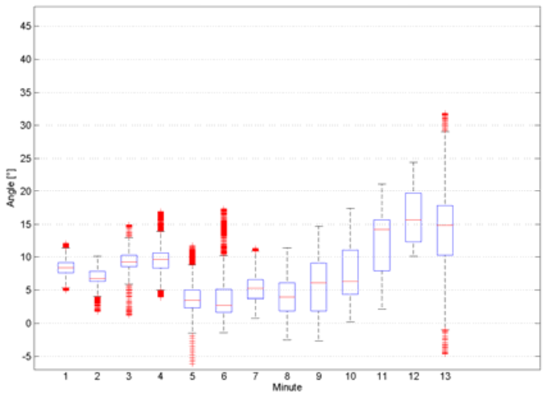
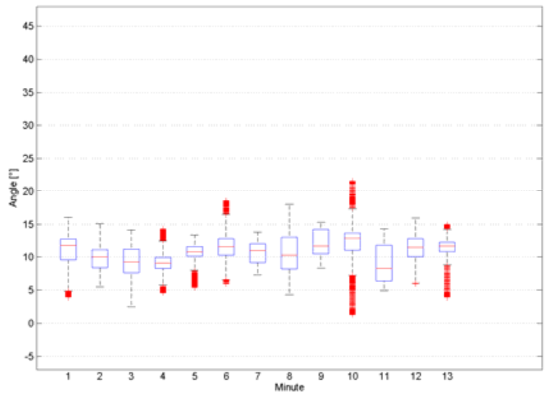
Table 6.6 demonstrates the subjects with the largest and smallest difference in median for the school chair. Subject S06 consistently demonstrated having the largest difference in medians for all three angles, with the most pronounced difference being the thoracic angle (15 degrees). Subject S02 consistently presented with the smallest difference in median for all three angles. The smallest difference in median was for the head angle, with a difference of 0.5 degrees.

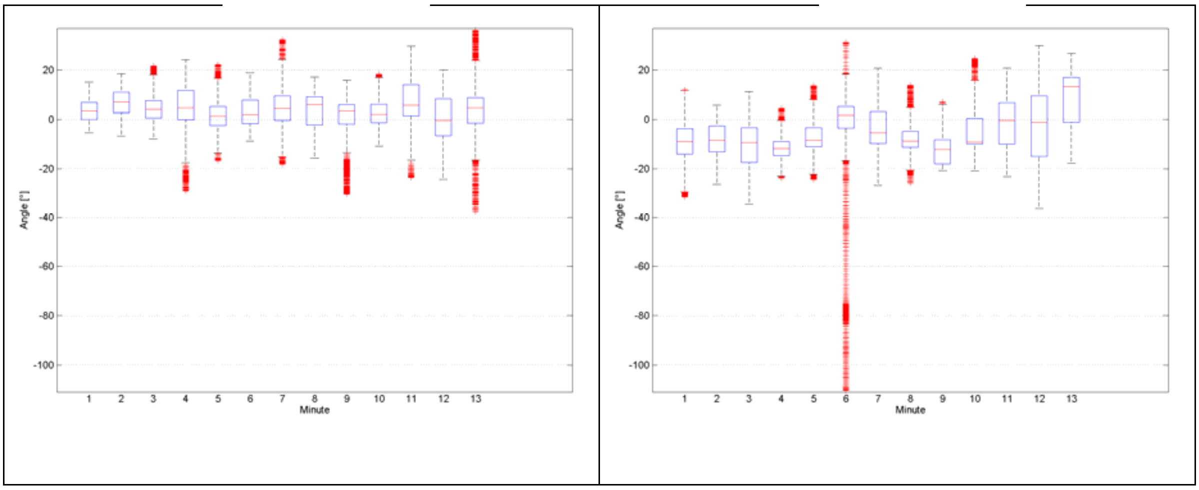
Table 6.6: The largest and smallest difference in median for the school chair

School chair					
Median difference	**Subject ID**	**Median (IQR) (degrees)**	**Min. median (degrees)**	**Max. median (degrees)**	**Median difference (degrees)**
Pelvic tilt					
Largest	S06	-7.9° (4.5°)	-10.4°	0.9°	11.3°
Smallest	S02	6.3° (1.8°)	5.9°	8.1°	2.3°
Thoracic flexion/extension					
Largest	S06	3.7° (5.8°)	-8.3°	6.7°	15.0°
Smallest	S02	14.1° (2.3°)	11.8°	15.0°	3.3°
Head flexion/extension					
Largest	S06	4.4° (8.7°)	-41.2°	-35.7°	5.5°
Smallest	S02	-8.1° (3.7°)	-41.2°	-40.8°	0.5°

To illustrate, we selected one subject (S10) was selected, in order to present the median and IQR per minute of the pelvis, thorax and head in the sagittal plane graphically. The box plots for the entire sample and other planes are presented in Addendum H. A large intra-subject variation of the median and IQR for both chairs is notable in the box plots (Table 6.7).

Table 6.7: Per-minute box plots of subject S10

<table>
<tr><th>School chair</th><th>Prototype ‘Dynamic’ chair</th></tr>
<tr><td colspan="2">Pelvic tilt</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Thoracic flexion/extension</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Head flexion/extension</td></tr>
</table>



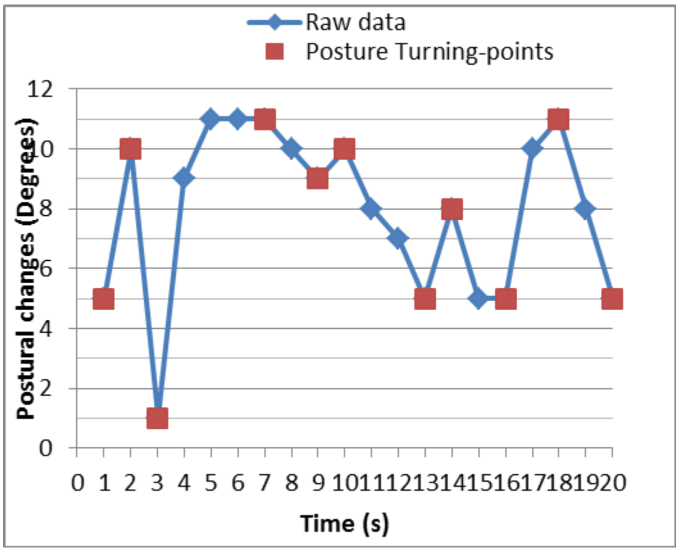
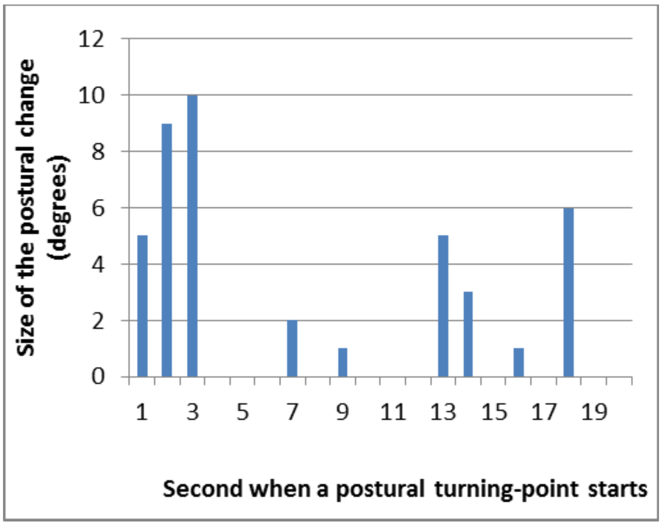
6.2.3.3 Descriptive analysis of the number of postural changes

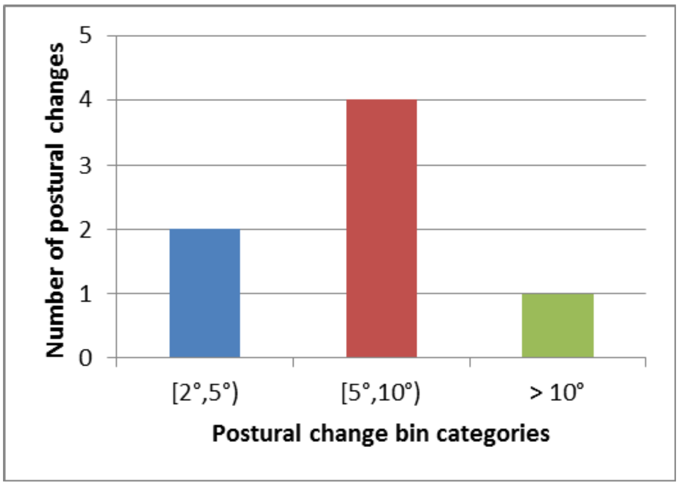
- *Statistical procedure: Number of postural changes*

To ascertain whether sitting in the prototype chair had facilitated more postural changes of the head, thorax and pelvis, a postural change was defined as the difference in degrees between one turning point (change in movement direction) and a successive turning point in the data of a given angle (Table 6.8). As each angle is a continuous function (even though it is discretised), the derivative of the data was used to calculate the turning points concerned. The absolute difference between successive turning points was calculated per subject, per chair. The histograms for the absolute differences were binned between zero and 180 degrees in increments of one degree. The bins were then clustered into categories of two to five degrees, between five and ten degrees, and more than ten degrees of movement. Histograms of the bins were created for descriptive comparison. All 'movements' smaller than two degrees were disregarded as system error (McGinley, Baker, Wolfe & Morris, 2009).

Table 6.8 illustrates how the postural turning points were determined, and how progression was made from identifying the turning points to illustrating the number of postural changes as a count in the bin categories of postural changes.

Table 6.8: The way in which turning points were calculated and counted

	The first graph illustrates example raw sitting posture data for an angle over a period of time. The red points indicate the turning points.
	The second graph illustrates the size (in degrees) of the postural change (between two successive turning points) at the time when postural change started to occur (first turning point).

	The third graph indicates how the relative postural changes were counted for each bin.

The ratio between the prototype 'Dynamic' chair postural change bin categories and the school chair postural change bin categories was then determined. If the prototype 'Dynamic' chair bin was larger than the school chair bin, then the count for the prototype 'Dynamic' chair bin would increment by 1 and *vice versa*. The following formula was used to calculate the ratio:

Ratio = (Prototype 'Dynamic' chair count / School chair count) – 1

The ratio illustrates in which chair more movement takes place for specific sized postural changes, as categorised in the bins. The interpretation of the ratio is that a positive value indicates more movement in the prototype 'Dynamic' chair and a negative value indicates more movement in the school chair.

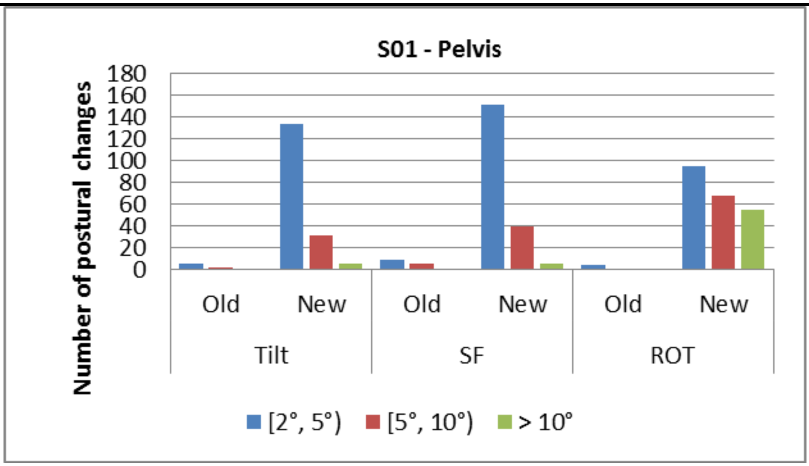
The statistical difference between the chair conditions was then determined for the combined count of all three bin categories. The Wilcoxon Matched Pairs Test (significance level at $\rho < 0.05$) was performed.

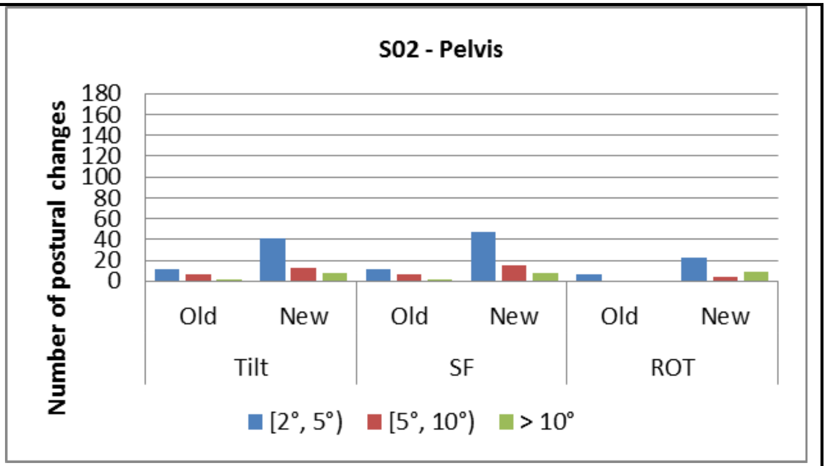
- *Results: Number of postural changes*

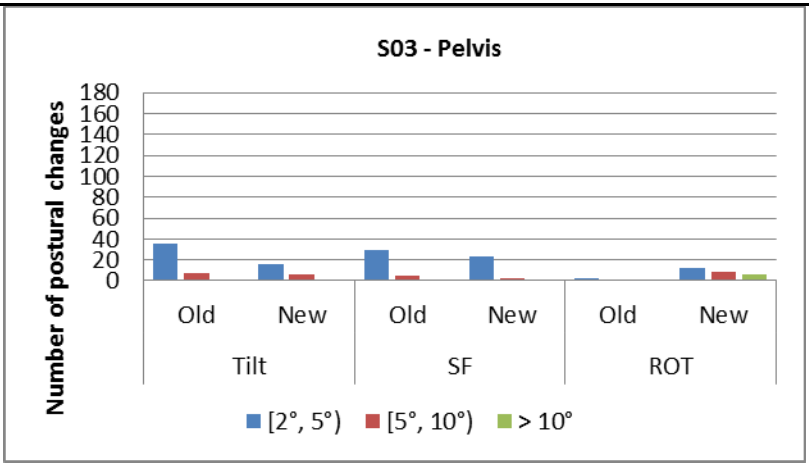
Three-dimensional pelvic movements

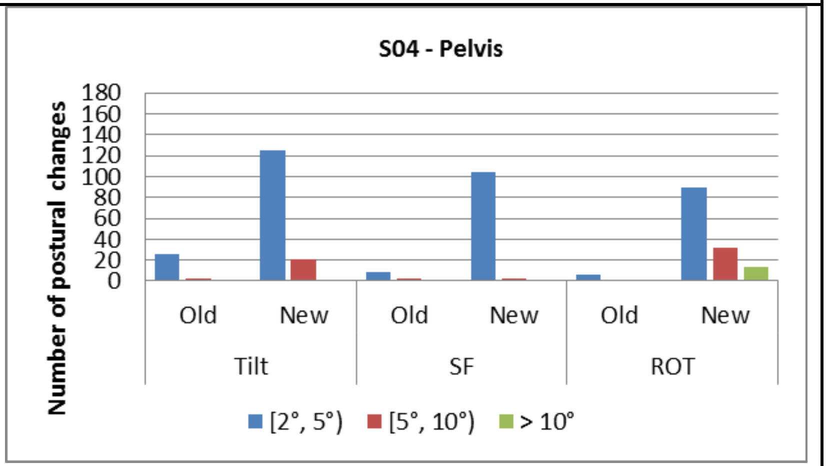
Table 6.9 reports on the number of pelvic movements per postural change bin category for each subject. It should be noted that reporting on all of the angles could not be done by using the same scale, as the number of movements of less than five degrees varied between angles. Nine of the eleven subjects showed an increased frequency of postural change, in all three movement planes, in the prototype 'Dynamic' chair compared to the frequency of such change in the school chair (S01–S02, S04, S06–S07, S09–S12). Only two subjects (S03, S05) showed an increased number of postural changes in the school chair for pelvic tilt. All subjects predominantly had a higher frequency of movements of less than 5 degrees in both chair conditions, compared to larger movements.

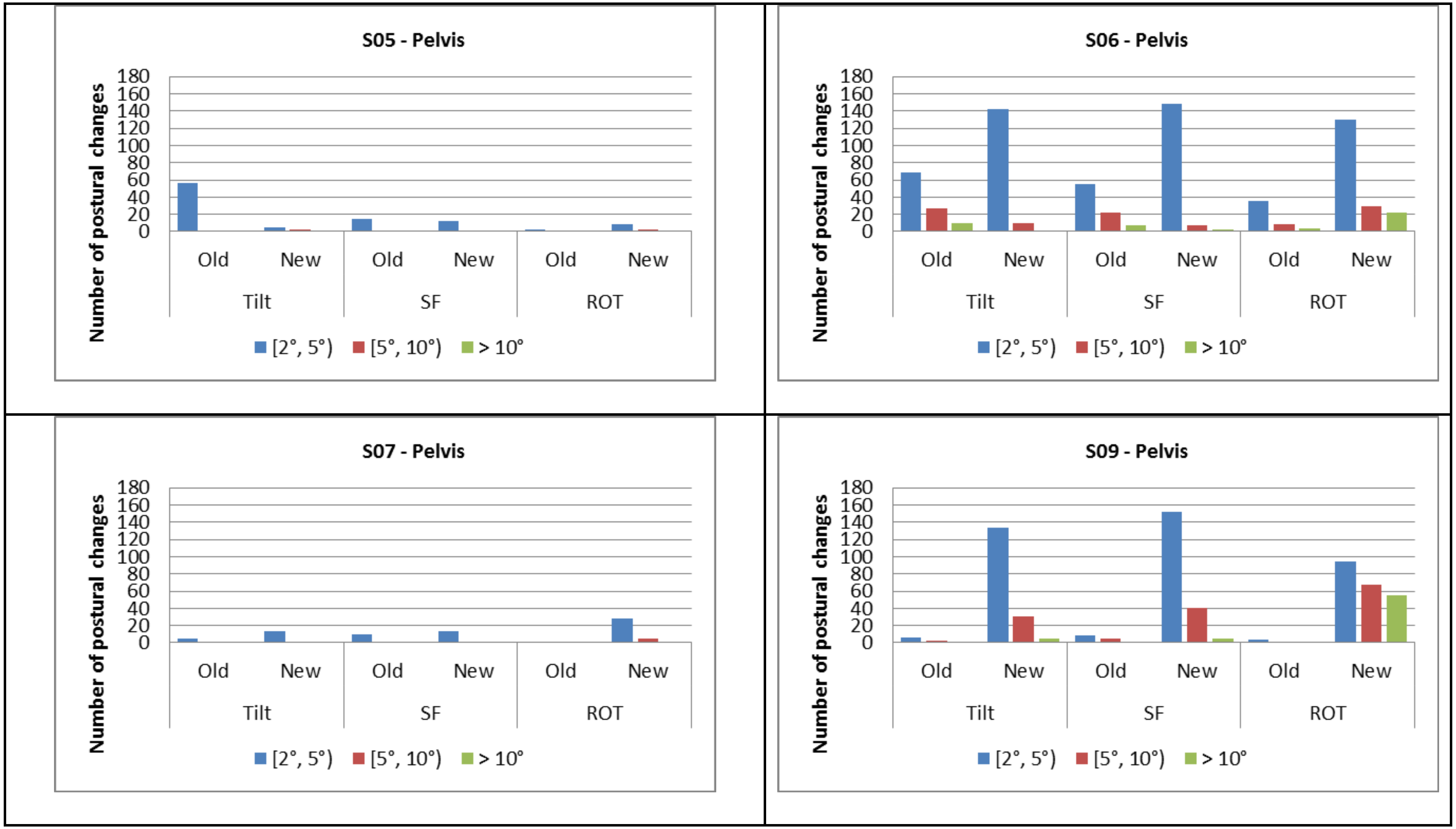
Table 6.9: The number of pelvic movements per movement group

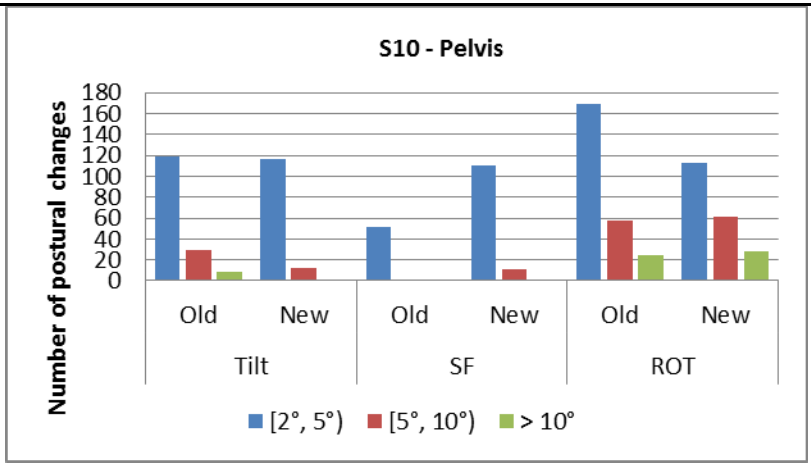


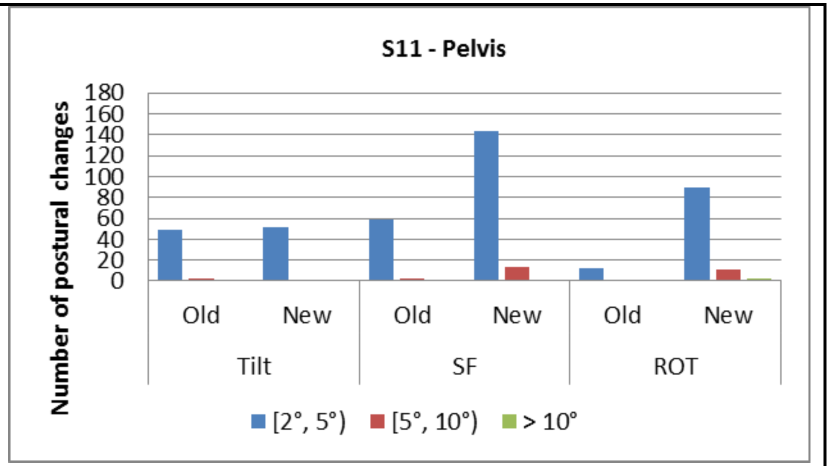


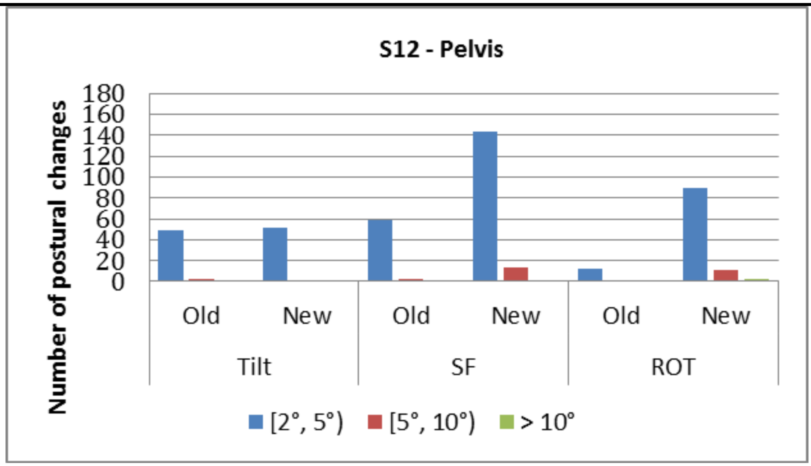





S05 - Pelvis
Number of postural changes
180
160
140
120
100
80
60
40
20
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°
S06 - Pelvis
Number of postural changes
180
160
140
120
100
80
60
40
20
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°
S07 - Pelvis
Number of postural changes
180
160
140
120
100
80
60
40
20
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°
S09 - Pelvis
Number of postural changes
180
160
140
120
100
80
60
40
20
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°


S10 - Pelvis
Number of postural changes
180
160
140
120
100
80
60
40
20
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°

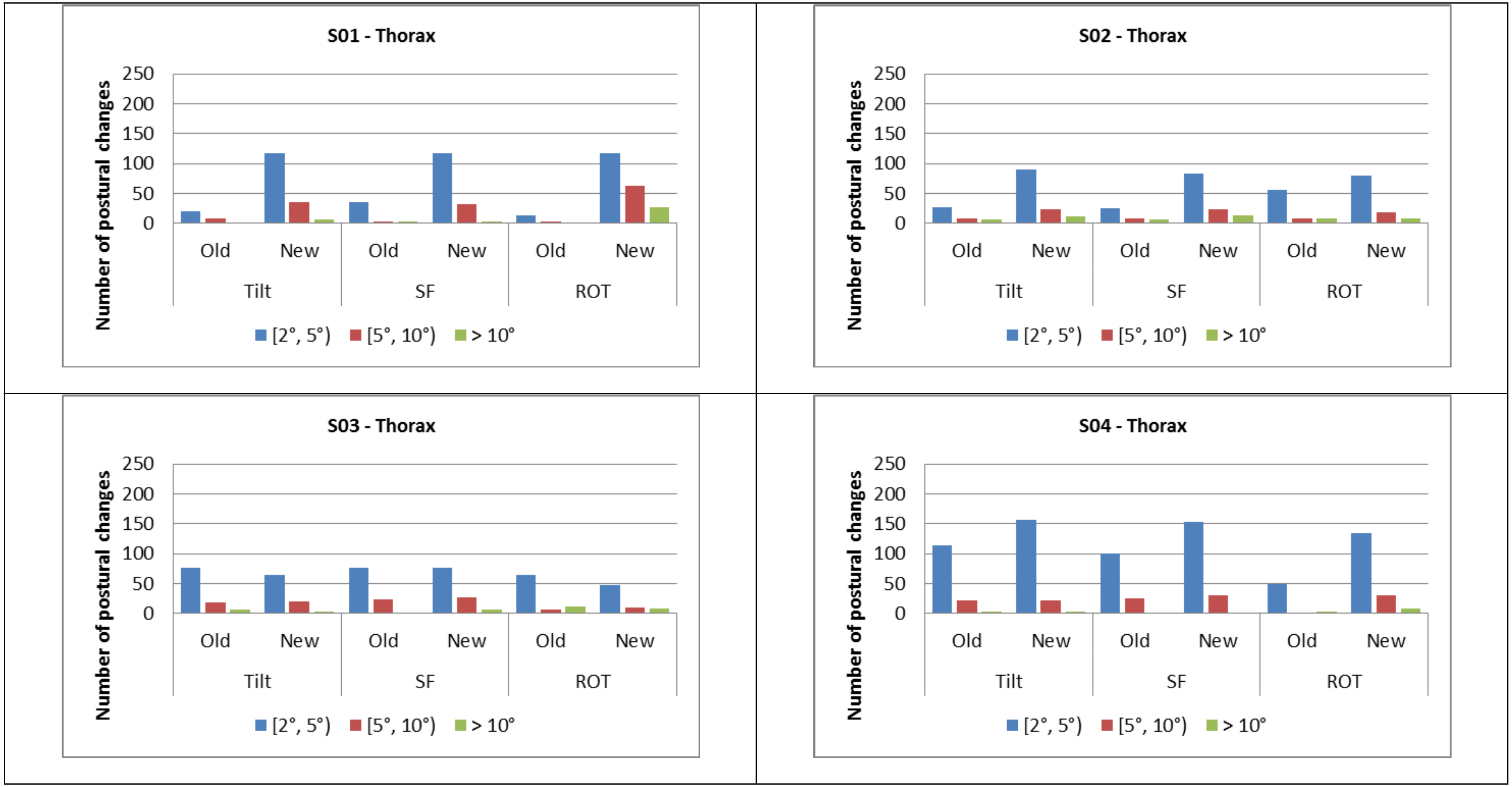

S11 - Pelvis
Number of postural changes
180
160
140
120
100
80
60
40
20
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°

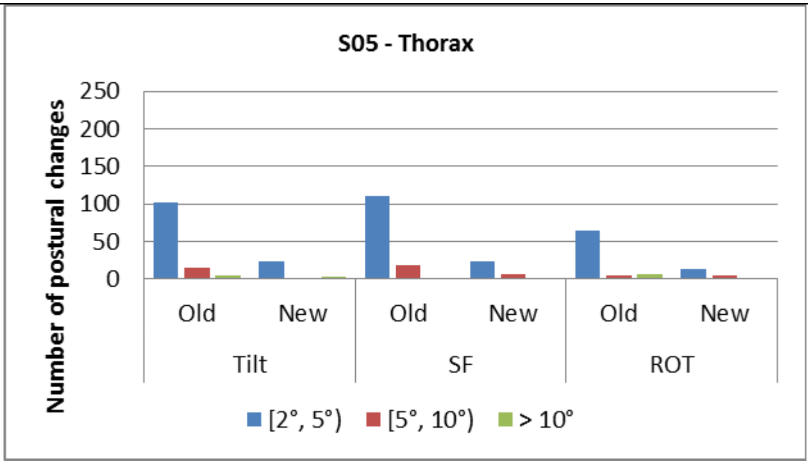

S12 - Pelvis
Number of postural changes
180
160
140
120
100
80
60
40
20
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°

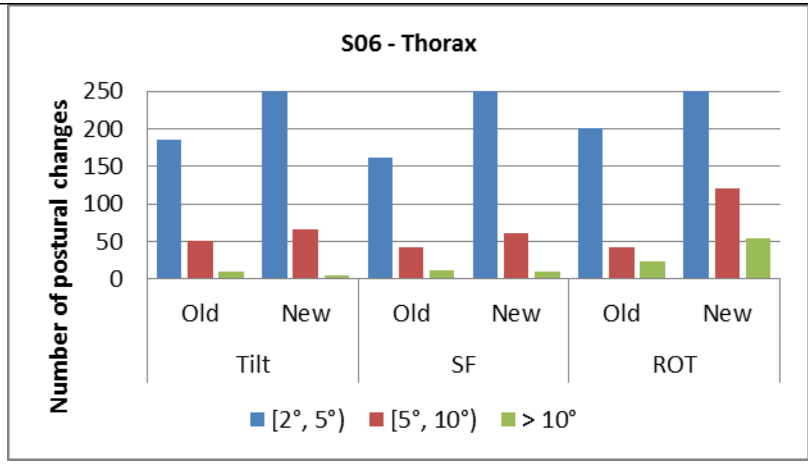
Three-dimensional thoracic movements

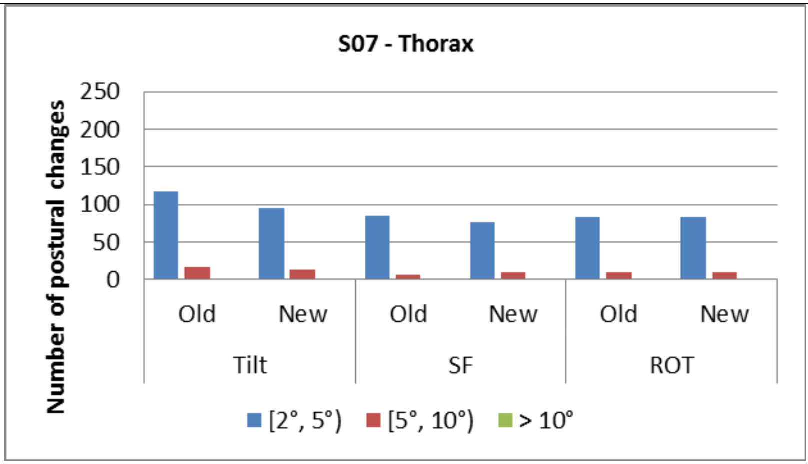
Table 6.10 reports on the number of thoracic movements per movement group for each subject of the study. Five of the eleven subjects showed an increased frequency of postural change, in all three movement planes, in the prototype 'Dynamic' chair compared to the school chair (S01–S02, S04, S06, and S09). Six subjects (S03, S05, S07, and S10–S12) showed an increased number of postural changes in the school chair for thoracic tilt of at least one of the three movement planes. All subjects predominantly had a higher frequency of movements of less than 5 degrees in both chair conditions, compared to larger movements.

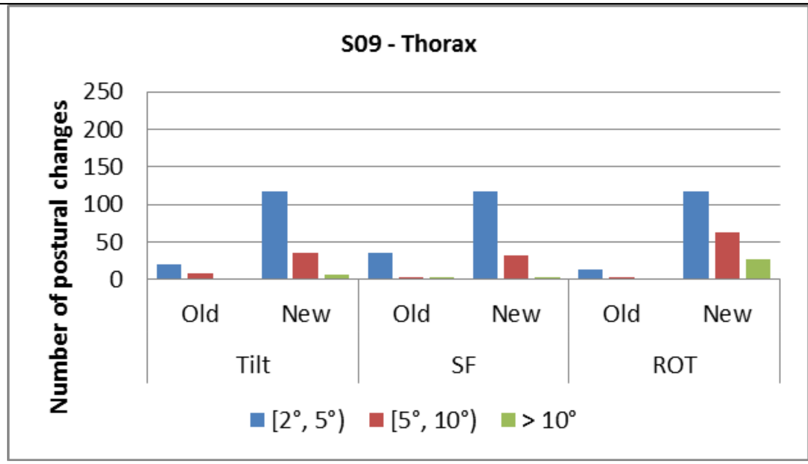
Table 6.10: The number of thoracic movements per movement group

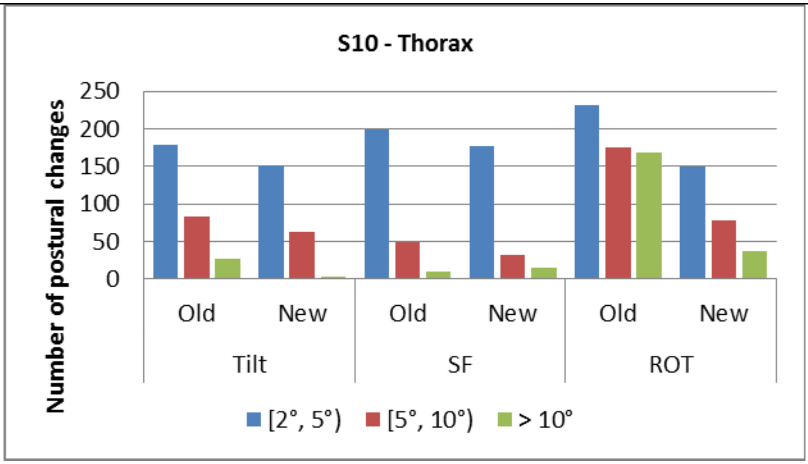


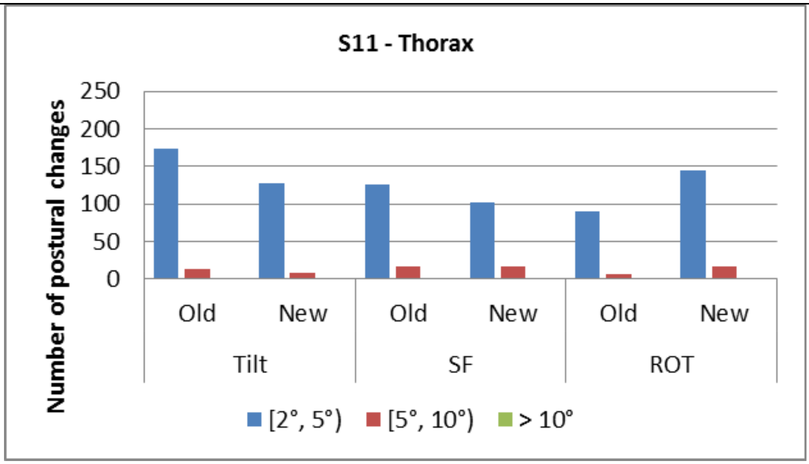

S05 - Thorax
Number of postural changes
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°

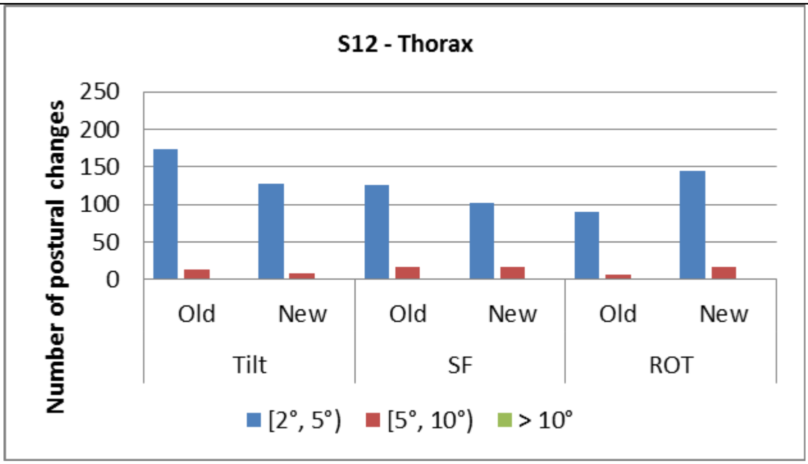

S06 - Thorax
Number of postural changes
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°


S07 - Thorax
Number of postural changes
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°


S09 - Thorax
Number of postural changes
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°


S10 - Thorax
Number of postural changes
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°

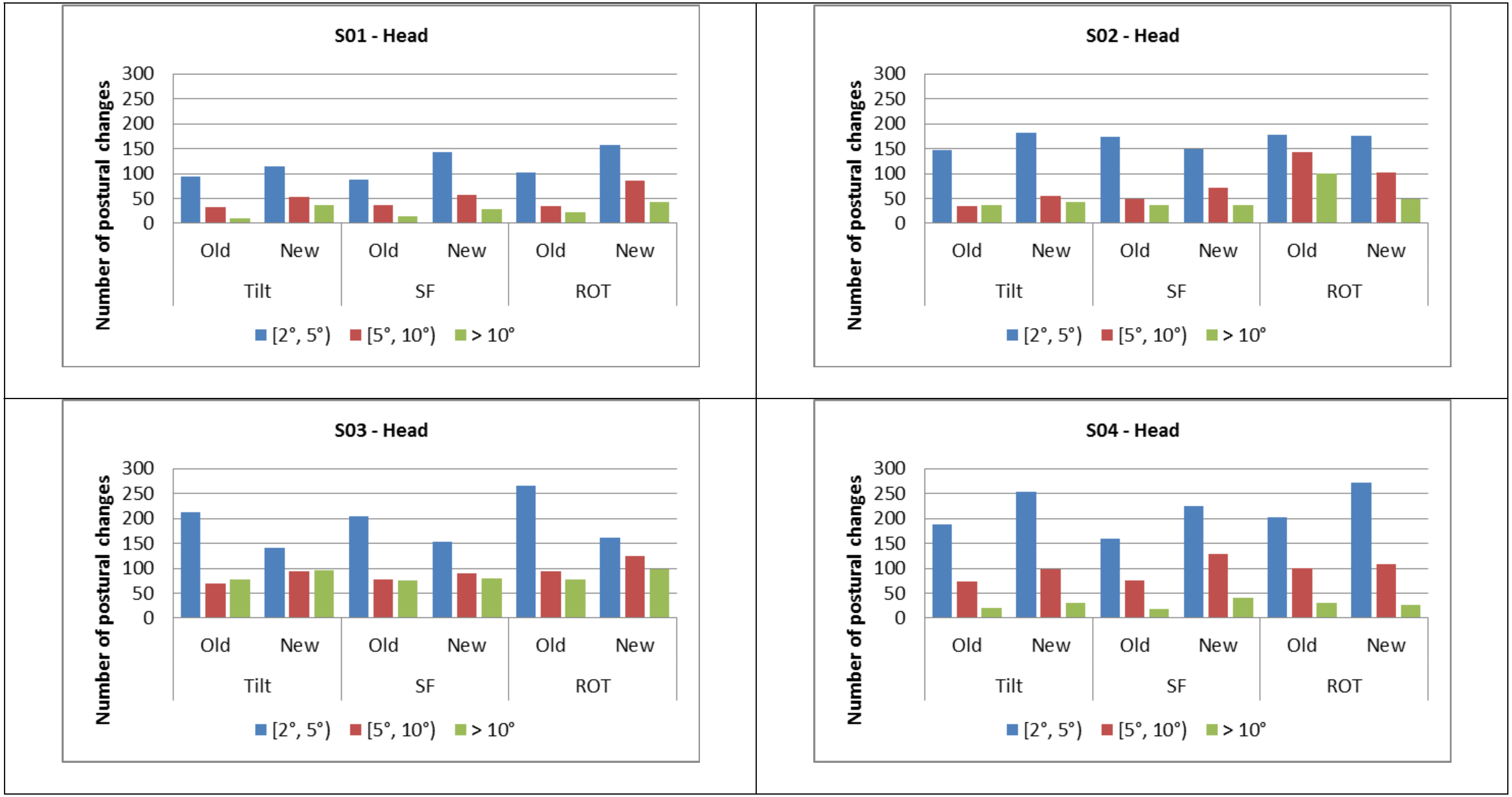

S11 - Thorax
Number of postural changes
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°

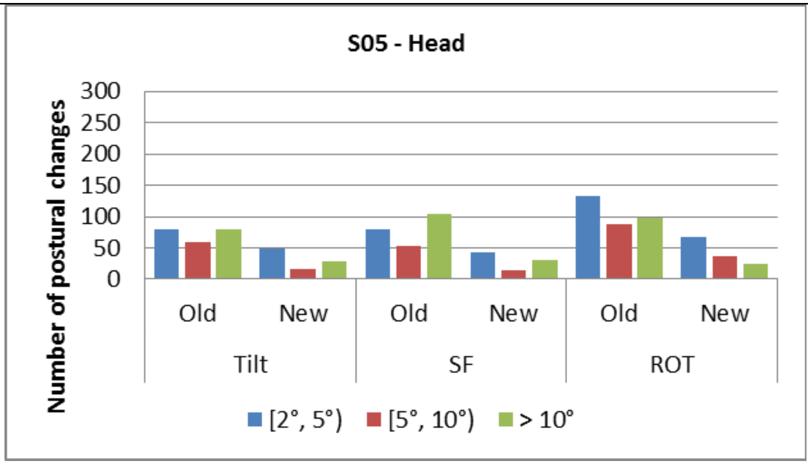

S12 - Thorax
Number of postural changes
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°

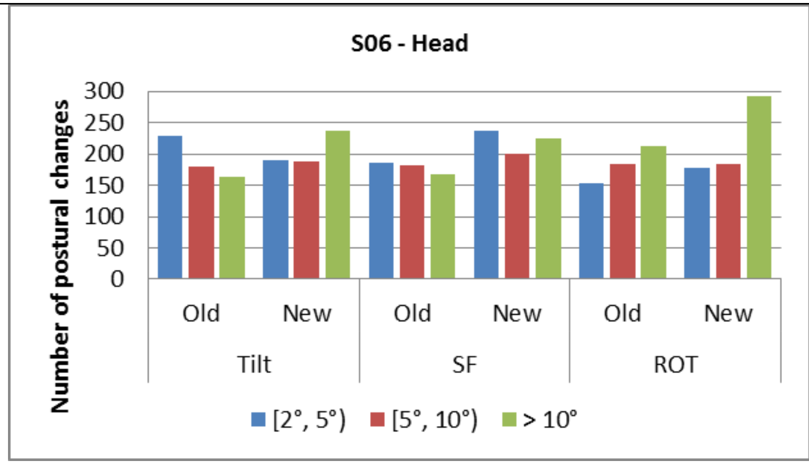
Three-dimensional head movements

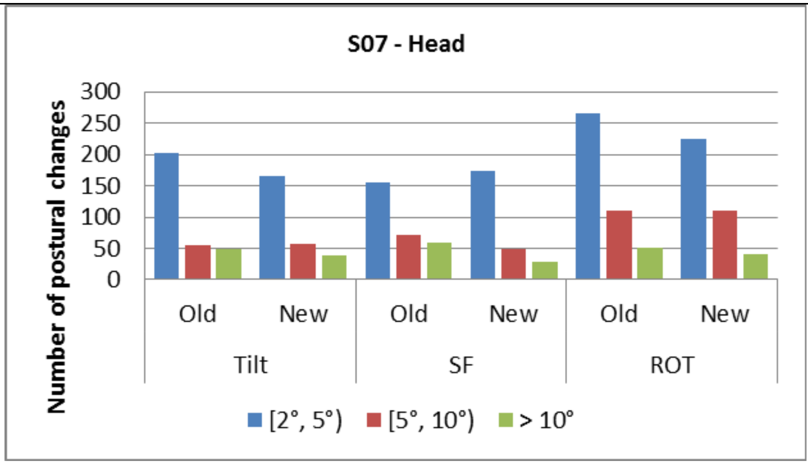
Table 6.11 reports the number of head movements per movement group for each subject. Five of the eleven subjects showed an increased frequency of postural change, in all three movement planes, in the prototype 'Dynamic' chair, compared to the school chair (S01, S02, S04, S09, S11). Six subjects (S03, S05–S07, S10, S12) showed an increased number of postural changes in the school chair for at least one of the movement planes. The head angle showed an increased frequency of larger movements (5 degrees and more), compared to the pelvic and thoracic angles.

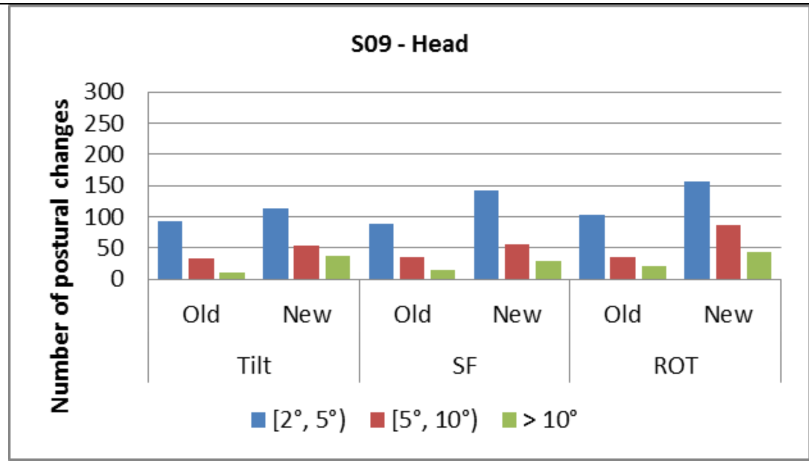
Table 6.11: The number of head movements per movement group



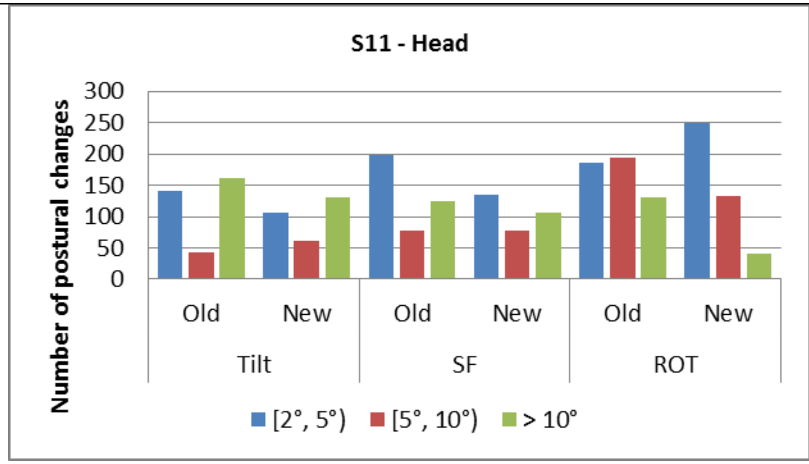

S05 - Head
Number of postural changes
300
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°


S06 - Head
Number of postural changes
300
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°


S07 - Head
Number of postural changes
300
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°


S09 - Head
Number of postural changes
300
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°


S10 - Head
Number of postural changes
300
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°


S11 - Head
Number of postural changes
300
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°

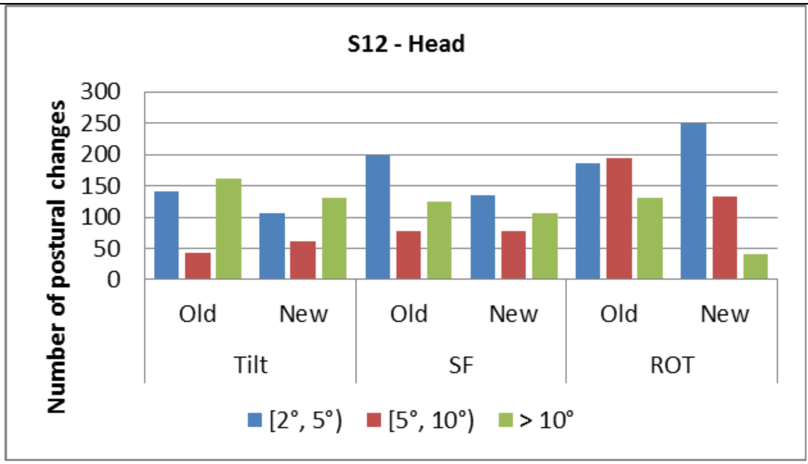

S12 - Head
Number of postural changes
300
250
200
150
100
50
0
Old
New
Old
New
Old
New
Tilt
SF
ROT
[2°, 5°)
[5°, 10°)
> 10°

Table 6.12 describes the ratio of the number of postural changes (all bins combined) of all three angles, for all subjects, in the prototype ‘Dynamic’ chair, in relation to the school chair. A positive ratio indicates that a greater number of postural changes occurred in the prototype ‘Dynamic’ chair compared to in the school chair. Pelvic rotation illustrated a substantially higher ratio (10.0 **) of postural changes, as well as a higher thorax rotation ratio (2.0) in the prototype ‘Dynamic’ chair, compared to in the school chair. Head rotation (-0.6) in the school chair indicated a noteworthy increase in the number of head rotation movements compared to the number of such movements that took place in the prototype ‘Dynamic’ chair.

Table 6.12: The ratio of the number of postural changes in the prototype 'Dynamic' chair compared to the school chair

** *Prototype 'Dynamic' chair moved more than the school chair for every single measure, and the school chair barely moved. The ratio approaches infinity.*

Angle	Tilt or flexion/extension	Side-flexion	Rotation
Pelvic	0.3	0.7	10.0**
Thorax	-0.5	0.0	2.0
Head	-0.2	-0.3	-0.6

One of the aims was to establish whether there was a statistical difference between the number of postural changes made under the different chair-imposed conditions. Table 6.13 reports on the outcome of the Wilcoxon Matched Paired test. There was a statistical significant increase in the number of postural changes in the prototype 'Dynamic' chair compared to the school chair, for both pelvic side-flexion and pelvic rotation (ρ=0.01).

Table 6.13: The difference in the number of postural changes between the prototype and school chair (significance at ρ <0.05)

	Pelvic tilt	**Pelvic side-flexion**	**Pelvic rotation**	**Thoracic flex-/extension**	**Thoracic side-flexion**	**Thoracic rotation**	**Head flex-/extension**	**Head side-flexion**	**Head rota-tion**
ρ-value	0.16	0.01*	0.01*	0.53	0.29	0.15	0.25	0.66	0.33

6.2.3.4 Count ratio of the number of postural changes and the range of movement (IQR) for the total sample

- *Statistical procedure: Count ratio of the number of postural changes and IQR for the entire sample*

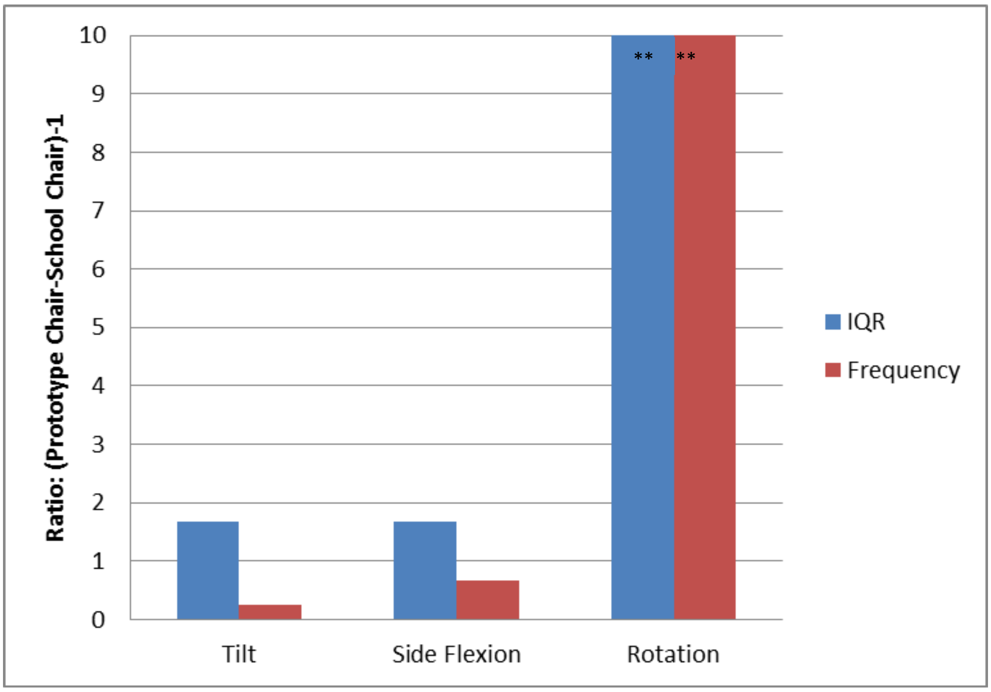
Lastly, the count ratio comparison of the total number of postural changes (histogram data) and the IQR for the entire sample was reported on, for ease of comparison. A count ratio was applied to the IQRs and the histogram data of each subject, for the prototype 'Dynamic' chair and the school chair per angle, in order to obtain a ratio for the entire group. The count for the prototype 'Dynamic' chair was increased by 1, when a subject had a larger total postural movement bin count for a specific angle compared to the total bin size of the same subject for the same angle in the school chair, and *vice versa*. The same method was employed for the IQRs. In this way, a calculation could be made of a ratio to illustrate which chair allowed more postural changes, as well as which chair allowed a larger range of postural changes per angle for the entire group of learners. The ratios were calculated with the following equation:

Ratio = (Prototype 'Dynamic' chair count / School chair count) – 1

A positive histogram ratio illustrated how many more postural changes occurred in the prototype 'Dynamic' chair compared to in the school chair. A negative ratio illustrated how many fewer postural changes occurred in the new chair compared to in the school chair. The IQR ratio illustrated how the size of the range of postural changes (in degrees) compared between chairs.

- *Results: Count ratio of the number of postural changes and IQRs for the entire sample*

The count ratio comparison for the IQRs and for the histogram data (HIST) for the entire sample, for the pelvic, thoracic and head angles are presented in Figures 6.13 to 6.15. In general, the IQR for was greater for all three angles in all three of the movement planes in the prototype 'Dynamic' chair. The pelvis showed a higher number of postural changes in all three movement planes, with most postural changes occurring in rotation.



*A ratio of 10** indicates that the prototype 'Dynamic' chair moved more that the school chair for every single measure. As the school chair barely moved, the ratio thus approaches infinity.*

Figure 6. 13: The count ratio comparison for the IQRs and histogram data (HIST) of the entire sample for the pelvis

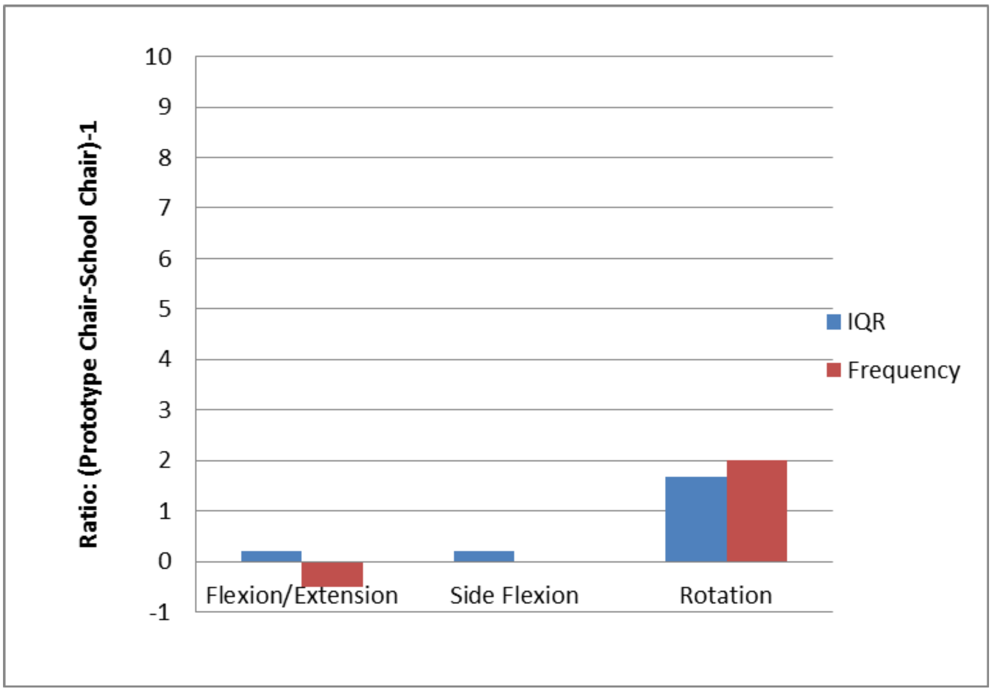


Figure 6.14: The count ratio comparison for the IQRs and histogram data (HIST) for the entire sample of the thoracic angle

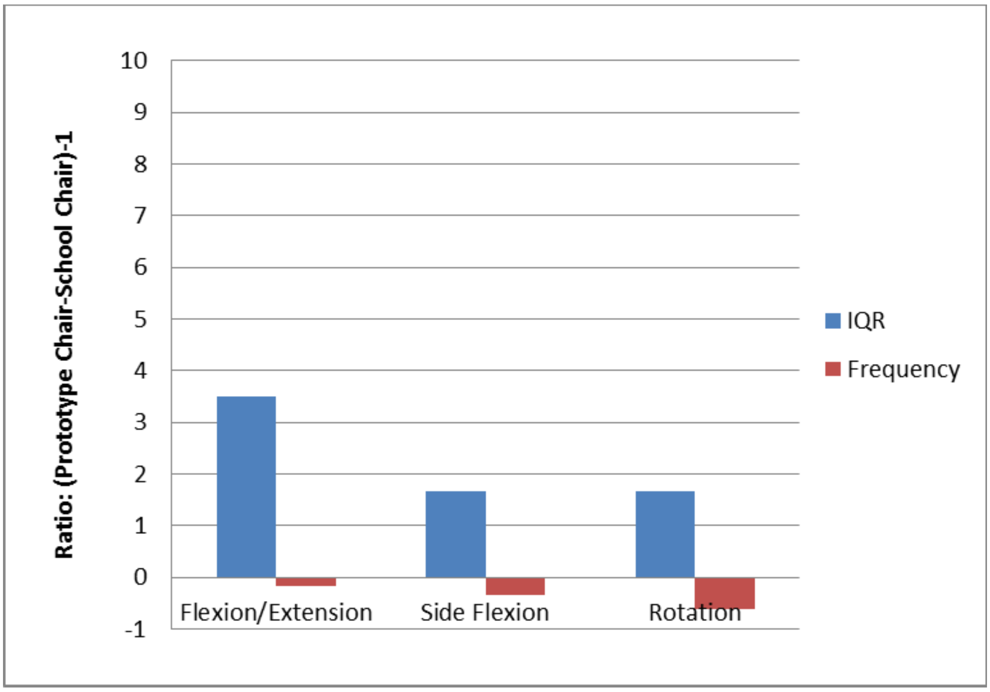


Figure 6.15: The count ratio comparison for the IQRs and the histogram data (HIST) for the entire sample of the head angle

6.2.4 Summary

The aim of the development and testing of the prototype 'Dynamic' chair was to increase the number of postural changes made whilst sitting at a desktop computer, with the aim being achieved in all three of the movement planes for the pelvis and in the transverse plane of the thorax. The prototype 'Dynamic' chair showed markedly more rotational movement compared to the school chair.

A concern was identified with the conventional manner of describing sitting posture which entails calculating a mean and SD of only a few minutes at the end of a capture while sitting. A significant amount of movement was seen throughout the capturing time in the prototype 'Dynamic' chair and in the school chair, as well as a sizeable difference between the minimum median and maximum median during the capturing time, which strengthens the notion that sitting is not a *static* posture. The final two minutes of captures seemed not to be representative of the subject's sitting posture, or, rather, the sitting behaviour, throughout the testing duration. Further research is required to measure, analyse and interpret posture analysis methods.

The above-mentioned encouraging findings provide a platform of knowledge for further research on a larger sample, and also allow for testing of the hypothesis of whether this increase of movement will have an effect on the musculoskeletal prevalence and intensity of high school learners in the Cape Metropole area, Western Cape, South Africa.

CHAPTER 7

Discussion

This thesis presents new information that address areas of latent morbidity, namely that of adolescent spinal health. The research adds to knowledge about adolescents' anthropometry and their use of computer chairs at school, in respect of the following.

- *The current research reports the first-known anthropometric profile, relevant to chair design, of post-apartheid high school learners in the Cape Metropole area, Western Cape, South Africa.*
- *The study highlights how few of the high school learners fit their school computer chairs, in terms of body-furniture mismatch.*
- *A new ergonomically designed chair was proposed, and a prototype was developed from 'spare' chair pieces, in order to build an affordable adjustable chair that could be used in school computer laboratories. The theoretical mismatch between the learners' anthropometry and the prototype chair was reported.*
- *The research explored how learners' sitting posture was influenced by sitting on the school chair and on the prototype 'Dynamic' chair, using the Plug-In Gait model patented by VICON, which model is adapted to measuring seated postures. A novel way of statistically analysing differences in sitting posture between the two chairs was proposed.*

- *The prototype 'Dynamic' chair shows a promising indication of facilitating more postural changes, especially in the transverse plane, compared to the number of such changes that were facilitated by the school chair.*

The findings of the study provide a promising step in the direction towards the development of an affordable adjustable chair that best fits the range of anthropometric features of high school learners (thus ensuring a more appropriate individual learner-chair match), as well as providing the learners with the opportunity to adjust their sitting posture easily in order to reduce the detrimental effect of prolonged posture in one position. Providing South African high school learners with such a chair for computer use might reduce the prevalence of current and future spinal pain, which would, potentially, reduce the amount of musculoskeletal health costs and sickness/disability costs incurred.

7.1 Anthropometric measurements

The social and economic changes that have occurred since apartheid was dismantled in 1992, has most probably influenced current school learners' body dimensions, largely through the burgeoning number of interracial marriages. It is therefore essential to take anthropometric measurements such as PH, BPL and HW into consideration when determining the dimensions of a chair that is likely to suit all its users. The schools of today are also differently populated than they were during the apartheid era. Today, schools have a mixed racial attendance. Therefore pre-1992 adolescent anthropometric data in South Africa, or data from other Western countries, might not be an accurate proxy for the current South African situation. The proposition highlights that the anthropometric profile of the high school learners is unique to the blend of races that is currently found in schools and that it is important to establish the anthropometric profile of other populations in South Africa in order to allow for the accommodating of all the different racial mixes found in other parts of the country.

7.2 Designing the chair

The prototype chair was a first attempt in designing a chair to fit the range of anthropometric measurements of the high school learners in the Cape Metropole area, Western Cape, South Africa. Due to budget constraints, it was not possible to custom design all the parts of the chair. The SH was determined as being the most important dimension that should fit the user, since height determines the angle of the knees and hips, which, in turn, influences the pelvic angle and determines the amount of lumbar flexion (Pheasant, 1996). Lumbar flexion or the lumbar lordosis plays an important role in the development of low-back pain (Milanese & Grimmer, 2004; Pheasant, 1996). Emphasis was therefore placed on ensuring an appropriate seat high fit, and less emphasis was placed on the SW and SD dimensions. Even though the SD and SW of the prototype chair was 4 and 7cm smaller, respectively, than the optimal dimensions, the former dimensions still provided a much better fit than did either of the school computer chairs and all of the commercially available chairs. When comparing the number of matching criteria that were met, the prototype ‘Dynamic’ chair was found to outperform both the school chairs and all of the commercially available chairs. The prototype ‘Dynamic’ chair also complies with the criteria set out in the ‘Computer laboratory Workstation Assessment Checklist’ (Addendum A), referred to in Chapter 1.

7.3 Data capture and analysis challenges

A great deal of time (45 minutes per five-minute trail) was required for processing the VICON data and for following the novel approach to analyse the sitting data. Therefore, only a pilot sample was tested, instead of a full representative sample as originally planned. The former approach was deemed appropriate since various ways of optimising the sitting data capturing procedure and analysis methods were identified. The recommendation was made that the cameras should be placed on tripods and positioned in closer proximity to the subject in order to optimise marker visibility, by reducing the distance from the camera to the marker, as well as preventing the marker from being obscured by other body parts, or by the furniture. It would also be advisable to develop a sitting-specific model instead of using the generic Plug-In Gait model provided by VICON.

The current study was the first of its type to be conducted on adolescents, in which the frequency of 3D postural change in sitting was measured over a period of time. For this reason, one of the research challenges that were faced was to establish the most appropriate approach for analysing the data.

7.3.1 Postural angle

The first challenge was to ascertain which angle to use for analysis. Since the seat would have a direct influence on the pelvis, the pelvic angle was used for primary analysis. In addition, the cervical and trunk angles have been found to be strongly associated with the position of the visual display, as well as with the activity concerned (i.e. whether it was computer-based or paper-based) (Straker *et al.*, 2008). Although the cervical and trunk angles were not expected to be influenced by the choice of chair, these angles were reported to obtain a comprehensive analysis of learner sitting behaviour.

7.3.2 Summary analysis

The pelvic, thoracic and head angles adopted when sitting was analysed by comparing the overall median per subject, the minimum and maximum median (from the per minute analysis) and the IQR for the entire duration of the capture, as part of the descriptive analysis (Chapter 6, section 3, Results). A large difference was detected in the minimum and maximum medians per subject, with, for one subject (S02), the difference being as large as 93.2 degrees in head flexion/extension whilst sitting in the prototype 'Dynamic' chair was noted (Table 6.5). There were also substantial differences between the 'per minute' medians for both chair conditions (as illustrated by the box plots in Table 6.7). The conventional approach to reporting on the 3D sitting posture of adolescents was undertaken by analysing the central tendency of the final two minutes of data capture, as described by Straker *et al.* (2008). The problem with the adopted approach of reporting on sitting posture was that the learners rarely sat static in any one given position, as was established in Chapter 6 (Tables 6.5 to 6.7). Although there were fewer postural changes in the static school chair, the learners still frequently changed their sitting posture on both chairs. Thus, the mean and SD of the final two minutes of a capture were unlikely to represent sitting behaviour effectively. The example provided in Chapter 7 (Table 6.7: Pelvic Tilt Old chair) shows that, if the mean of the final two minutes, being -10.9 degrees, had been taken, the sitting posture of the subject would have been taken as sitting in a posterior tilt position of -10.9 degrees, whereas, in reality, the subject hardly ever sat in such a position. In fact, the subject concerned spent most of the time at a much smaller amount of posterior tilt, with large variability between positions. It was clear that the conventional approach merely provided a snapshot of the sitting position at a specific point in time. Therefore, there was need for a revised approach to measuring and describing sitting posture.

Due to the inadequacies of the 'conventional' manner of reporting on sitting posture, the identification of a new approach was warranted. At first, it was thought that the data should be approached in a similar manner to the approach taken in analysing EMG signals. However, adopting such an approach did not work, as interest lay in the frequency of movement and not only in the amplitude of movement. Thus, the 'area under the curve' approach could not be taken, as doing so would have masked the frequency of movement by highlighting the amplitude of the movement involved. The hypothesis was drawn that learners might have to make fewer, but larger, amplitude movements in order to offer relief to compromised spinal tissues, due to the static nature of sitting on the school chair. The proposal was also made that smaller, but more frequent, movements would occur in the prototype 'Dynamic' chair, as the chair allowed greater freedom of movement and more opportunity for postural adjustment than did the school chair. As a second approach, use was made of Fourier analysis, which is normally employed for signal processing. Again, the approach mentioned was found not to be appropriate, as the reliability of the Fourier analysis at low frequencies was problematic. The power density integrals were also difficult to interpret when comparing the two types of chairs. The form of analysis concerned would have required so many assumptions regarding the filter frequency for the data sets that the results would have required a large amount of *ad hoc* justification. With too little time remaining to allow for the full investigation of the use of Fourier analysis in the specific context mentioned (without it being a proven method), it was decided upon to focus on using other methods.

Finally, a novel approach was decided upon, in terms of which the angular change was classified into 'bins' of two to five degrees, 5.1 to ten degrees, and larger than ten degrees. The number of events in each of the movement bins was counted for each angle. The number of movements in each bin was then compared between the prototype 'Dynamic' chair and the school chair. The analysis provided an opportunity for demonstrating the hypothesis that the learners made more frequent posture changes in the prototype 'Dynamic' chair, for some of the angles, compared to the number of movements that they made in the current school chair.

Pelvic side-flexion and rotation showed the most marked increase in the number of postural changes made in the prototype 'Dynamic' chair (ρ= 0.01). Many researchers (Adams & Dolan, 2005; Ariëns *et al.*, 2001; Bernard *et al.*, 1994; Mandal, 1981; Pope *et al.*, 2002; Tittiranonda *et al.*, 1999; Troussier *et al.*, 1999) have concluded that an increase in the number of movements might have a positive effect on learners who are exposed to sitting for prolonged periods of time. Research into the effect of dynamic sitting on the spine has proposed that pelvic rotations have a positive impact on the spine by varying the load of the spinal structures, which, in turn, serves to decrease the number of compressive forces on the disc and which also aids in disc height recovery and increased stature (McGill & Fenwick, 2009; Van Deursen *et al.*, 2001; Van Dieën *et al.*, 2001). The increase in stature is seen as a positive effect of pelvic rotation in sitting, as it reflects an influx of fluids and, consequently, of nutrients into the avascular disc (Urban & McMullin, 1988). Although the findings concerned are very promising, the prototype 'Dynamic' chair aided in the performance of much larger pelvic movements than were found to occur in the above-mentioned studies (Van Deursen *et al.*, 2001; Van Dieën *et al.*, 2001). Descriptive and prospective studies are, thus, needed to ascertain whether the relatively larger range of pelvic rotations also yields positive effects for the underlying spinal structures.

Contrary to the initial proposition, the learners actually had a greater range (IQR) of movement in the prototype 'Dynamic' chair than they did in the school chair (Figures 7.13 to 7.14). The greater range might be due to the dynamic nature of the chair, which provided the subject with the possibility of moving through a larger range of movement than did the static school chair. The increased range of movement might encourage the user to move into end-range positions of the neck, thorax and pelvis, which might increase the strain on spinal structures and, consequently, lead to pain (Brink, Crous, Louw, Grimmer-Somers & Schreve, 2009). The large IQR is perhaps one aspect that should be addressed in the second version of the prototype 'Dynamic' chair. The tension of the dynamic spring-based system might have to be increased in order to provide more resistance towards the end of the range, which would hinder a very large outer range of movements.

The pelvic movement also appeared to encourage movement of the thoracic spine. (Refer to Table 6.9.) The thorax demonstrated more postural changes in the prototype 'Dynamic' chair compared to in the school chair (Table 6.10). Prolonged computer usage is typically associated with pain in the thoracic region, particularly the upper thoracic region. The increased dynamism of the thoracic spine might have a positive effect on the underlying structures, by preventing prolonged strain. The enhanced frequency in postural change is also advantageous, as it helps to prevent stiffness, which could also lead to pain (Song, Jo, Sung & Kim, 2012).

The head was the only segment that showed an increase in the number of postural changes in the school chair compared to in the prototype 'Dynamic' chair. Although movement is advocated, it is not advantageous to have the movement limited to only one segment, as doing so might lead to localised strain of the same neuromusculoskeletal structures, and, consequently, to pain (Adib, Davies, Grahame, Woo & Murray. 2005). The lack of increase of head movement in the prototype 'Dynamic' chair might have been due to the unstable nature of the chair, which might have required the learners to seek stability in one body segment, which might have been achieved by maintaining the head in more or less the same position. As has been mentioned in the preceding paragraphs, the second version of the prototype chair should address the tension of the dynamic spring-based system, in order to provide more stability when sitting. Having such an enhanced sense of controlled stability might allow the movement in the pelvis and thorax to propagate upwards towards the head, and, thereby, also facilitate small deviations of the head position and movements concerned.

7.4 Adolescent spinal pain

With no computer chair (either school or commercially available) providing an adequate fit for a good percentage of the high school learners in the Cape Metropole area, Western Cape, South Africa, it would seem that the learners concerned are being exposed to considerable risk for the development of spinal pain. The risk could be associated with increases in the already high prevalence rate of spinal pain amongst high school learners in the Western Cape, with the point prevalence being reported by Smith (2007) as about 70% of high school learners in the Cape Metropole area, Western Cape, South Africa.

Even more concerning are the results of an in-depth review of the literature, which showed that an anthropometrically poor fit between school chairs and learners, such as has been reported in this thesis, influences sitting posture, which, in turn, has the potential to lead to spinal pain (Kumar, 1994; Milanese & Grimmer, 2004; Bernard, 1997; Parcells *et al.*, 1999; Pheasant, 1996; Yeats, 1997). The height of the chair, in particular, plays an important role in sitting posture. Pheasant (1996) reports that too low a SH may lead to increased angles of lumbar flexion during sitting, and predispose the seated person to increased risk of lower-back pain. The SH mismatch for the two school chairs were 67% and 75% respectively, predisposing the majority of high school learners in the Cape Metropole area, Western Cape, South Africa to potential musculoskeletal injury on a daily basis.

Due to the poor design and anthropometric fit of the school chairs concerned, the learners in the current study were required to exert greater muscular force and control to maintain their stability and equilibrium whilst sitting than they might otherwise have been expected to do. Such a requirement, in turn, exposes the already at-risk group of learners to fatigue and discomfort, and it is likely to lead to poor postural habits, as well as to spinal complaints (Parcells *et al.*, 1999). Prolonged sitting in a poorly-designed chair, which facilitates poor postural alignment, accentuates the problem, as asymmetric attenuation of compressive and tensile forces acting on the body leads to harmful shear or compressive forces (Ariëns *et al.*, 2001; Bernard *et al.*, 1994; Mandal, 1981; Tittiranonda *et al.*, 1999; Troussier, 1999). In addition, incorrect body alignment reduces the ability of antigravity muscles to generate torque. The body's neuromuscular systems can, consequently, not respond optimally to such external forces as gravity. Abnormal physiological strain on the neuromuscular systems, induced by poorly designed and inappropriate-sized chairs, leads to repetitive strain and pain (Ariëns *et al.*, 2001; Bernard *et al.*, 1994; Mandal, 1981; Tittiranonda *et al.*, 1999; Troussier, 1999).

7.5 Mismatch and chair design

The match between the anthropometry of high school learners aged 13 to 18 years, attending randomly-selected high schools in the Cape Metropole area, Western Cape, South Africa and current computer laboratory chairs used in South African schools was not known at the beginning of the current study. However, given the description in international research of the poor match between chairs and the anthropometrics of other school learner populations (Brewer *et al.*, 2009; Cotton *et al.*, 2002; García-Acosta &. Lange-Morales, 2007; Gouvali & Boudolos, 2006; Milanese & Grimmer, 2004; Panagiotopoulou *et al.*, 2004; Parcells *et al.*, 1999; Saarni *et al.*, 2007), as well as the lack of ergonomic features of current school chairs used in South African schools (Smith, 2007), this lack in information was not ideal. Further research was therefore warranted. From the results of this study, it was however not surprising that a substantial mismatch was detected between the anthropometric profile of the high school learners and their school computer chair. Neither could a commercially available computer chair be found to provide an adequate fit for the anthropometric measurements of participants. The findings of the study concurred with the published literature (Brewer *et al.*, 2009; Cotton *et al.*, 2002; García-Acosta &. Lange-Morales, 2007; Gouvali & Boudolos, 2006; Milanese & Grimmer, 2004; Panagiotopoulou *et al.*, 2004; Parcells *et al.*, 1999; Saarni *et al.*, 2007), in that the conclusion was drawn that the chairs that were being used in schools at the time of the current study were not found to be suitable for the anthropometric ranges of the learners using them.

Of note is the fact that the dimensions of the school furniture that was measured in the current study were similar to those reported in Australia (Milanese & Grimmer, 2004), New Zealand (Bruynel & McEwan Stotter, 1985) and Denmark (Aagaard-Hensen & Storr-Paulsen, 1995). However, the adolescent sample that was reported on in the current research came from a multiracial background. It is unlikely that such a group of high school learners can be appropriately supported by chairs that are manufactured in Western countries, or that are used by children in Western environments (such as those who are reported on in the school furniture research literature).

It has been proposed that one way around the issue of differently-sized young people in school classes would be to supply schools with different sized chairs per grade level (García-Acosta &. Lange-Morales, 2007), but acting on such a suggestion would not provide a solution to the problem in the unique South African setting. The results obtained highlight the fact that, even if the Education Department, or individual schools, would like to improve the chair profile of the computer laboratories, they would not be able to do so, as an affordable computer chair that matches the learners' anthropometric measurements was not available on the South African market at the time of the current study. Thus, it appears to be important that South African-specific furniture be considered for South African adolescents and their school requirements.

7.5.1 Prototype 'Dynamic' chair

This study showed that it is possible to design a chair, using available material, to fit the anthropometric profile of the high school learners in the Cape Metropole area, Western Cape, South Africa. The chair designed for the purposes of the present study has a unique movable seat, in an attempt to encourage more postural movements during sitting. The prototype chair allowed for a marked ten times more rotational movement compared to the amount of such movement that was allowed for by the school chair. The encouraging findings form a basis of knowledge for further research to be undertaken on a larger sample and also for testing of the hypothesis as to whether the envisaged increase in movement will have an effect on the musculoskeletal prevalence and intensity of high school learners in the Cape Metropole area, Western Cape, South Africa.

At the conclusion of the this thesis, a process of securing a patent for the prototype chair was under way, and discussions were being held with the Industrial Design Department of the Cape Peninsula University of Technology (CPUT) to investigate the possibility of using recycled materials to build the chair. If funding is secured to produce an upgraded prototype chair that can be used in all the school computer laboratories in the Cape Metropole area, Western Cape, South Africa (and, possibly, nationally), the production of the chairs would create local employment opportunities that are desperately needed.

The prototype chair currently provides an opportunity for the Education Department of the Western Cape, South Africa to improve the ergonomic profile of the computer laboratories at high schools, by providing the schools with a locally-produced chair that is specifically designed for the high school learners of the area in question. It is important that the education authorities be made aware that the school chairs that are currently used in the computer laboratories have serious consequences in terms of musculoskeletal health and consequent economic costs, which is likely to affect the future workforce of the country adversely.

CHAPTER 8:

Limitations and Recommendations

The current study presented promising results and provided a good foundation for future research. The present chapter discusses the various limitations encountered, as well as the recommendation for future research in the area of chair design for high school learners.

8.1 Anthropometric measurements

Although this thesis provides novel information on the lower-body anthropometric profile of high school learners in the Cape Metropole area of the Western Cape, South Africa, it is important to note that the anthropometric data and subsequent chair design dimensions cannot be extrapolated to the rest of South Africa, as the racial combinations differ from district to district. The different racial groups are not evenly distributed throughout South Africa, and the interracial combinations vary. Also, the chairs that are used in the various high schools around South Africa might differ, and, therefore, the percentage of learners matching the specific chairs might also be different. No claim can, therefore, be made that the mismatch results obtained in the study will be the same for other high school learners in different parts of South Africa. It is, therefore, imperative that the lower-body anthropometric profile of high school learners and the match to their school computer laboratory chair should be established throughout South Africa. When the relevant data are available, adjustments, if necessary, can be made to the prototype 'Dynamic' chair to provide a suitable chair that matches the anthropometric profile of all South African high school learners.

Budget constraints prevented the use of an anthropometer for the anthropometric measurements. However, as most of the measurements were linear, no major measurement errors were foreseen. It is, nevertheless, advised that an anthropometer should be used in any future study, especially for the measurement of the HW.

8.2 Chair design

As the school computer laboratory chair proved to be the egronomical aspect of the computer laboratory set-up that most urgently required attention, a decision to focus on the chair design was taken. The chair would also be the least costly and the easiest modification for schools to make if they would like to improve the ergonomic profile of their computer laboratories. However, future research should also include the consideration of workstation dimensions, as the height and width of the workstation impact on the use of the chair. For instance, if a very narrow workstation were to be used, a broad chair might not fit under the work surface concerned, which might have a negative influence on the posture that is assumed when working at the workstation. The above might lead to possible consideration of the dimensions of the chair, or the possible changing of the workstation to fit the chair.

Providing a footrest that is attached to the chair would be an important modification to the prototype 'Dynamic' chair. Seeing that the height of the prototype 'Dynamic' chair is adjustable to fit the learner's size, the chair might be to low to use with the given work surface. Therefore, if the chair height, in regards to the attached footrest, can be adjusted to fit the learner, then the entire chair could be lifted higher to fit the workstation concerned. Subsequent design modification to the prototype 'Dynamic' chair would also be to custom design the seat according to the proposed optimal chair dimensions, instead of using available materials that might not provide a perfect fit.

8.3 Posture measurements

Although all of the learners in the current study completed an identical computer task while undergoing posture data capturing, it might be advisable to provide tasks in such a manner that each subject would spend the exact same amount of time on any given activity. Doing so might facilitate the analysis, as the researcher concerned would know exactly what type of task (e.g. typing, mouse activity, etc.) the learner was busy with at any given time. Such knowledge would also allow for a comparison to be drawn between the sitting behaviour of different learners during each specific activity.

During the current study, the work surface and computer screen set-up remained identical throughout the testing duration. Adjusting the workstation and screen height to the individual in future studies would, however, allow for a more ergonomically sound set-up and perhaps provide increased insight into the 'normal' sitting behaviour of learners, as well as facilitating the development of preventative strategies for musculoskeletal symptoms related to sitting.

A problem was encountered with marker visibility; whist the capturing of seating-related data was taking place. This led to the need for a very time-consuming post-processing of each trail, and even to the exclusion of one subject (S08), due to too many markers not being visible to the cameras, as a result of being obscured by certain body parts, the computer screen, or the table. At the time of data capturing, the VICON camera system in Stellenbosch University's Motion Analysis laboratory was fixed to the walls. If the cameras were to be placed on tripods, which would allow for closer positioning to the subjects to optimise marker visibility, the distance from the camera to the marker would be reduced, as well as the obscuring of markers by other body parts or the furniture prevented.

A further suggestion is made that a VICON software model that is specifically designed for capturing sitting data should be developed. The model in mind should focus on the spinal and pelvic angle outputs, and should also revisit marker placement to avoid problems with marker visibility. The model would then have to be validated to ensure the retrieval of valid and reliable data.

8.4 Future research

The following future research is recommended:

- *Future research should embark on conducting an RCT by introducing the modified prototype 'Dynamic' chair to schools and assessing the effect that the chair has on musculoskeletal symptom prevalence and prevention.*
- *A nationwide lower body anthropometric survey should be conducted combined with establishing the chair-user fit.*

- *The posture measurement protocol of the current study should be conducted on a larger, more representative sample to establish the effect of the prototype 'Dynamic' chair on postural changes, as well as to ascertain the 'normal' sitting behaviour of high school learners whilst using the computer over a period of time.*
- *Future studies should also embark on EMG studies to establish the muscle work that is done by the postural stability muscles whilst the subject is sitting on the prototype 'Dynamic' chair, as the muscles concerned might have to work harder to stabilise the body whilst the subject is sitting on the prototype 'Dynamic' chair, rather than on a normal school chair.*
- *The time that learners spend in one sustained posture whilst using a computer should also be assessed in future studies.*

CHAPTER 9:

Conclusions

This thesis is the first to report on the following:

- *the lower-body anthropometric profile of high school learners in the Cape Metropole area of the Western Cape, South Africa;*
- *the anthropometric match between high school learners in the Cape Metropole area of the Western Cape, South Africa between the chairs that were, at the time of the current study, being used in school computer laboratories and the commercially available, adjustable chairs that were manufactured/distributed in the Western Cape, South Africa;*
- *the design and development of a prototype chair referred to as the 'prototype "Dynamic" chair', which fits a large proportion of the high school learners in the Cape Metropole area of the Western Cape, South Africa; and*
- *the sitting behaviour of high school learners on the prototype 'Dynamic' chair at a desktop computer workstation, compared to when seated at a chair used in the school computer laboratory.*

This thesis is also the first to report on the lower-body anthropometric size of high school learners of the Cape Metropole area, Western Cape, South Africa. The anthropometric profile was essential for determining whether the learners could find a computer chair to fit their body dimensions. Not surprisingly, neither the chairs used at the school computer laboratory, nor the commercially available adjustable computer chairs offered an acceptable fit for the anthropometric measurements of the local group of high school learners concerned. The substantial mismatch found might be associated with the high occurrence of musculoskeletal pain in the population. The findings warranted the need to establish the dimensions of a chair that was adjustable to fit the majority of the group of learners in mind.

The prototype 'Dynamic' chair was consequently developed. The chair in question was unique, as it provided a dynamic seat for encouraging postural changes during sitting. The prototype chair was associated with an increase in the number of postural changes of the pelvis and thorax in those seated on it. The promising results obtained warrant further exploration of the prototype chair and of the potential effect of the chair on musculoskeletal school symptoms of high school learners in the Cape Metropole, Western Cape, South Africa.

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164.

Addendum A: School computer laboratory workstation assessment

COMPUTER LABORATORY WORKSTATION ASSESSMENT

School Name:

Date:

Number of Labs:

Lab Nr:

Assessed by:

Study Nr:

1

WORKING ENVIRONMENT	Yes	No
1. Classroom is climate controlled by means of an air conditioner.		
2. Draughts at the level of head and knees.		
3. Noise level interferes with concentration.		

SPATIAL ENVIRONMENT	Yes	No
1. Number of learners in computer laboratory during one lesson/ class, not exceeding 30.		
2. Aisle width between desks or workstations is in the range of 152cm- 183 cm.		
3. Adequate space exists for easy movement among workstations, book cases, shelves and doorways/ exits.		
4. Book cases and shelves are of sufficient size to display and/ or store necessary learning materials.		

WORKSPACE ENVIRONMENT

Chair	Yes	No
1. Chair has movable rolling coasters		
2. Surface of seat to floor in range of 380-510mm		
3. Seat pan depth in the range of 330-430mm		
4. Back support's height is adjustable		
5. Back support's angle is adjustable		
6. Arm supports present		
7. Arm support's height is adjustable		

Desk	Yes	No
1. Desk height is adjustable		
2. Desk width from left to right edge is 1500mm minimum		
3. Desk depth from front to back edge is 900mm minimum		
4. Width of legs space under desk when in seated position 800mm minimum		
5. Depth of space for legs when seated 550mm minimum		
6. Height of space between legs and desk when seated 580mm minimum		
7. Footrest provided		
8. Footrest area: 300x 375mm		
9. Footrest angle is adjustable		

Computer Screen	Yes	No
1. Screen depth (front of screen to table edge): 500-750mm		
2. Screen height measured from floor to centre of screen: 900-1150mm		
3. Screen dimension: ____________________ mm/mm		
4. Inclination of viewing monitor is adjustable : 88°-105° from the horizontal		
5. Usable manuscript holder attached to screen		

Keyboard	Yes	No
1. Keyboard positioned on separate tray		
2. Height from floor to home row of keyboard is in the range of 700-850mm		
3. Height of home row of keyboard to desk level in the range of 100-260mm		
4. Keyboard angle is adjustable		
5. Gel wrist support in use		

Input Device	Yes	No
1. Mouse used as in-put device		
2. Mouse has an adjustable position		
3. Mouse can be used ambidextrously		
4. Mouse pad available and used		

VISUAL ENVIRONMENT	Yes	No
1. Screen image is stable		
2. Monitor has adjustable brightness and contrast controls		
3. Control of glare through the use of screens, indirect lighting sources or equipment positioning		
4.Good quality light with natural or indirect lighting sources		

Addendum B: Data extraction template

Data Extraction Template	
Author(s)	
Year published	
Title of paper	
Journal title	
Year published	
Country of origin	
Study design	
Research Question	
Research Aim(s)	
Population	
Sample size	
Gender of sample	
Age of sample	
Study Outcomes	
Full reference	

Addendum C: Letter of invitation

To Whom It May Concern

Re: Research project in conjunction with the Physiotherapy Department of the University of Stellenbosch

With this letter I would like to invite your school to participate in a research project that forms part of a doctoral degree thesis in physiotherapy. This project aims at finding the most appropriate chair to use in a computer laboratory. A recent study done in South Africa showed that 73% of high school learners suffer from pain when they use a desktop computer. In another study, it has been reported that musculoskeletal symptoms are one of the top ten health problems among schoolchildren. Data on furniture size for South African adolescents and children are lacking.

We aim to measure the anthropometry (body dimensions) of high school learners aged 13-18 years old in order to match this with the current measurement of the computer chairs. The study will take place in three phases; learners from your school might be selected to take part in one or more of the phases of this project.

During Phase 1, each learner will be measured by one of four different research assistants. Each assistant will do three body measurements. During Phase 2 the learners' posture will be measured by the non-invasive Vicon motion analysis system at the Stellenbosch

University. First, the learners' posture will be measured in the chair that they normally use in school and then in the new proposed chair.

We will also measure the school's computer chairs and this will include: SH, SD and seat slope. Your school was one of 20 schools that were randomly selected from a pool of schools in the Cape Metropole Area.

In order to inform the school principal, educators and teachers, we will make arrangements with each school to present the aim, objectives, reasons and procedures of the project. Then we will invite learners to indicate whether they are willing to volunteer to be in the pool for random selection. In Phase 1, 36 learners, three boys and three girls from each age group (13-18 years) will be randomly selected. In Phase 2, 2 learners per age group (13-18 years) will be randomly selected. Your school will not necessarily be randomly selected to participate in Phase 1A and Phase 3, but will definitely take part in Phase 1B, if you consent to it doing so. Learners, who agree to participate in the study, will then receive a consent form, which must be completed by a parent or legal guardian.

A suitable time and date will be arranged with the school principal. Testing will take place between January and November 2010.

Please contact me should you require any further information with regards to this project. I will contact you in due course to enquire as to your participation.

Thank you and kind regards,

Sjan-Mari van Niekerk (M.Sc. Physiotherapy)

Principal Researcher
071 6739748
smvanniekerk@sun.ac.za

Addendum D: Consent form (minors)

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM FOR USE BY PARENTS / LEGAL GUARDIANS

TITLE OF THE RESEARCH PROJECT:
Ergonomic chair design for school computer laboratories in the Cape Metropole area, Western Cape, South Africa

REFERENCE NUMBER:
PRINCIPAL INVESTIGATOR: Sjan-Mari van Niekerk (M.Sc. Physiotherapy)
ADDRESS: Division Physiotherapy, Department Interdisciplinary Health Sciences, Faculty of Medicine and Health Sciences, University of Stellenbosch, Tygerberg campus
CONTACT NUMBER: 071 6739748

Your child is being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how your child could be involved. Also, your child's participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you or your child negatively in any way whatsoever. You are also free to withdraw him/her from the study at any point, even if you do initially agree to let him/her take part.

This study has been approved by the **Committee for Human Research at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

The aim of this research project is to match the body measurements of high school students aged 13 to 18 years in the Cape Metropole area with the dimension of the school computer chair. In one of our previous studies, it was found that 73% of high school students in the Cape Metropole experience pain while using a desktop computer. In a different study, it has been reported that musculoskeletal symptoms are one of the top ten health problems among high school students. With this study, we hope to be able to recommend the most appropriate chair for our students in Cape high schools.

Your child might be randomly selected to take part in either one or both phases of this project. In phase 1, each child's body dimensions will be measured by one of four different research assistants. The measurements will be made with a non-invasive measuring tape and all measurements will be done at the school. Four research assistants will measure four students simultaneously. In Phase 2, an appropriate computer chair will be selected, and the students will be tested at the Motion Analysis Laboratory at the Stellenbosch University. The students' posture will be analysed while they sit in a school chair, and then in the proposed chair. The analysis will be done by placing non-invasive markers on the students, which will be visible to the Vicon Motion Analysis System. The students will remain clothed during all testing procedures.

During Phase 1, students will only miss one hour of school and, during Phase 3, students will miss roughly 4 hours of schooling. The most appropriate times for testing will be agreed upon by the main researcher and the school principal.

Why has your child been invited to participate?

The school that your child attends was randomly selected from all schools that form part of the Cape Metropole. The 13- to 18-year-old students from the school have been invited to participate in the study.

What will your responsibilities be?

Your responsibility is only to provide consent should you agree for your child to participate in the study.

Will your child benefit from taking part in this research?

Your child's participation will help the research team to develop educational guidelines on sitting posture and promotion of good spinal health. Your child and future students may benefit, since these guidelines may reduce the incidence of spinal and shoulder pain experienced by children using computers and thus prevent youth from developing long-term joint and muscle problems.

Are there any risks involved in your child taking part in this research?

There are no risks involved in participating in this research project.

Who will have access to your child's records?

All the information collected with this project will be treated as confidential and will be protected. If this information is used in a thesis or publication, the identity of your child will remain anonymous. Only the researcher and her team will have access to the information. The records will be kept in safe storage in the Physiotherapy Department, Stellenbosch University.

What will happen in the unlikely event of your child getting injured in any way, as a direct result of taking part in this research study?

The testing will take part in the Motion Analysis Laboratory at Stellenbosch University. The school or Stellenbosch University will provide transport, and third-party insurance will cover your child if the vehicle should be involved in an accident.

Will you or your child be paid to take part in this study and are there any costs involved?

You or your child will not be paid to take part in the study. There will be no costs involved for you if your child does take part.

Is there anything else that you should know or do?

- You can contact Sjan-Mari van Niekerk at tel. 071 673 974 if you have any further queries or encounter any problems.
- You can contact the Committee for Human Research at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your child's study doctor.
- You will receive a copy of this information and consent form for your own records.

Assent of Minor

I (*Name of Child/Minor*)……………………………………………. have been invited to take part in the above research project.

- The study leader and my parents have explained the details of the study to me, and I understand what they have said to me.
- I also know that I am free to withdraw from the study at any time if I am unhappy.
- By writing my name below, I voluntarily agree to take part in this research project. I confirm that I have not been forced either by my parents or doctor to take part.

……………………………………………………………………………..

Name of child as independent witness

(To be written by the child if possible)

Declaration by parent / legal guardian

By signing below, I *(name of Parent/Legal Guardian)* …………………………………..…… agree to allow my child (name of child) ……………………………….…, who is ………. years old, to take part in a research study entitled 'The anthropometric match between high school students and their computer workstations'.

I declare that:

- I have read or had read to me this information and consent form and that it is written in a language with which I am fluent and comfortable.
- If my child is older than 7 years, he/she must agree to take part in the study and his/her ASSENT must be recorded on this form.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to let my child take part.
- I may choose to withdraw my child from the study at any time and my child will not be penalised or prejudiced in any way.
- My child may be asked to leave the study before it has finished if the study doctor or researcher feels it is in my child's best interests, or if my child does not follow the study plan as agreed to.

Signed at (*place*) ....……….. on (*date*) …………....……….. 2010.

Signature of parent / Legal guardian Signature of witness

Declaration by investigator

I *(name)* ……………………………………………….……… declare that:

- I explained the information in this document to …………………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above.
- I did / did not use a translator (i*f a translator is used, then the translator must sign the declaration below).*

Signed at (*place*) ....…........................... on (*date*) ………….…………. 2010.

Signature of investigator **Signature of witness**

Declaration by translator

I *(name)* ……………………………………………….……… declare that:

I assisted the investigator (*name*) ……….............................. to explain the information in this document to (*name of parent/legal guardian*) ……..…………………….... using the language medium of Afrikaans/Xhosa.

We encouraged him/her to ask questions and took adequate time to answer them.

I conveyed a factually correct version of what was related to me.

I am satisfied that the parent / legal guardian fully understands the content of this informed consent document, and has had all his/her questions satisfactorily answered.

Signed at (*place*) .... on (*date*) .... 2010.

Signature of translator   Signature of witness

DEELNEMERINLIGTINGSBLAD EN -TOESTEMMINGSVORM VIR GEBRUIK DEUR OUERS/WETTIGE VOOGDE

TITEL VAN DIE NAVORSINGSPROJEK:

Die ontwikkeling van 'n ergonomies korrekte stoel vir rekenaar laboratoriums in die Kaapse Metropool, Wes-Kaap, Suid Afrika.

VERWYSINGSNOMMER:

HOOFNAVORSER: Sjan-Mari van Niekerk (M.Sc. Fisioterapie)

ADRES: Afdeling Fisioterapie, Departement Interdissiplinêre Gesondheidswetenskappe, Fakulteit Mediese en Gesondheidswetenskappe, Stellenbosch Universiteit, Tygerberg Kampus.

KONTAKNOMMER: 071 673 9748

U kind *(of pleegkind, indien van toepassing*) word genooi om deel te neem aan 'n navorsingsprojek. Lees asseblief hierdie inligtingsblad op u tyd deur aangesien die besonderhede van die projek daarin verduidelik word. Indien daar enige deel van die projek is wat u nie ten volle verstaan nie, is u welkom om die navorsingspersoneel of dokter daaroor uit te vra. Dit is baie belangrik dat u ten volle moet verstaan wat die navorsing behels en hoe u kind daarby betrokke kan wees. U kind se deelname is ook **volkome**

vrywillig en dit staan u vry om deelname te weier. U kind sal op geen wyse hoegenaamd negatief beïnvloed word indien u sou weier om hom/haar te laat deelneem nie. U mag u kind ook te enige tyd aan die studie onttrek, selfs al het u ingestem om hom/haar te laat deelneem.

Hierdie studie is deur die Komitee vir Mensnavorsing van die Universiteit Stellenbosch **goedgekeur en sal uitgevoer word volgens die etiese riglyne en beginsels van die Internasionale Verklaring van Helsinki en die Etiese Riglyne vir Navorsing van die Mediese Navorsingsraad (MNR).**

Wat behels hierdie navorsingsprojek?

Die doel van die studie is om die liggaamsmates van hoërskool leerlinge tussen die ouderdomme van 13 en 18 jaar, in die Kaapse Metropool area, met die afmetings van die skool se rekenaar stoele te vergelyk. In een van ons vorige studies is daar gevind dat 73% van hoërskool leerlinge pyn ervaar tydens die gebruik van 'n rekenaar. In 'n ander studie is daar gevind dat muskuloskeletale pyn een van die top tien gesondheidsprobleme van skoolleerlinge is. Die mees geskikte stoel moet vasgestel word.

U kind mag dalk lukraak gekies word om deel te neem aan een of meer van die drie fases van die projek. In Fase 1 word elke leerling een maal gemeet deur een van vier verskillende navorsingsassistente. Die afmetings sal met ‘n nie-indringende maatband geneem word en alle afmetings sal by die skool geneem word. Vier leerlinge sal gelyktydig gemeet word deur vier navorsingsassistente. Gedurende Fase 2 word die mees toepslike stoel gekies vir hoërsool leerlinge; geen leerlinge word benodig tydens hierdie deel van die fase nie. Daarna sal leerlinge by Stellenbosch Universiteit se Bewegingsanaliese Labratorium getoets word. Die leerlinge se sit-postuur sal geanaliseer word terwyl hulle eers in 'n stoel sit wat gewoonlik by die skool gebruik word en dan in die voorgeskrewe stoel sit. Die analiese word gedoen deur merkers op die leerlinge te plaas wat dan deur die VICON beweginsanaliese systeem geanaliseer word. Die leerlinge sal ten alle tye geklee bly. Gedurende Fase 1 sal die lukraak gekose leerlinge slegs 1 uur van skool mis en gedurende Fase 3 om en by vier ure. Die mees gepaste tye vir die afmetings sal met die skoolhoof onderhandel word.

Waarom is u kind genooi om deel te neem?

Die skool waaraan u kind behoort is lukraak gekies uit al die skole in die Kaapse Metropool. Die 13 tot 18 jarige leerders van die skool is genooi om deel te neem aan die projek.

Wat sal u verantwoordelikhede wees?

U is slegs verandwoordelik om toestemming te gee vir u kind se deelname aan die projek indien u sou instem.

Sal u kind voordeel trek deur deel te neem aan hierdie navorsing?

U kind se deelname help die navorsingspan om opvoedkundige riglyne op te stel vir die korrekte sittende postuur en die bevordering van goeie rug gesondheid. U kind en toekomstige leerders kan voordeel trek aangesien hierdie riglyne die voorkoms van rug en skouer pyn deur kinders wat rekenaars gebruik ervaar word, kan help voorkom. Dit sal ook help met die voorkoming van langtermyn gewrig- en spierprobleme.

Is daar enige risiko's verbonde aan u kind se deelname aan hierdie navorsing?

Daar is geen gevare verbonde aan die deelname aan hierdie navorsingsprojek nie.

Wie sal toegang hê tot u kind se mediese rekords?

Alle inligting wat ingesamel word in hierdie projek word as konfidensieel beskou en sal sodanig beskerm word. Indien hierdie inligting in 'n tesis of ander publikasie gebruik word sal u kind se identiteit anoniem bly. Slegs die navorser en haar span sal toegang hê tot die inligting. Die rekords sal veilig gestoor word by die Fisioterapie Departement, Stellenbosch Universiteit.

Wat sal gebeur in die onwaarskynlike geval van 'n besering wat mag voorkom as gevolg van my kind se deelname aan hierdie navorsingsprojek?

Die toetsing vind plaas by die Departement van Fisioterapie by Stellenbosch Universiteit. Vervoer word verskaf deur die skool of die Universiteit Stellenbosch. Daar is derde party versekering wat u kind sal dek indien die voertuig in 'n ongeluk betrokke sou wees.

Sal u of u kind betaal word vir deelname aan die projek en is daar enige koste verbonde aan deelname?

Nee, nie u of u kind sal betaal word vir deelname aan die projek nie. Deelname aan die projek sal u niks kos nie.

Is daar enigiets anders wat u moet weet of doen?

- U kan Sjan-Mari van Niekerk kontak by tel 071 673 9748 indien u enige vêrdere vrae het of enige probleme ondervind.
- U kan die Komitee vir Mensnavorsing kontak by 021-938 9207 indien u enige bekommernis of klag het wat nie bevredigend deur u studiedokter hanteer is nie.
- U sal 'n afskrif van hierdie inligtings- en toestemmingsvorm ontvang vir u eie rekords.

Instemming van minderjarige

Ek (naam van kind/minderjarige) ……………………………........................……… is genooi om deel te neem aan bogenoemde navorsingsprojek.

- Die studiedokter/verpleegster en my ouers het die besonderhede van bogenoemde navorsingsprojek aan my verduidelik en ek verstaan wat hulle aan my gesê het.
- Ek weet ook dat ek te enige tyd aan die navorsingsprojek kan onttrek indien

ek ongelukkig is.

- Deur my naam hieronder in te vul, onderneem ek om vrywillig aan die navorsingsprojek deel te neem. Ek bevestig ook dat ek nie deur my ouers of studiedokter gedwing is om deel te neem nie.

....	....
Naam van kind	Onafhanklike getuie
(Deur kind geskryf te word indien moontlik)	

Verklaring deur ouer/wettige voog

Met die ondertekening van hierdie dokument onderneem ek, (*naam van ouer/wettige voog*) ……………………………………………………….., om my kind *(naam van kind)* ……………………………………………………….., wat ……… jaar oud is, te laat deelneem aan ’n navorsingsprojek getiteld ‘**Die ontwikkeling van 'n ergonomies korrekte stoel vir rekenaar laoratoriums in die Kaapse Metropool**
’

Ek verklaar dat:

- Ek hierdie inligtings- en toestemmingsvorm gelees of aan my laat voorlees het en dat dit in ’n taal geskryf is waarin ek vaardig en gemaklik mee is.
- My kind moet instem om aan die navorsingsprojek deel te neem as hy/sy ouer as 7 jaar is, en dat sy/haar INSTEMMING op hierdie vorm aangeteken sal word.
- Ek geleentheid gehad het om vrae te stel en dat al my vrae bevredigend beantwoord is.
- Ek verstaan dat deelname aan hierdie projek **vrywillig** is en dat daar geen druk op my geplaas is om my kind te laat deelneem nie.
- My kind te enige tyd aan die projek mag onttrek en dat hy/sy nie op enige wyse daardeur benadeel sal word nie.
- My kind gevra mag word om aan die projek te onttrek voordat dit afgehandel is indien die studiedokter of navorser van oordeel is dat dit in sy/haar beste belang is, of indien my kind nie die ooreengekome studieplan volg nie.

Geteken te (*plek*) .... op (*datum*) .... 2010.

....

Handtekening van ouer/wettige voog Handtekening van getuie

Verklaring deur navorser

Ek (naam) …………………………………………………. verklaar dat:

1 Ek die inligting in hierdie dokument verduidelik het aan …………………...

2 Ek hom/haar aangemoedig het om vrae te vra en voldoende tyd gebruik het om dit te beantwoord.

3 Ek tevrede is dat hy/sy al die aspekte van die navorsingsprojek soos hierbo bespreek, voldoende verstaan.

4 Ek ’n tolk gebruik het/nie ’n tolk gebruik het nie. (*Indien ’n tolk gebruik is, moet die tolk die onderstaande verklaring teken.)*

Geteken te (*plek*) .... op (*datum*) .... 2010.

....

Handtekening van navorser Handtekening van getuie

Verklaring deur tolk

Ek (*naam*) …………………………………………………. verklaar dat:

1 Ek die navorser (*naam*) ………………………………………………. bygestaan het om die inligting in hierdie dokument in Afrikaans/Xhosa aan (*naam van ouer/wettige*

voog) ……….................................. te verduidelik.

2 Ons hom/haar aangemoedig het om vrae te vra en voldoende tyd gebruik het om dit te beantwoord.

3 Ek ’n feitelik korrekte weergawe oorgedra het van wat aan my vertel is.

4 Ek tevrede is dat die ouer/wettige voog die inhoud van hierdie dokument ten volle verstaan en dat al sy/haar vrae bevredigend beantwoord is.

Geteken te (*plek*) .... op (*datum*) ……….................. 2010.

....

Handtekening van tolk Handtekening van getuie

INCWADANA ENGOLWAZI NGOMTHATHI-NXAXHEBA KUNYE NEFOMU YEMVUMELWANO EKUMELE ISETYENZISWE NGUMZALI/NGUMGCINI-MNTWANA OSEMTHETHWENI

ISIHLOKO SEPROJEKTHI YOPHANDO:

INOMBOLO YONXULUMANO:

UMPHANDI OYINTLOKO:

IDILESI:

INOMBOLO YOQHAGAMSHELWANO:

Umntwana wakho *(okanye omgcinayo, ukuba ukhona*) uyamenywa ukuba athathe inxaxheba kwiprojekthi yophando. Nceda thatha ixesha lokufunda ulwazi oluvezwe apha, oluzakuthi luchaze iinkcukacha zale projekthi.Nceda buza nayiphina imibuzo emalunga nayiphina indawo ongayiqondiyo ngokupheleleyo kubasebenzi besi sifundo okanye kugqirha.Kubaluleke kakhulu ukuba waniliseke ngokupheleleyo yinto yokuba ucacelwe kakuhle ukuba yintoni ebangwa sesi sifundo kwaye ungabandakanyeka njani.Kwakhona, ukuthatha komntwana wakho inxaxheba **kungentando yakhe ngokupheleleyo** kwaye ukhululekile ukuba angarhoxa ekuthatheni inxaxheba.Ukuba uthi hayi, oku akusayi kuchaphazela ukungavumi kwakhe nangayiphina indlela.Ukwakhululekile ukuba ukumyekisa kwesi sifundo naninina, nkqu nokokuba ubuvumile ukuba athatha inxaxheba ekuqaleni.

Olu phando luvunywe ziinqobo ezisesikwenizeKomiti yoPhando Lomntu kwiYunivesithi yaseStellenbosch**kwaye luzakwenziwa ngokwemigaqo esesikweni lophando elamkelekileyo kwiSaziso sehlabathi sika-Helsinki, iMigaqo eLungileyo yoMzantsi Afrika**

yokuSebenza eKliniki kunye neBhunga lezoPhando ngamaYeza (MRC) iMigaqo yeNqobo yezoPhando.

Simalunga nantoni esi sifundo sophando?

Injongo yolu phando kukungqamanisa imilinganiselo yemizimba yabafundi bamabanga aphakamileyo abaminyaka yobudala iqalela kweli-13 kude kufikwe kweli-18 bengingqi yesiXeko seKapa abanobubanzi obulingana nesitulo esihlala umntu osebenzisa ikhompyutha.Kwesinye sezifundozethu zangaphambili kwafumaniseka ukuba ama-73 eepesenti zabafundi bamabanga aphakamileyo kwisiXeko seKapa baziva besezintlungwini ngeli xesha bahleli ezidesikeni besebenzisa iikhompyutha.Kwisifundo esahlukileyo kunikwe ingxelo yokuba imiqondiso zezihlunu ezomeleleyo ezikumxokelelwano wamathambo izezona ngxaki zilishumi ziphambili kubafundi bamabanga aphakamileyo.Ngolu phando sinethemba lokuba singancoma uhlobo lwesitulo esisesona sibafaneleyo abafundi beziKolo zeMfundo ePhakamileyo eKapa.

Umntwana wakho angafane akhethelwe ukuthatha inxaxheba kwicandelo elinye okanye kwangaphezulu kwelinye kulawo mathathu ale prowujekti.
KwiCandelo 1 ububanzi bomzimba womntwana ngamnye buza kulinganiselwa kathathu ngabantu abane abahlukileyo abancedisa kulo phando.Imilinganiselo yemizimba yabantu iza kwenziwa ngesixhobo sokulinganisela esingagabangxiyo nesobunzululwazi ekuthiwa yi-Anthropometer, yonke imilinganiselo iya kwenzelwa esikolweni.Ngexesha elinye kuza kulinganiselwa abafundi abane ngabancedisi bophando abane.KwiCandelo 2 kuza kukhethwa isitulo sekhompyutha esifanelekileyo; kweli icandelo akukho bafundi baza kubandakanyeka.KwiCandelo 2 abafundi baza kuxilongwa kwiLebhu yokuCalula iNtshukumo kwiDyunivesithi yaseStellenbosch.Kuza kucalulwa ukuma nqo komzimba womfundi ngeli xesha ahleli esikolweni, emva koko ukuma kwakhe kuza kuhlahlelwa xa ekweso situlo sikhethiweyo.Olu calulo luza kwenziwa ngokubekwa kwemibhalo engacimiyo nengagabangxiyo kubafundi, leyo iza kubonakala kwiNkqubo yoCalulo lweNtshukumo yeVicon.Abafundi baza kuhlala benxibe impahla yabo ngeli xesha baxilongwayo.

Ngexesha leCandelo 1 abafundi baza kuphoswa yiyure enye kuphela yexesha lesikolo, kanti ngexesha leCandelo 2 baza kuphantse baphoswe ziiyure ezi-4 zesikolo.Awona maxesha lungele ingxilongo kuza kuvunyelwana ngawo ngumphandi oyintloko nenqununu yesikolo.

Kutheni emenyiwe umntwana wakho ukuba uthathe inxaxheba?

Isikolo afunda kuso umntwana wakho sifane sakhethwa kwezo zilapho kwisiXeko seKapa.Abafundi abaminyaka yobudala iqalela kwi-13 kude kufikwe kweli-18 bamemnyelwe ukuba mabathathe inxaxheba kwesi sifundo.

Luyakuba yintoni uxanduva lwakho?

Uxanduva lwakho kuphela lukukubonelela ngemvume xa umntwana uthanda ukuba makathathe inxaxheba kwesi sifundo.Ukuqokelelwa kweenkcukacha kuza kuthatha ixesha kuphela abafundi begumbi elinye abajongene nelo candela, oku kwenzelwa ukunqanda ukuba abafundi mabangaphoswa ngumsebenzi wesikolo obalulekileyo.

Ingaba uza kuzuza umntwana wakho ekuthatheni inxaxheba kolu phando?

Intatho-nxaxheba yomntwana wakho iza kulinceda iqela eliphandayo ekuqulunqeni izikhokelo zemfundo malunga nokuhlala komntu esitulweni athi nkqo nenkuthazo yempilo entle yelungu elingumqolo.Umntwana wakho, nabanye abasaza kufunda bangancedakala, ezi zikhokelo zingazinciphisa iintlungu zomqolo nezamagxa eziviwayo ngabantwana abasebenzisa iikhompyutha. Oku kuthintela ulutsha ukuba lungabinazo iingxaki zemisipha nezezihlunu zexesha elide.

Ingaba zikho iingozi ezibandakanyekayo ekuthatheni komntwana wakho inxaxheba kolu phando?

Awukho umngcipheko ekungenwa kuwo xa kuthathwa inxaxheba kule prowujkti yophando.

Ngubani uza kufumana ingxelo yomntwana wakho yamayeza?

Zonke iinkcukacha eziqokelelweyo kule prowujekti ziza kugcinwa ziyimfihlelo yaye ziza kukhuselwa.Ukuba ezi nkcukacha ziyasetyenziswa kwithisisi okanye elupapashweni, igama lomntwana wakho alisayi kukhankanywa, akakho oya kumchonga.Ngumphandi kuphela kunye neqela aphanda nalo abaza kufikelela kwezo nkcukacha.Imibhalo eneeenkcukacha iza kugcinwa apho kukhuselekileyo *kwiSebe le*-Physiotherapy leDyunivesithi yaseStellenbosch.

Kuza kwenzeka ntoni kwimeko yesiganeko esingalindekanga sokwenzakala komntwana wakho nangephina indlela; ngenxa yokuthatha kwakhe inxaxheba kwesi sifundo sophando?

Awukho umngcipheko wokwenzakala.

Ingaba wean okanye umntwana uza kuhlawulwa ngokuthatha inxaxheba kwesi sifundo kwaye ingaba kukho iindleko ezibandakanyekayo?

Wena okanye umntwana wakho akasayi kuhlawulwa ngokuthatha inxaxheba kwesi sifundo, kodwa isithuthi sakho/sakhe neendleko zokutya ziza kuhlawulelwa kundwendwelo ngalunye lwesifundo.Akusayi kubakho zindleko ezibandakanyelwa wena, ukuba umntwana wakho uthatha inxaxheba.

Ingaba ikho enye into ekumele uyazi okanye uyenze?

- Ungaqhgamshelana no …Sjan-Mari van Niekerk….. kule inombolo yomnxeba …071 6739748 ukuba unemibuzo engaphaya okanye uhlangabezana neengxaki.
- Ungaqhagamshelana neKomiti yoPhando Lomntu kwa-021-938 9207 ukuba unenkxalabo okanye izikhalazo ezingasonjululwanga kakuhle ngugqirha wesifundo somntwana wakho.
- Uza kufumana ikopi yolu lwazi kunye nefomu yemvumelwano ukwenzela iingxelo zakho.

Imvume yomntwana

Mna (Igama lomntwana)…………………………………………….. ndimenyiwe ukuba ndithathe inxaxheba kule projekthi yophando ingentla.

- Ugqirha wesifundo/umongikazi kunye nabazali bam bandichazele iinkcukacha zesifundo kwaye ndiyakuqonda abandixelele kona.
- Bakwandicacisele ukuba esi sifundo siza kubandakanya (chaza nayiphina inkqubo ehlaselayo kuquka ukuthathwa kwegazi*, ukuthiwa kwamanzi njl njl.)*
- Kwaye ndiyazi ukuba ndikhululekile ukuba ndirhoxe kwisifundo ukuba andonwabanga.
- Ngokubhala igama lam ngezantsi, ndivuma ngokuzithandela ukuthatha inxaxheba kule projekthi yophando. Ndiyaqinisekisa ukuba andikhange ndinyanzelwe ngabazali okanye ugqirha ukuba ndithathe inxaxheba.

……………………………………………………………… ………………………………………………………….

Igama lomntwana Ingqina elizimeleyo

(Kumele libhalwe ngumntwana)

Isifungo somzali/somngcini-mntwana osemthethweni

Ngokutyikitya apha ngezantsi, Mna *(igama lomzali/lomgcini-mntwana osemthethweni)* ……………………………….……… ndiyamvumela umntwana wam (igama lomntwana) …………………………………. oneminyaka ………. ubudala, ukuba athathe inxaxheba kwisifundo sophando esinesi sihloko *(faka isihloko sesifundo)*

Ndiyafunga ukuba:

- Ndilufundile okanye ndalufunda olu lwazi kunye nefomu yemvumelwano kwaye ibhalwe ngolwimi endiliciko nendikhululekileyo kulo
- Umntwana wam uneminyaka esi-7 ubudala, kumele avume ukuthatha inxaxheba kwisifundo kwaye IMVUME yakhe kumele ishicilelwe kule fomu.
- Bendinalo ithuba lokuba ndibuze imibuzo kwaye yonke imibuzo yam iphendulwe ngokwanelisayo.
- Ndiyakuqonda ukuba ukuthatha inxaxheba kolu phando **kukuzithandela** kwaye andikhange ndinyanzelwe ukuba ndivumele umntwana wam athathe inxaxheba.
- Ndingakhetha ukuba asishiya isifundo naninina umntwana wam kwaye akasayi kohlwaywa okanye aqal' agwetywe nangayiphi indlela.
- Umntwana wam usenokucelwa ukuba asishiye isifundo phambi kokuba siphele, ukuba ugqirha wesifundo okanye umphandi ukubona kuyinzuzo kumntwana wam, okanye ukuba umntwana wam akandisilandeli isicwangciso sesifundo ekuvunyelenwe ngaso.

Kutyikitywe e-(indawo) .... ngo-(usuku) .... 2010.

....

Umtyikityo womzali/womgcini-mntwana osemthethweni **Umtyikityo wengqina**

Isifungo somphandi

Mna *(igama)* .... ndiyafunga ukuba:

- Ndilucacisile ulwazi olu kweli xwebhu ku-.......................................
- Ndimkhuthazile ukuba abuze imibuzo kwaye athathe ixesha elifanelekileyo ukuba ayiphendule.
- Ndiyaneliseka kukuba uyakuqonda ngokwanelisayo konke okumalunga nophando okuxoxwe ngasentla.

- Ndisebenzise/andisebenzisanga toliki. (*Ukuba itoliki isetyenzisiwe kumele ityikitye isaziso ngezantsi.*

Kutyikitywe e-(indawo) ……………………………… ngo-(usuku) …………………… 2010.

……………………………………………………………… ………………………………………………………………

Umtyikityo womphandi Umtyikityo wengqina

Isifungo setoliki

Mna *(igama)* ……………………………………………… ndazisa ukuba:

- Ndicende umphandi (igama) ………………………… Ekucaciseni ulwazi olu lapha kweli xwebhu ku-(igama lomthathi-nxaxheba) …………………………… ndisebenzisa ulwimi lwesiAfrikaans/lwesiXhosa.
- Simkhuthazile ukuba abuze imibuzo kwaye athathe ixesha elifanelekileyo ukuba ayiphendule.
- Ndimxelele eyona nto iyiyo malunga nokunxulumene nam.
- Ndiyaneliseka kukuba umzali/umgcini-mntwana ukuqonda ngokupheleleyo okuqulathwe loluxwebhu lwemvumelwano eyazisiweyo kwaye nemibuzo yakhe yonke iphendulwe ngokwanelisayo.

Kutyikitywe e-(indawo) ……………………………… ngo-(usuku) …………………… 2010.

……………………………………………………………… ………………………………………………………………

Umtyikityo wetoliki Umtyikityo wengqina

Addendum E: Consent form (for students 18 years of age)

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT:

Ergonomic chair design for school computer laboratories in the Cape Metropole, Western Cape, South Africa

REFERENCE NUMBER:

PRINCIPAL INVESTIGATOR: Sjan-Mari van Niekerk (M.Sc. Physiotherapy)

ADDRESS: Division Physiotherapy, Department Interdisciplinary Health Sciences, Faculty of Medicine and Health Sciences, University of Stellenbosch, Tygerberg campus

CONTACT NUMBER: 071 673 9748

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the Health Research Ethics Committee (HREC) at Stellenbosch University and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

The aim of this research project is to match the body measurements of high school students aged 13 to 18 years in the Cape Metropole area with the dimensions of the school computer chair. In one of our previous studies, it was found that 73% of high school students in the Cape Metropole experience pain while using a desktop computer. In a different study, it has been reported that musculoskeletal symptoms are one of the top ten health problems among high school students. With this study, we hope to be able to recommend the most appropriate chair for our students in Cape high schools.

You might be randomly selected to take part in either one or both phases of this project. In phase 1, your body dimensions will be measured by one of four different research assistants. The measurements will be made with a non-invasive measuring tape and all measurements will be done at the school. Four research assistants will measure four students simultaneously. In Phase 2, an appropriate computer chair will be selected, and the students will be tested at the Motion Analysis Laboratory at the Stellenbosch University. The students' posture will be analysed while they first sit in a school chair and then in the proposed chair. The analysis will be done by placing non-invasive markers on the students, which will be visible to the Vicon Motion Analysis System. You will remain clothed during all testing procedures.

During Phase 1 you will only miss one hour of schooling and during Phase 3 you will miss roughly 4 hours of schooling. The most appropriate times for testing will be agreed upon by the main researcher and the school principal.

Why have you been invited to participate?

The school that you attend was randomly selected from all schools that form part of the Cape Metropole. The 13- to 18-year-old students from your school have been invited to participate in the study.

What will your responsibilities be?

Your responsibility is only to provide consent, should you agree to participate in the study. Data collection will only take up the time of one class per phase, in order to avoid students missing significant schoolwork.

Will you benefit from taking part in this research?

Your participation will help the research team to develop educational guidelines on sitting posture and the promotion of good spinal health. You and future students may benefit, since these guidelines may reduce the incidence of spinal and shoulder pain experienced by children using computers and thus prevent youth from developing long-term joint and muscle problems.

Are there any risks involved in your taking part in this research?

There are no risks involved in participating in this research project.

Who will have access to your medical records?

All the information collected with this project will be treated as confidential, and will be protected. If this information is used in a thesis or publication, your identity will remain anonymous. Only the researcher and her team will have access to the information. The records will be kept in safe storage in the Physiotherapy Department, Stellenbosch University.

What will happen in the unlikely event of some form of injury occurring as a direct result of your taking part in this research study?

The testing will take part at The Department of Physiotherapy at Stellenbosch University. The school or Stellenbosch University will provide transport and third-party insurance will cover you if the vehicle should be involved in an accident.

Will you be paid to take part in this study and are there any costs involved?

No, you will not be paid to take part in the study, but your transport and meal costs will be covered for each study visit. There will be no costs involved for you, if you do take part.

Is there anything else that you should know or do?

- *You can contact Sjan-Mari van Niekerk at tel. 071 673 974 if you have any further queries or encounter any problems.*
- You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study doctor.
- You will receive a copy of this information and consent form for your own records.

Declaration by participant

By signing below, I …………………………………..………… agree to take part in a research study entitled *Ergonomic chair design for school computer laboratories in the Cape Metropole, Western Cape, South Africa.*

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.

- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) .... on (*date*) .... 2009.

....

Signature of participant Signature of witness

Declaration by investigator

I *(name)* ……………………………………………..……… declare that:

- I explained the information in this document to …………………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above.
- I did /did not use a interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.*)

Signed at (*place*) .... on (*date*) …………......…….. 2010

....

Signature of investigator Signature of witness

Declaration by interpreter

I *(name)* ……………………………………………..…….. declare that:

- I assisted the investigator (*name*) ………………………………………. to explain the information in this document to (*name of participant*) ……………..…………………………….. using the language medium of Afrikaans/isiXhosa.
- We encouraged him/her to ask questions and took adequate time to answer them.
- I conveyed a factually correct version of what was related to me.
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her questions satisfactorily answered.

Signed at (*place*) .... on (*date*) …………….....................

....

Signature of interpreter | Signature of witness

DEELNEMERINLIGTINGSBLAD EN -TOESTEMMINGSVORM

TITEL VAN DIE NAVORSINGSPROJEK:

Die ontwikkeling van 'n ergonomies korrekte stoel vir rekenaar laboratoriums in die Kaapse Metropool, Wes-Kaap, Soud Afrika.

VERWYSINGSNOMMER:

HOOFNAVORSER: Sjan-Mari van Niekerk (M.Sc. Fisioterapie)

ADRES: Afdeling Fisioterapie, Departement Interdissiplinêre Gesondheidswetenskappe, Fakulteit Mediese en Gesondheidswetenskappe, Stellenbosch Universiteit, Tygerberg Kampus.

KONTAKNOMMER: 071 673 9748

U word genooi om deel te neem aan ’n navorsingsprojek.Lees asseblief hierdie inligtingsblad op u tyd deur aangesien die detail van die navorsingsprojek daarin verduidelik word.Indien daar enige deel van die navorsingsprojek is wat u nie ten volle verstaan nie, is u welkom om die navorsingspersoneel of dokter daaroor uit te vra.Dit is baie belangrik dat u ten volle moet verstaan wat die navorsingsprojek behels en hoe u daarby betrokke kan wees.U deelname is ook **volkome vrywillig** en dit staan u vry om deelname te weier.U sal op geen wyse hoegenaamd negatief beïnvloed word indien u sou weier om deel te neem nie.U mag ook te eniger tyd aan die navorsingsprojek onttrek, selfs al het u ingestem om deel te neem.

Hierdie navorsingsprojek is deur die Komitee vir Mensnavorsing van die Universiteit Stellenbosch **goedgekeur en sal uitgevoer word volgens die etiese riglyne en beginsels van die Internasionale Verklaring van Helsinki en die Etiese Riglyne vir Navorsing van die Mediese Navorsingsraad (MNR).**

Wat behels hierdie navorsingsprojek?

Die doel van die studie is om die liggaamsmates van hoërskool leerlinge tussen die ouderdomme van 13 en 18 jaar, in die Kaapse Metropool area, met die afmetings van die skool se rekenaar stoele te vergelyk. In een van ons vorige studies is daar gevind dat 73% van hoërskool leerlinge pyn ervaar tydens die gebruik van 'n rekenaar. In 'n ander studie is daar gevind dat muskuloskeletale pyn een van die top tien gesondheidsprobleme van skoolleerlinge is. Die mees geskikte stoel moet vasgestel word.

U mag dalk lukraak gekies word om deel te neem aan een of meer van die drie fases van die projek. In Fase 1 word elke leerling een maal gemeet deur een van vier verskillende navorsingsassistente. Die afmetings sal met ‘n nie-indringende maatband geneem word en alle afmetings sal by die skool geneem word. Vier leerlinge sal gelyktydig gemeet word deur vier navorsingsassistente. Gedurende Fase 2 word die mees toepslike stoel gekies vir hoërsool leerlinge; geen leerlinge word benodig tydens hierdie deel van die fase nie. Daarna sal leerlinge by Stellenbosch Universiteit se Bewegingsanaliese Labratorium getoets word. Die leerlinge se sit-postuur sal geanaliseer word terwyl hulle eers in 'n stoel sit wat gewoonlik by die skool gebruik word en dan in die voorgeskrewe stoel sit. Die analiese word gedoen deur merkers op die leerlinge te plaas wat dan deur die VICON beweginsanaliese systeem geanaliseer word. Die leerlinge sal ten alle tye geklee bly. Gedurende Fase 1 sal die lukraak gekose leerlinge slegs 1 uur van skool mis en gedurende Fase 3 om en by vier ure. Die mees gepaste tye vir die afmetings sal met die skoolhoof onderhandel word.

Waarom is u genooi om deel te neem?

Die skool waaraan u behoort is lukraak gekies uit al die skole in die Kaapse Metropool. Die 13 tot 18 jarige leerders van die skool is genooi om deel te neem aan die projek.

Wat sal u verantwoordelikhede wees?

U is slegs verandwoordelik om toestemming te gee vir u deelname aan die projek indien u sou instem. Die data opname sal slegs een periode duur om te verhoed dat leerders belangrike skool werk sal mis.

Sal u voordeel trek deur deel te neem aan hierdie navorsingsprojek?

U deelname help die navorsingspan om opvoedkundige riglyne op te stel vir die korrekte sittende postuur en die bevordering van goeie rug gesondheid. U en toekomstige leerders kan voordeel trek aangesien hierdie riglyne die voorkoms van rug en skouer pyn deur kinders wat rekenaars gebruik ervaar word, kan help voorkom. Dit sal ook help met die voorkoming van langtermyn gewrig- en spierprobleme.

Is daar enige risiko's verbonde aan u deelname aan hierdie navorsingsprojek?

Daar is geen gevare verbonde aan die deelname aan hierdie navorsingsprojek nie.

Wie sal toegang hê tot u mediese rekords?

Alle inligting wat ingesamel word in hierdie projek word as konfidensieel beskou en sal sodanig beskerm word. Indien hierdie inligting in 'n tesis of ander publikasie gebruik word sal u kind se identiteit anoniem bly. Slegs die navorser en haar span sal toegang hê tot die inligting. Die rekords sal veilig gestoor word by die Fisioterapie Departement, Stellenbosch Universiteit.

Wat sal gebeur in die onwaarskynlike geval van 'n besering wat mag voorkom as gevolg van u deelname aan hierdie navorsingsprojek?

Die toetsing vind plaas by die Departement van Fisioterapie by Stellenbosch Universiteit. Vervoer word verskaf deur die skool of die Universiteit Stellenbosch. Daar is derde party versekering wat u sal dek indien die voertuig in 'n ongeluk betrokke sou wees.

Sal u betaal word vir deelname aan die navorsingsprojek en is daar enige koste verbonde aan deelname?

Nee, u sal betaal word vir deelname aan die projek nie. Deelname aan die projek sal u niks kos nie.

Is daar enigiets anders wat u moet weet of doen?

- U kan Sjan-Mari van Niekerk kontak by tel 071673 9748 indien u enige verdere vrae het of enige probleme ondervind.

- U kan die Komitee vir Mensnavorsing kontak by 021-938 9207 indien u enige bekommernis of klagte het wat nie bevredigend deur u studiedokter hanteer is nie.
- U sal ’n afskrif van hierdie inligtings- en toestemmingsvorm ontvang vir u eie rekords.

Verklaring deur deelnemer

Met die ondertekening van hierdie dokument onderneem ek, ……...................……..................………., om deel te neem aan ’n navorsingsprojek getiteld **‘**Die ontwikkeling van 'n ergonomies korrekte stoel vir rekenaar laboratoriums in die Kaapse Metropool.

Ek verklaar dat:

- Ek hierdie inligtings- en toestemmingsvorm gelees het of aan my laat voorlees het en dat dit in ’n taal geskryf is waarin ek vaardig en gemaklik mee is.
- Ek geleentheid gehad het om vrae te stel en dat al my vrae bevredigend beantwoord is.
- Ek verstaan dat deelname aan hierdie navorsingsprojek **vrywillig** is en dat daar geen druk op my geplaas is om deel te neem nie.
- Ek te eniger tyd aan die navorsingsprojek mag onttrek en dat ek nie op enige wyse daardeur benadeel sal word nie.

- Ek gevra mag word om van die navorsingsprojek te onttrek voordat dit afgehandel is indien die studiedokter of navorser van oordeel is dat dit in my beste belang is, of indien ek nie die ooreengekome navorsingsplan volg nie.

Geteken te (*plek*) .... op (*datum*) .... 2010.

....

Handtekening van deelnemer Handtekening van getuie

Verklaring deur navorser

Ek *(naam)* ……………………………………...…………… verklaar dat:

- Ek die inligting in hierdie dokument verduidelik het aan …………………...…….
- Ek hom/haar aangemoedig het om vrae te vra en voldoende tyd gebruik het om dit te beantwoord.
- Ek tevrede is dat hy/sy al die aspekte van die navorsingsprojek soos hierbo bespreek, voldoende verstaan.
- Ek ’n tolk gebruik het/nie ’n tolk gebruik het nie.(*Indien ’n tolk gebruik is, moet die tolk die onderstaande verklaring teken.)*

Geteken te (*plek*) .... op (*datum*) .... 2010.

....

Handtekening van navorder Handtekening van getuie

Verklaring deur tolk

Ek *(naam)* ……………………………………..……………… verklaar dat:

- Ek die navorser (*naam*) …………………………………………………. bygestaan het om die inligting in hierdie dokument in Afrikaans/Xhosa aan *(naam van deelnemer)* ……………………………….................... te verduidelik.
- Ons hom/haar aangemoedig het om vrae te vra en voldoende tyd gebruik het om dit te beantwoord.
- Ek 'n feitelik korrekte weergawe oorgedra het van wat aan my vertel is.
- Ek tevrede is dat die deelnemer die inhoud van hierdie dokument ten volle verstaan en dat al sy/haar vrae bevredigend beantwoord is.

Geteken te (*plek*) .... op (*datum*) .... 2010.

....

Handtekening van tolk Handtekening van getuie

Addendum F: Raw data of research assistants training session

	Assistant 1			Assistant 2			Assistant 3			Assistant 4			Assistant 5			Assistant 6			Assistant 7		
Stature																					
Weight																					
PH																					
BPL																					
HW																					

Addendum G: Median and IQR of the head, thorax and pelvic angles in all three movement planes

Pelvis										
		Tilt			Side-flexion			Rotation		
Subject ID	Chair	Median (IQR)	Min median	Max. median	Median (IQR)	Min median	Max. median	Median (IQR)	Min median	Max. median
S01	**Prototype**	-3(1.2)	-3.8	-0.2	-2.8(2.3)	-6.7	-0.3	-48.6(1.8)	-50.1	-46.3
	School	-0.5(1.1)	-1.5	2.6	-9.6(3.2)	-12.4	-2.4	39.5(0.8)	38.5	40.0
S02	**Prototype**	3.2(11.4)	-2.0	15.5	-7.6(6.1)	-9.5	10.0	39.7(89.2)	-44.7	48.5
	School	6.3(1.8)	5.9	8.1	-0.4(1.9)	-2.3	0.5	-41.1(0.3)	-41.2	-40.8
S03	**Prototype**	0.9(1.9)	-1.3	3.0	2.2(5.4)	-2.5	3.9	39.1(84.4)	-49.4	43.4
	School	-0.3(2.6)	-2.0	1.9	4.6(2.5)	3.3	6.8	42.9(0.6)	42.4	43.4
S04	**Prototype**	-18.8(2.5)	-3.8	-0.2	21.4(1.9)	-6.7	-0.3	-38.4(2.4)	-50.1	-46.3
	School	-22.9(2.5)	-25.6	-20.5	-15.4(1.3)	-17.6	-14.0	36.1(0.6)	34.3	36.9
S05	**Prototype**	-9.8(3.2)	-12.6	-1.5	4.5(2.0)	-9.8	6.0	-40.1(2)	-44.7	-38.4
	School	-2.8(2.2)	-4.5	-0.4	-1.5(3.4)	-5.6	2.3	-40.5(0.5)	-41.0	-39.7
S06	**Prototype**	-0.1(1.4)	-0.9	0.5	-1.6(5.3)	-4.5	2.4	44.4(3.9)	40.5	49.6
	School	-7.9(4.5)	-10.4	0.9	13.7(5.1)	7.4	14.7	-37.7(3.3)	-41.2	-35.7
S07	**Prototype**	-11.6(1.7)	-13.7	-9.5	-5.9(1.7)	-6.9	-4.0	31.6(1.9)	30.1	33.3
	School	-13.8(1.3)	-14.7	-11.7	-14.3(0.9)	-15.8	-13.1	40.6(1.1)	39.6	41.9

S09	**Prototype**	-25.8(3.7)	-29.2	-21.8	21.8(44.8)	-28.6	25.7	-33.1(75.7)	-38.3	48.4
	School	-34.5(2.7)	-37.7	-32.6	24.7(1.2)	23.7	26.8	-26.7(1.2)	-27.8	-25.8
S10	**Prototype**	-8.9(5.4)	-29.2	-21.8	6.9(5.0)	-28.6	25.7	-37.6(7.1)	-38.3	48.4
	School	-8.6(10.5)	-1.5	2.6	7.4(10.3)	0.6	13.7	-36.7(2.1)	-38.1	-34.0
S11	**Prototype**	-13.1(1.9)	-14.3	-11.8	-14.2(3.1)	-15.7	-11.5	39.4(1.7)	37.9	40.6
	School	-8.5(1.5)	-14.2	-11.7	5.4(1.3)	-19.6	-16.1	-42.3(0.3)	40.2	41.5
S12	**Prototype**	-9.2(4.5)	-10.3	-3.9	2.4(4.4)	0.0	5.3	-42.9(1.2)	-43.7	-41.5
	School	-8.5(1.5)	-10.0	-5.8	5.4(1.3)	3.4	7.1	-42.3(0.3)	-43.1	-42.2

Thorax										
		Flexion/Extension			**Side-flexion**			**Rotation**		
Subject ID	**Chair**	**Median (IQR)**	**Min median**	**Max. median**	**Median (IQR)**	**Min median**	**Max. median**	**Median (IQR)**	**Min median**	**Max. media n**
S01	**Prototype**	-5.3(3.2)	-13.7	-3.0	4.3(7.2)	-13.7	10.6	-41.1(6.8)	-2.2	-3.0
	School	10.4(4.8)	0.0	13.5	5.2(3.3)	-1.9	6.8	42.454571(2.8)	0.0	13.5
S02	**Prototype**	-4.4(9.6)	-14.7	17.8	0.4(14.1)	-14.7	10.6	36.4(88.6)	-7.2	17.8
	School	14.1(2.3)	11.8	15.0	-18.7(2.4)	-22.6	-16.3	-44.7(1.7)	11.8	15.0
S03	**Prototype**	2.9(10.2)	-5.2	8.8	-0.6(8.8)	-5.2	1.8	35.3(87.8)	-8.8	8.8
	School	2.2(3.1)	-0.8	3.6	1.3(3.1)	-0.5	4.2	39.3(1.4)	-0.8	3.6
S04	**Prototype**	5.7(2.0)	-13.7	-3.0	0.2(1.8)	-13.7	10.6	-45.4(2.6)	-2.2	-3.0
	School	3.3(2.3)	1.7	7.4	5.1(3.1)	1.3	8.5	38.6(1.7)	1.7	7.4

S05	**Prototype**	-2.1(1.5)	-4.8	6.2	7.1(0.8)	-4.8	7.5	-44.7(4.0)	-3.0	6.2
	School	6.2(3.2)	4.3	7.9	-0.6(4.3)	-2.9	3.1	-48.6(2.9)	4.3	7.9
S06	**Prototype**	-1.8(2.6)	-2.8	-0.5	-7.8(3.9)	-2.8	-5.4	47.3(4.4)	-9.6	-0.5
	School	3.7(5.8)	-8.3	6.7	-6.5(5.7)	-11.0	0.3	-42.3(4.8)	-8.3	6.7
S07	**Prototype**	7.4(2.6)	5.8	9.9	3.1(4.2)	5.8	6.7	38.3(2.4)	0.4	9.9
	School	5.2(2.1)	3.0	7.3	3.1(2.2)	0.8	4.7	45.4(3.9)	3.0	7.3
S09	**Prototype**	4.6(6.0)	-7.0	8.2	-4.3(5.4)	-7.0	7.0	-37.5(86.4)	-7.3	8.2
	School	1.2(3.7)	-3.6	3.0	-1.5(3.1)	-3.6	2.1	-45.1(1.1)	-3.6	3.0
S10	**Prototype**	10.9(3.3)	-7.0	8.2	-12.1(4.0)	-7.0	7.0	-38.3(4.9)	-7.3	8.2
	School	7.9(6.7)	2.8	15.6	-6.5(6.8)	-12.4	-0.9	-38.9(4.1)	2.8	15.6
S11	**Prototype**	16.3(2.8)	14.4	17.5	7.2(2.1)	14.4	8.6	41.6(2.5)	6.0	17.5
	School	-1.3(1.6)	13.8	17.1	3.1(1.3)	-1.5	4.1	-43.6(1.6)	13.8	17.1
S12	**Prototype**	4.8(4.7)	-0.5	9.8	2.2(5.1)	-0.5	5.7	-41.5(1.5)	-2.7	9.8
	School	-1.3(1.6)	-2.6	1.2	3.1(1.3)	1.8	4.0	-43.6(1.6)	-2.6	1.2

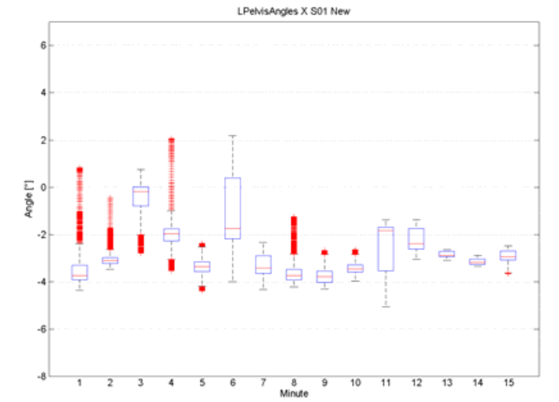
Head										
		Flexion/Extension			Side-flexion			Rotation		
Subject ID	Chair	Median (IQR)	Min median	Max. median	Median (IQR)	Min median	Max. median	Median (IQR)	Min median	Max. median
S01	Prototype	8.3(7.6)	-50.1	-46.3	9.7(5.4)	4.9	13.4	-56.1(10.4)	-61.3	-47.1
	School	6.5(6.1)	38.5	40.0	-4.7(7.6)	-18.2	-1.5	36.8(6.8)	32.9	44.3
S02	Prototype	2.5(7.3)	-44.7	48.5	-0.5(8.1)	-13.5	5.6	18.1(92,4)	-63.0	36.1
	School	-8.1(3.7)	-41.2	-40.8	-8.3(4.3)	-9.8	-5.6	-61.4(6.4)	-63.5	-59.2
S03	Prototype	1.4(10.3)	-49.4	43.4	6.6(6.2)	-1.9	11.4	36.6(85.3)	-52.1	43.0
	School	1.5(7.5)	42.4	43.4	7.1(4.3)	0.7	9.6	37.5(4.6)	35.8	40.6
S04	Prototype	-2.1(4.6)	-50.1	-46.3	-3.4(5.1)	4.9	13.4	-51.2(2.9)	-61.3	-47.1
	School	-1.2(4.1)	34.3	36.9	5.7(4.5)	1.4	7.4	26.1(4.5)	21.7	33.5
S05	Prototype	17.2(3.8)	-44.7	-38.4	18.1(3.0)	-1.8	20.3	-52.1(8.1)	-63.5	-48.2
	School	1.1(18.7)	-41.0	-39.7	5.9(13.5)	-4.7	11.5	-55.2(7.4)	-60.0	-53.3
S06	Prototype	-0.7(11.1)	40.5	49.6	1.5(10.8)	-3.6	3.8	45.8(11.7)	40.9	53.3
	School	4.4(8.7)	-41.2	-35.7	7.3(8.7)	-0.6	11.3	-47.4(9.1)	-50.5	-41.9
S07	Prototype	-3.5(7.6)	30.1	33.3	2.8(5.9)	-7.1	6.8	39.2(5.8)	32.9	42.9
	School	2.8(5.5)	39.6	41.9	0.5(8.4)	-5.9	6.9	39.2(4.5)	32.5	42.8
S09	Prototype	8.3(4.5)	-38.3	48.4	4.7(16.9)	-9.2	11.3	-32.5(86.2)	-38.0	57.2
	School	7.3(4.9)	-27.8	-25.8	9.1(7.3)	1.1	14.5	-43.1(5.6)	-45.8	-40.7

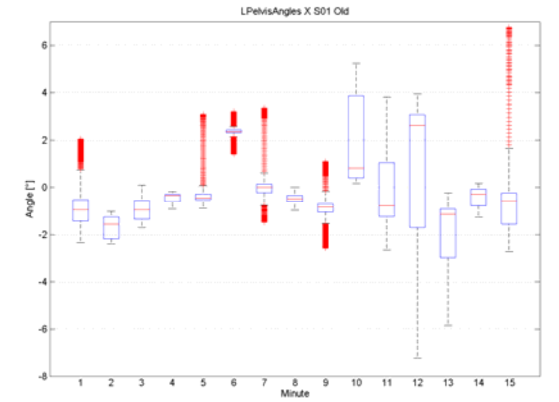
S10	**Prototype**	-7.2(13.8)	-38.3	48.4	-8.2(19.1)	-9.2	11.3	-47.4(11.4)	-38.0	57.2
	School	3.7(9.5)	-38.1	-34.0	-0.6(14.4)	-8.8	8.6	-57.2(10.1)	-62.6	-50.5
S11	**Prototype**	-20.3(11.0)	37.9	40.6	7.6(9.6)	0.1	11.9	35.4(4.4)	33.0	37.4
	School	-3.6(4.5)	40.2	41.5	-7.8(6.9)	-4.1	1.7	-47.1(4.2)	31.2	42.4
S12	**Prototype**	0.8(7.3)	-43.7	-41.5	-6.3(13.1)	-12.3	8.4	-45.9(4.1)	-48.8	-41.3
	School	-3.6(4.5)	-43.1	-42.2	-7.8(6.9)	-11.6	-1.9	-47.1(4.2)	-48.8	-44.6

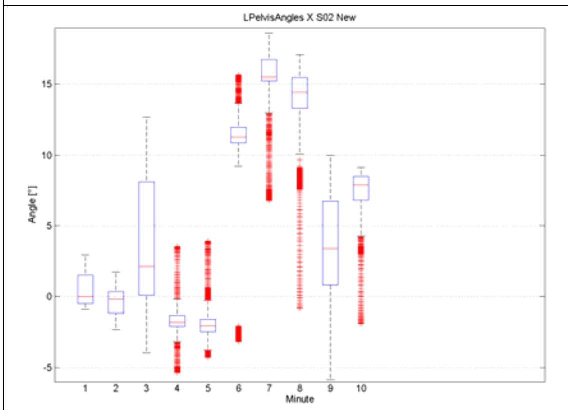
Addendum H: Per minute box plots for each subject for the pelvis, thorax and head, in all three movement planes (X,Y,Z)

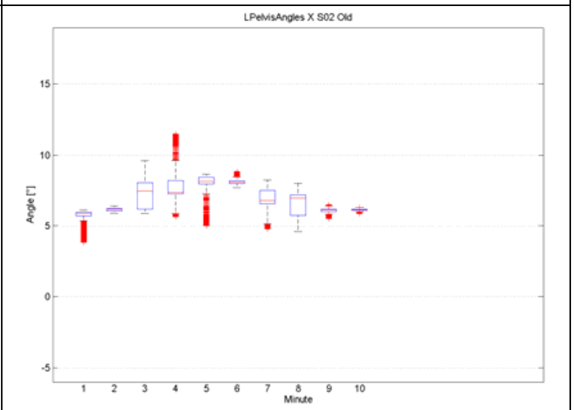
'Old chair' refers to the school chair, and 'new chair' refers to the prototype 'Dynamic' chair.

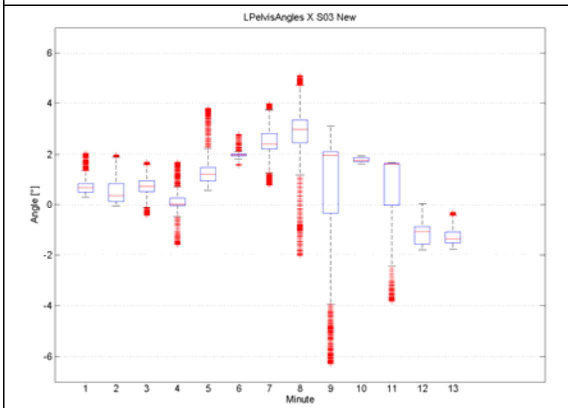
The first set of graphs is for pelvic tilt (X-axis).

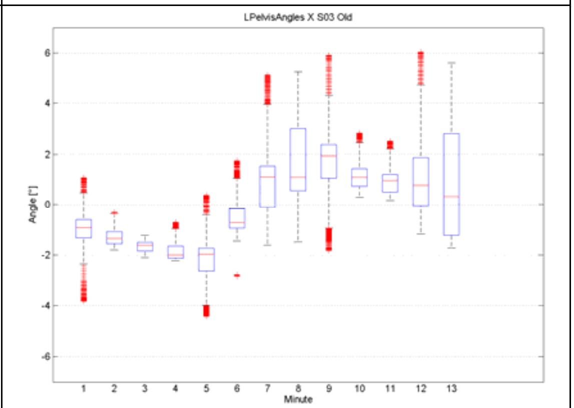


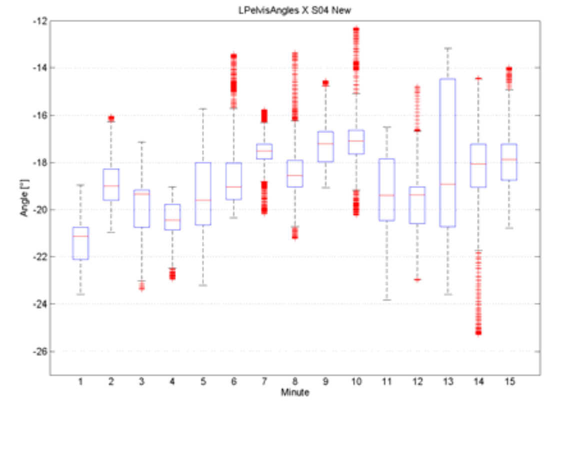


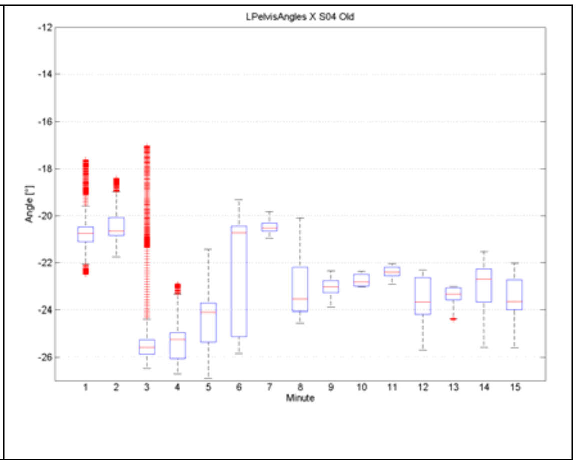









LPelvisAngles X S04 New
Angle [°]
Minute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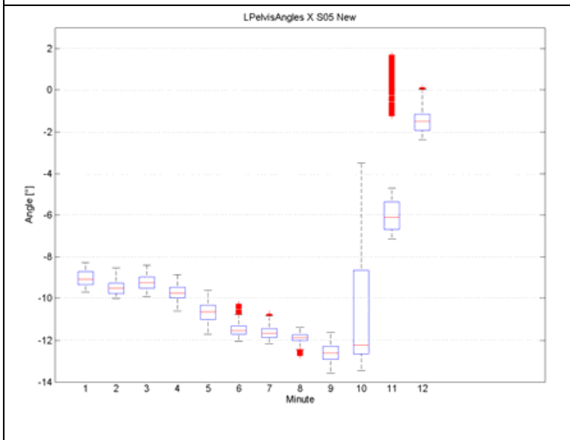
Angle [°]
Minute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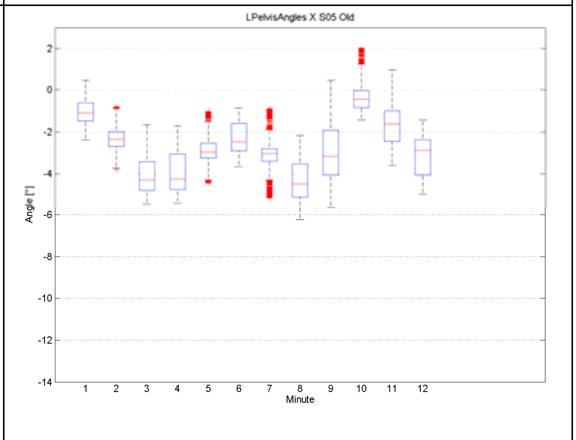
Angle [°]
Minute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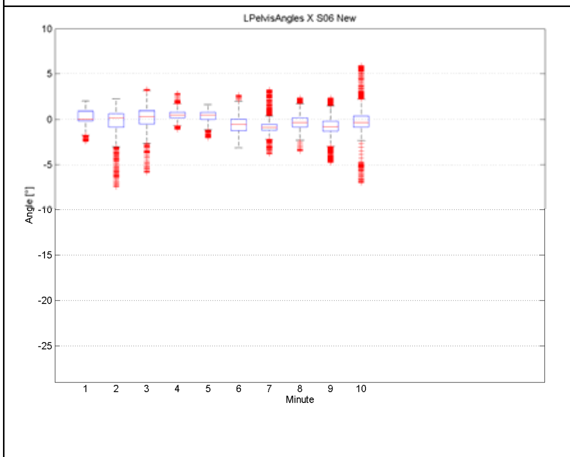
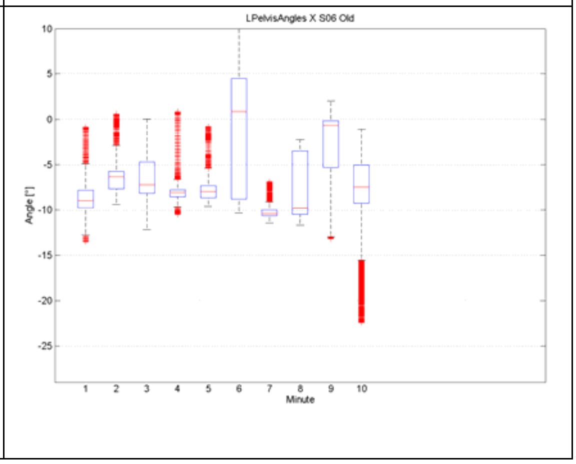
Angle [°]
Minute


LPelvisAngles X S06 New
Angle [°]
Minute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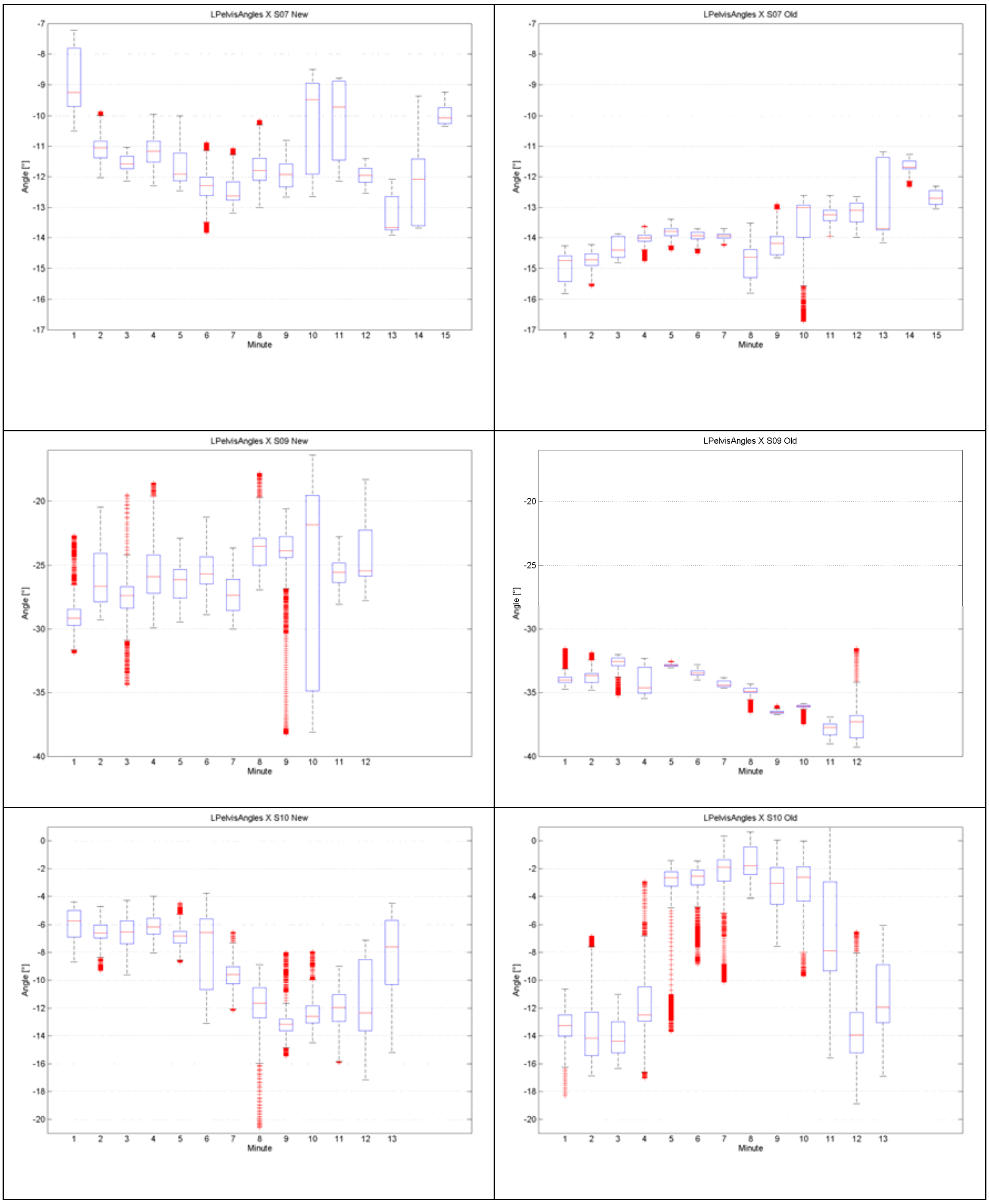
Angle [°]
Minute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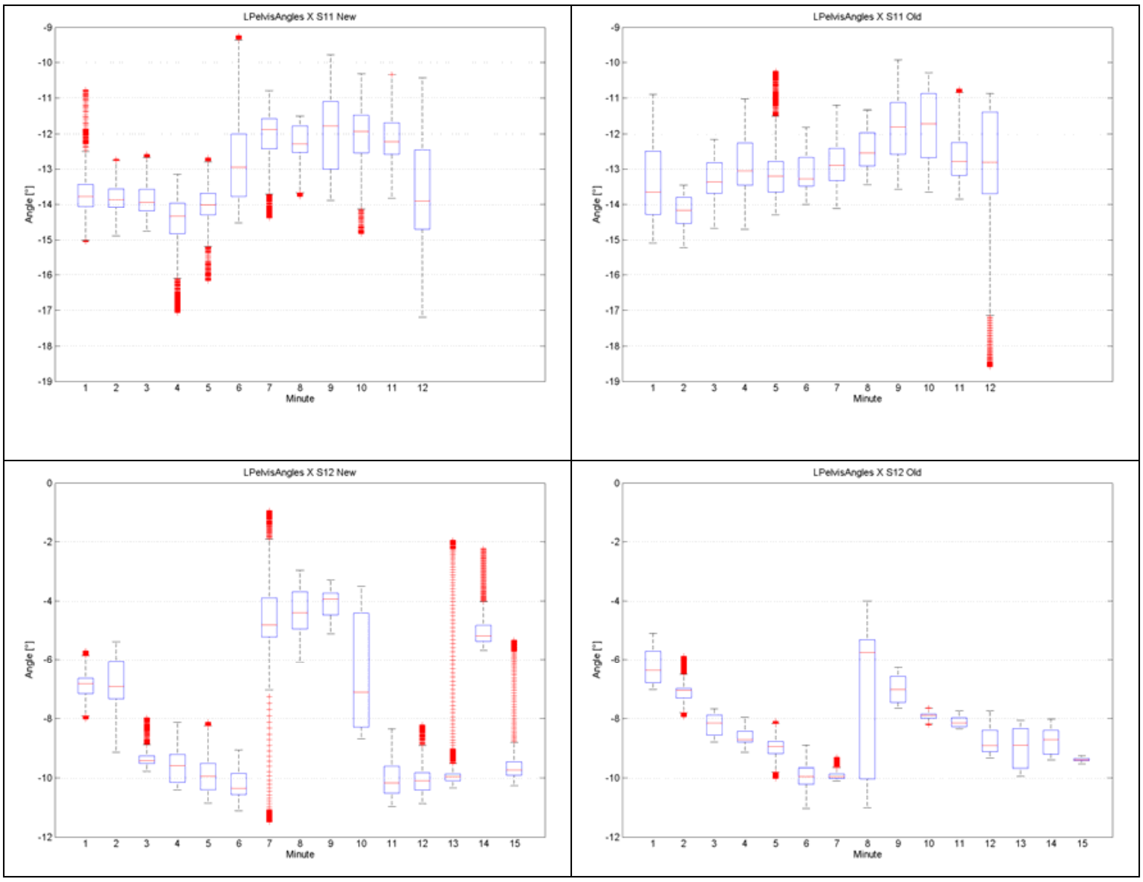
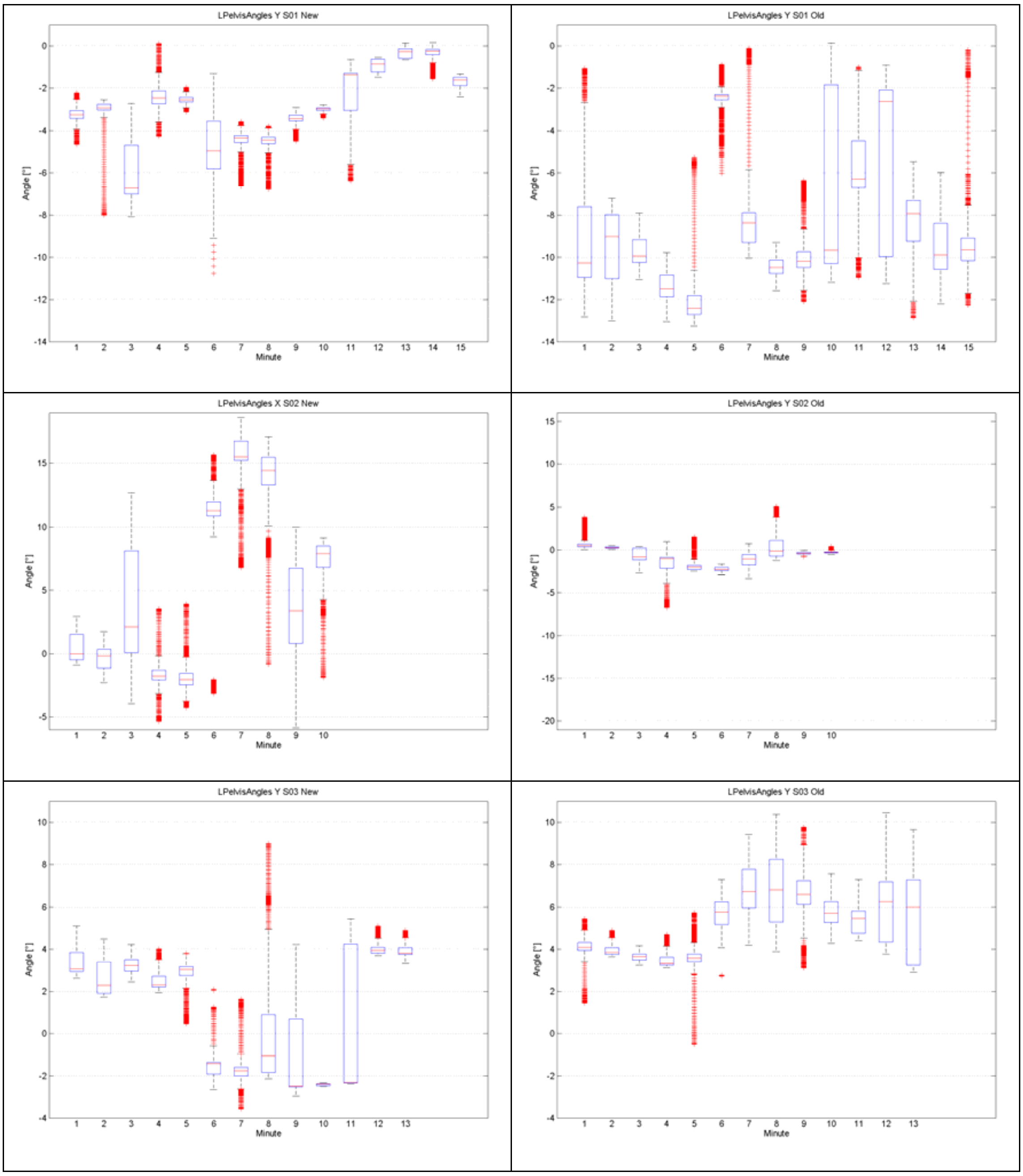
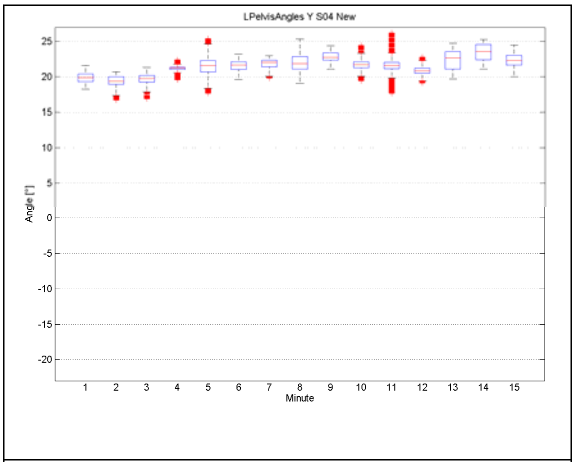
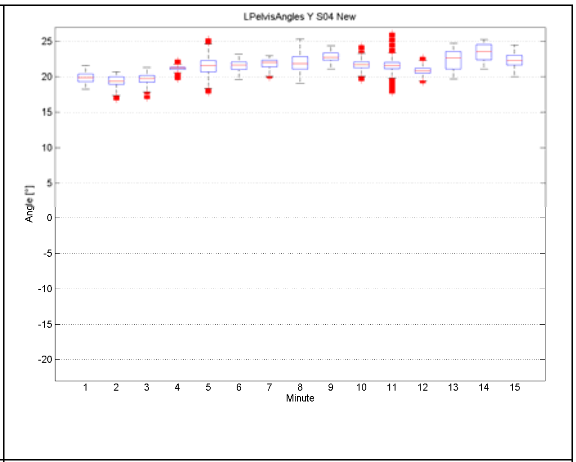
LPelvisAngles X S07 Old
LPelvisAngles X S09 New
LPelvisAngles X S09 Old
LPelvisAngles X S10 New
LPelvisAngles X S10 Old
Angle [°]
Minute

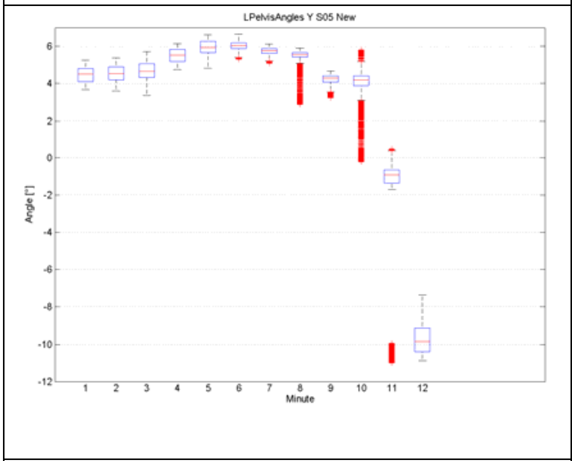

LPelvisAngles X S11 New
LPelvisAngles X S11 Old
LPelvisAngles X S12 New
LPelvisAngles X S12 Old
Angle [°]
Minute

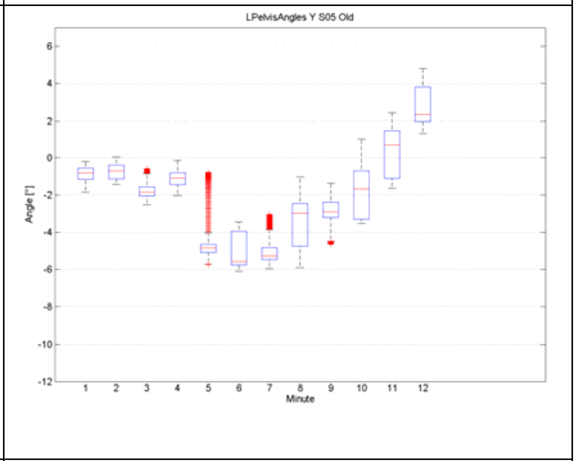
Pelvic side-flexion (Y-axis)

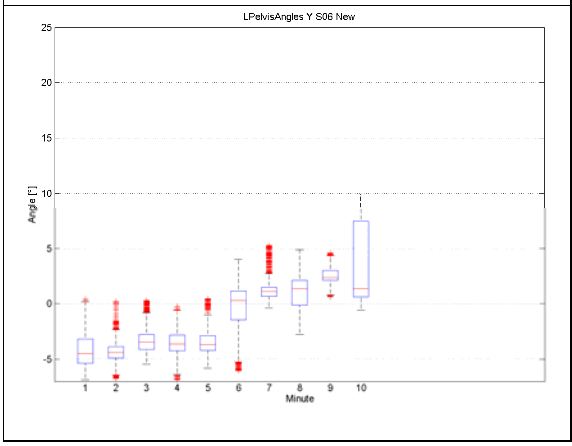


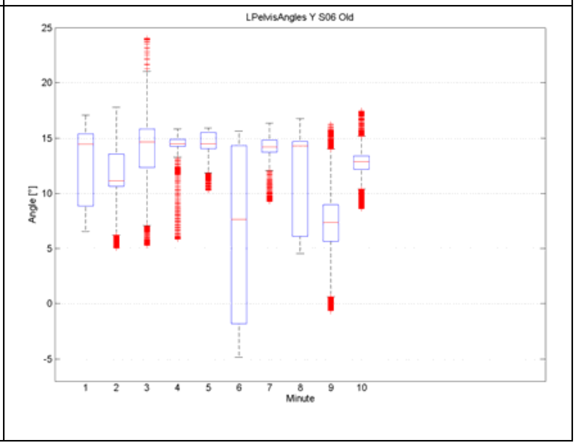

LPelvisAngles Y S04 New
Angle [°]
Minute

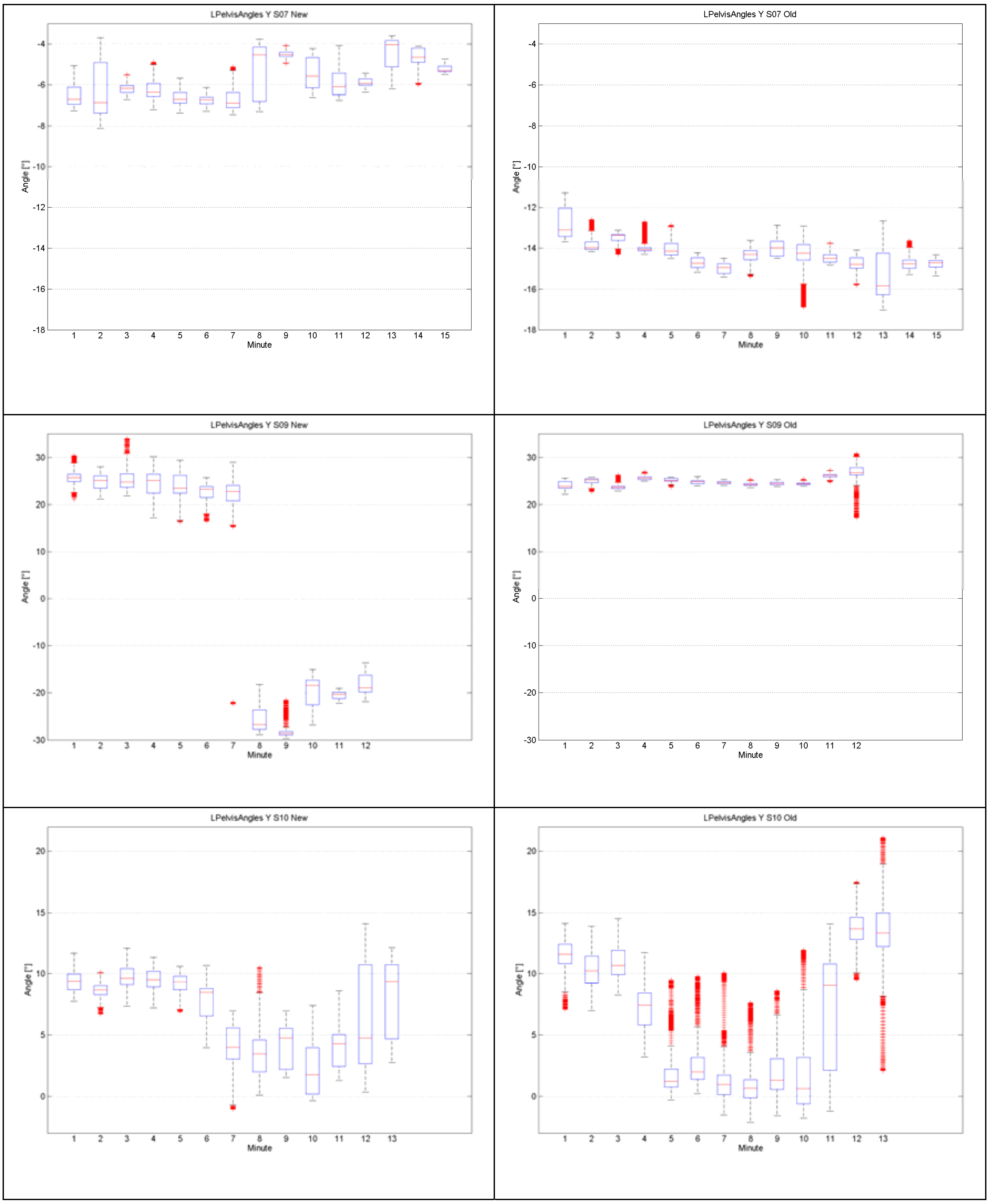

LPelvisAngles Y S04 New
Angle [°]
Minute


LPelvisAngles Y S05 New
Angle [°]
Minute


LPelvisAngles Y S05 Old
Angle [°]
Minute


LPelvisAngles Y S06 New
Angle [°]
Minute


LPelvisAngles Y S06 Old
Angle [°]
Minute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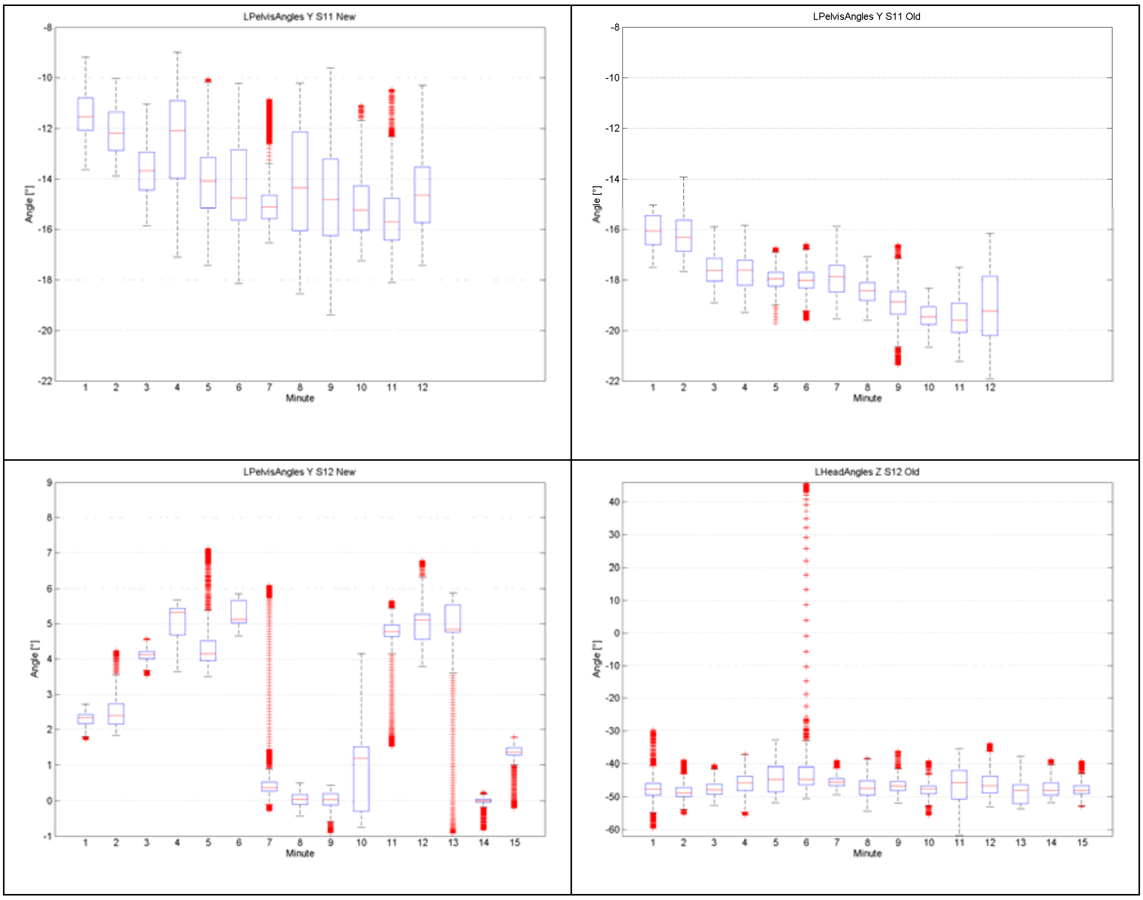
LPelvisAngles Y S07 Old
LPelvisAngles Y S09 New
LPelvisAngles Y S09 Old
LPelvisAngles Y S10 New
LPelvisAngles Y S10 Old
Angle [°]
Minute


LPelvisAngles Y S11 New
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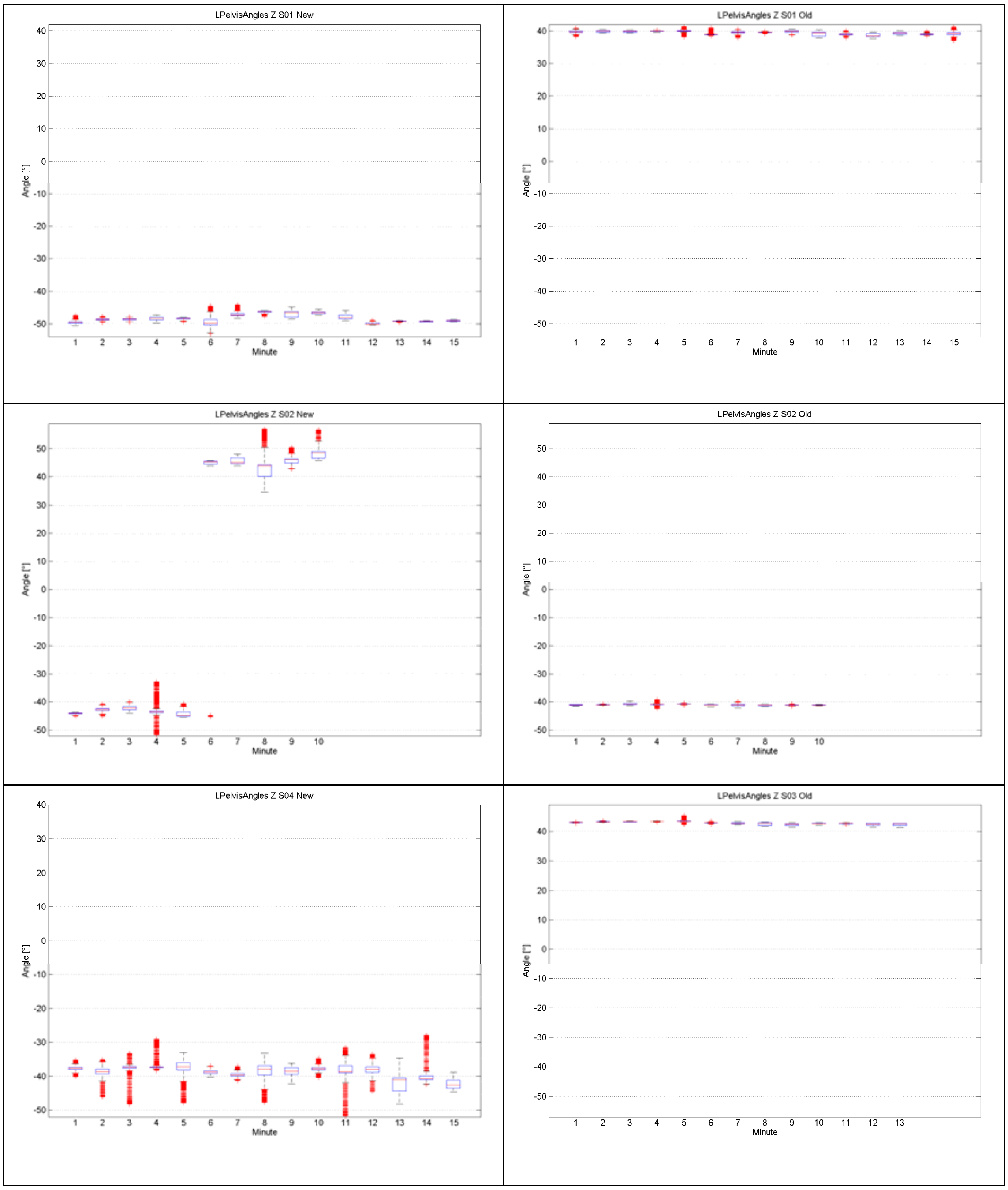
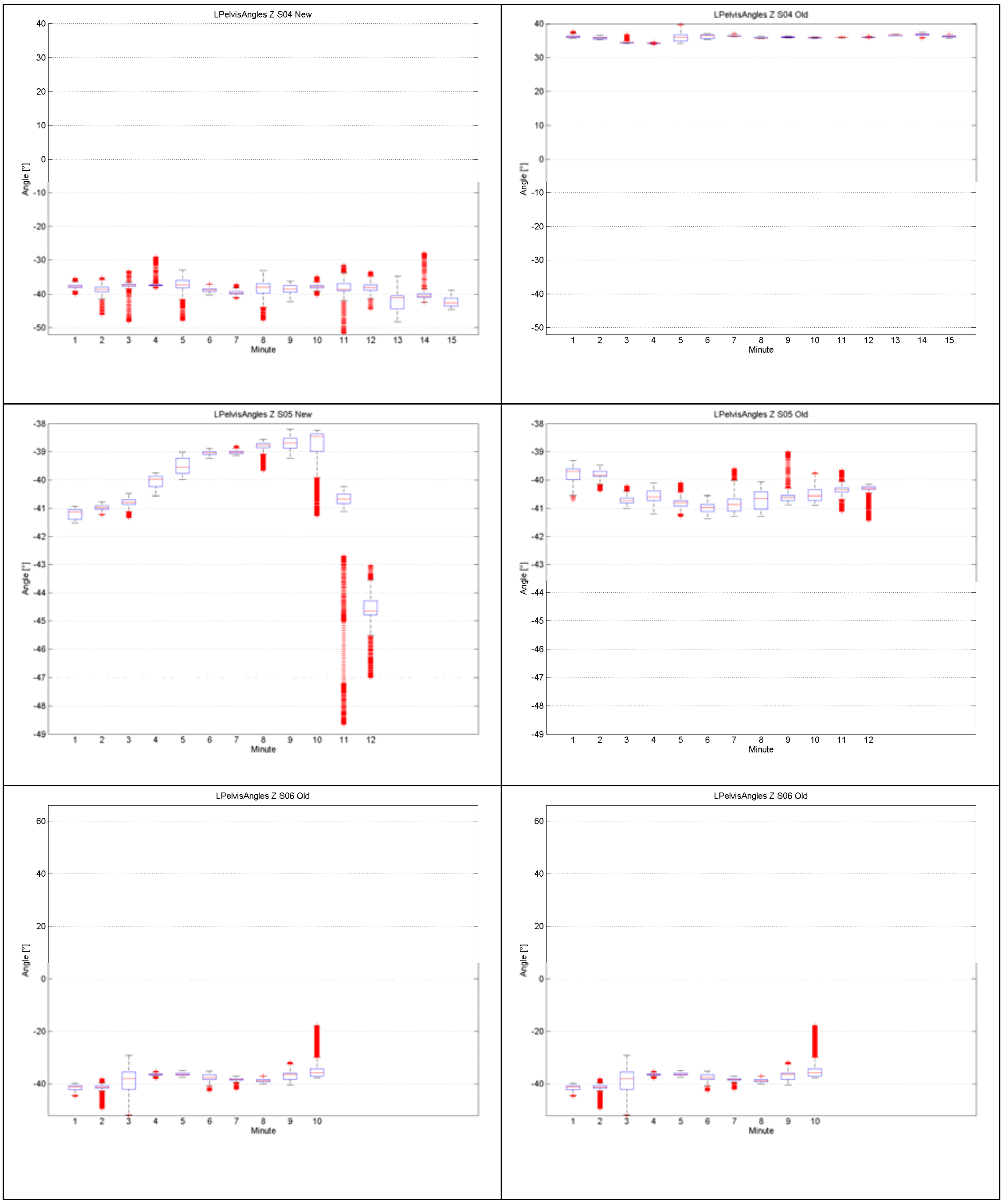
LPelvisAngles Y S12 New
LHeadAngles Z S12 Old
Angle [°]
Minute

Pelvic rotation (Z-axis)

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LPelvisAngles Z S05 New
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LPelvisAngles Z S06 Old
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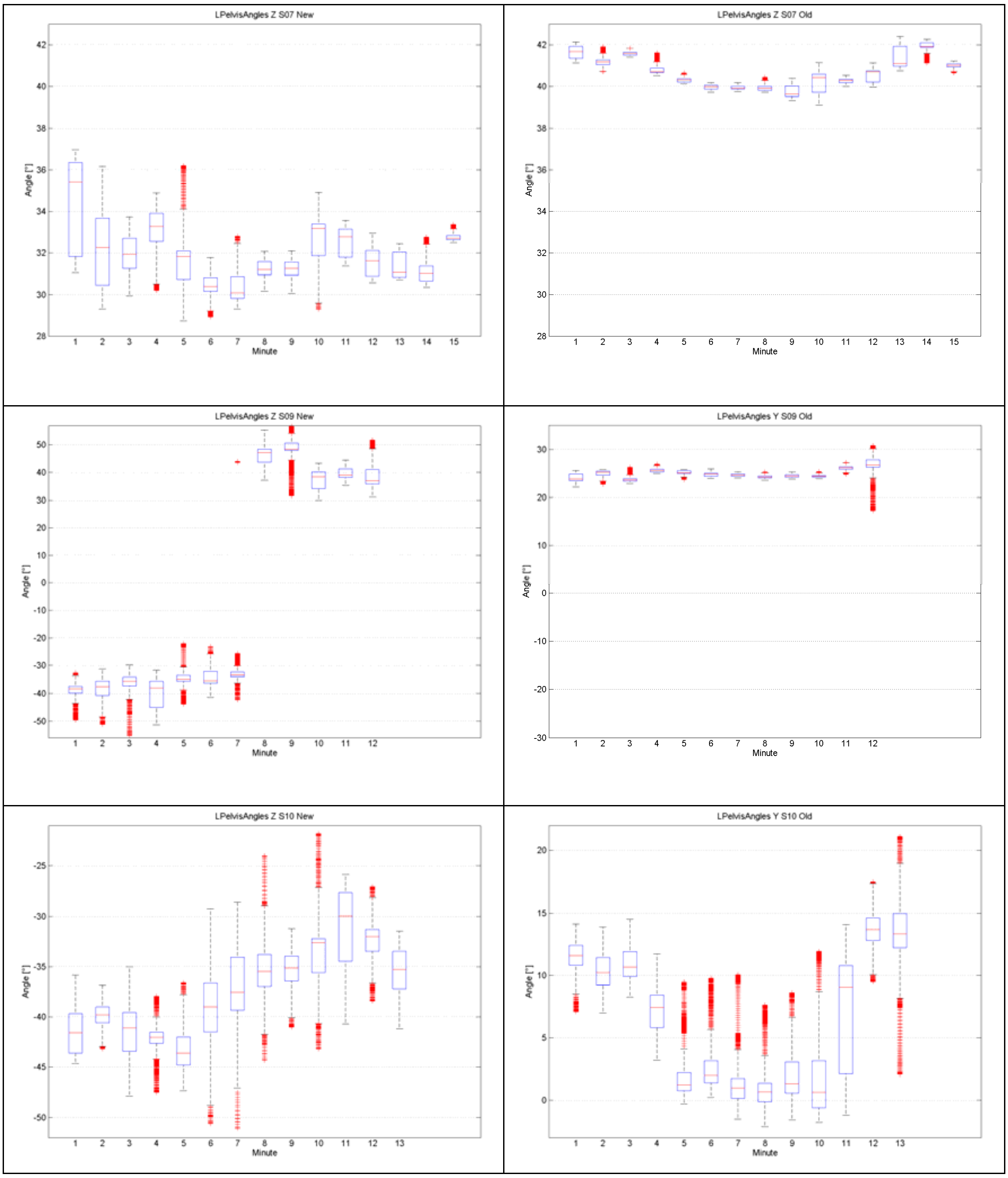
Angle [°]
Minute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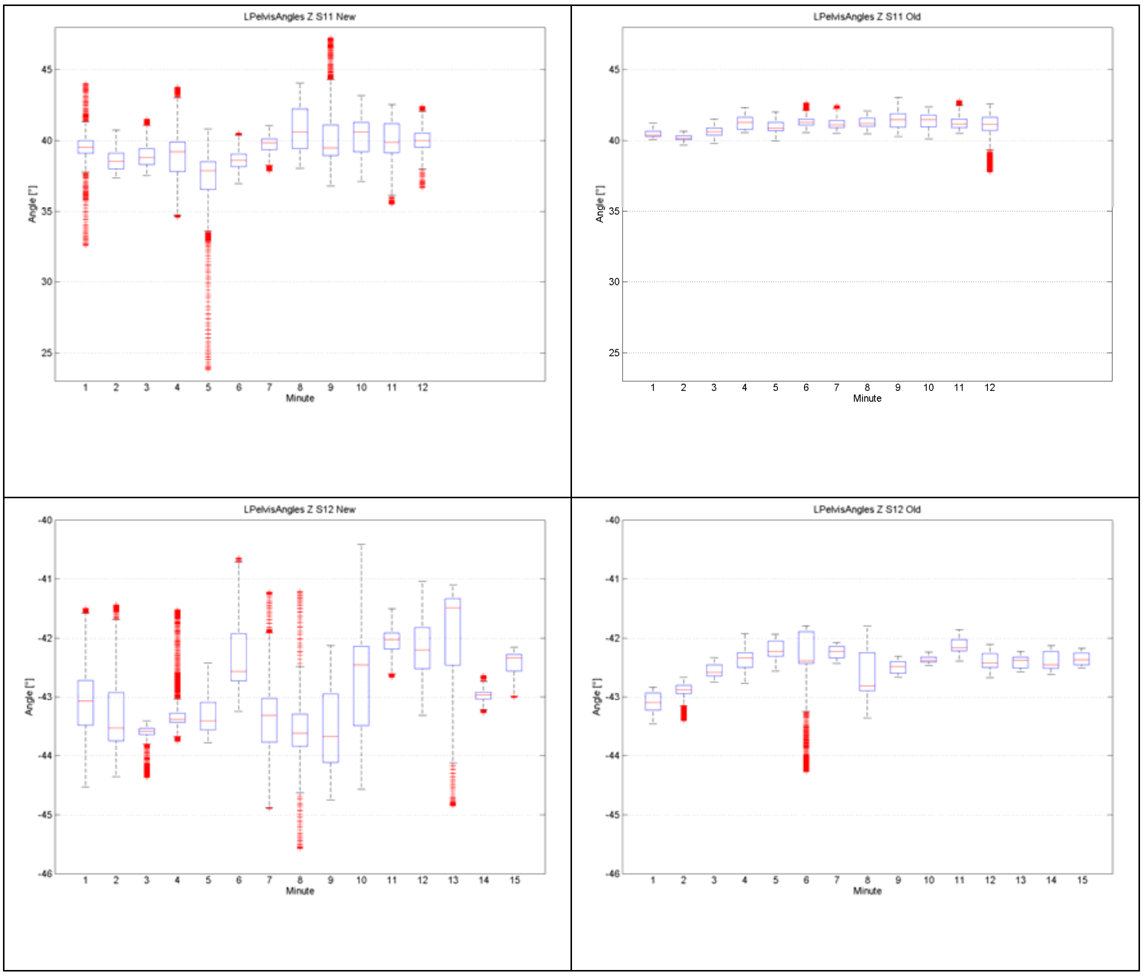
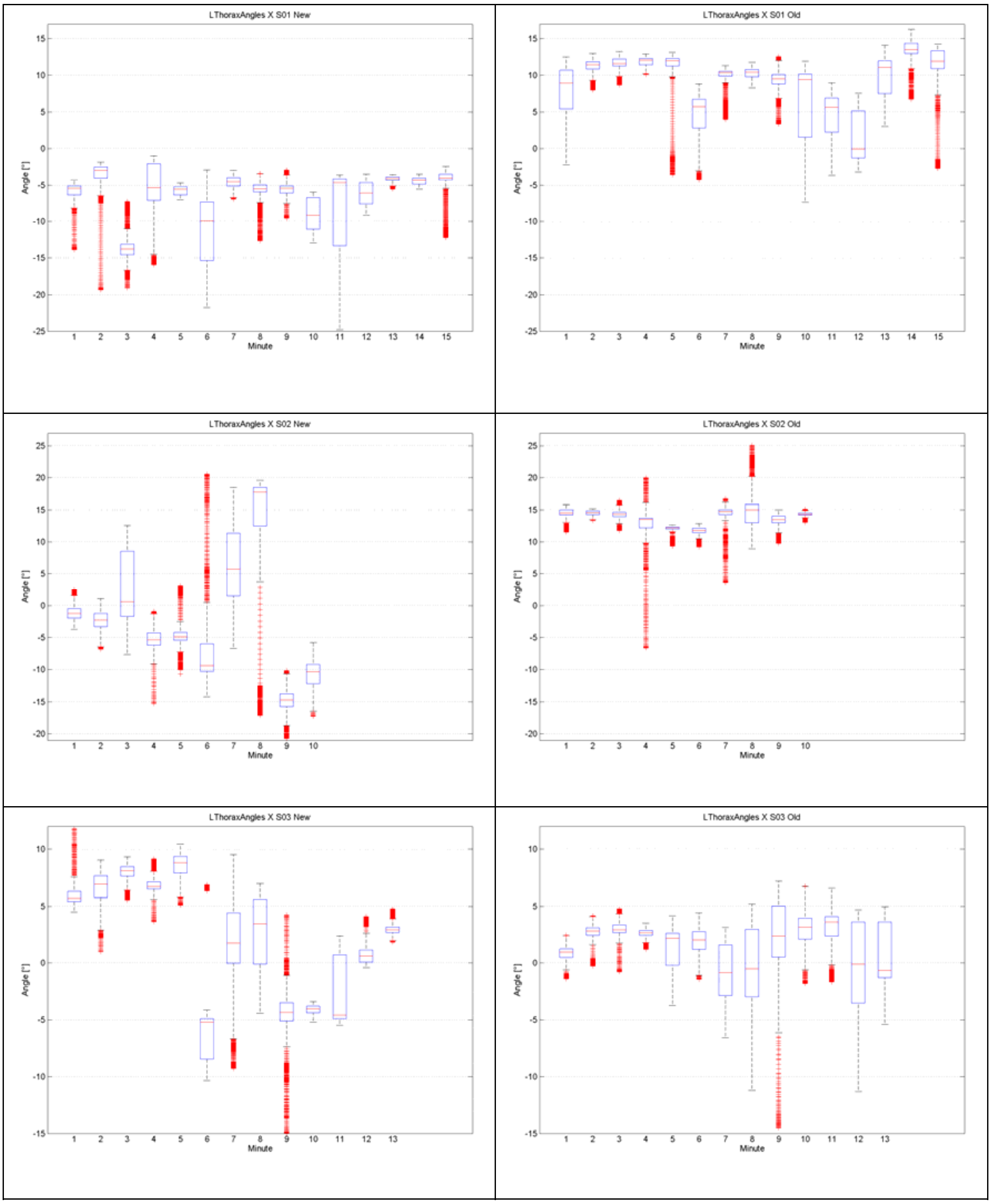
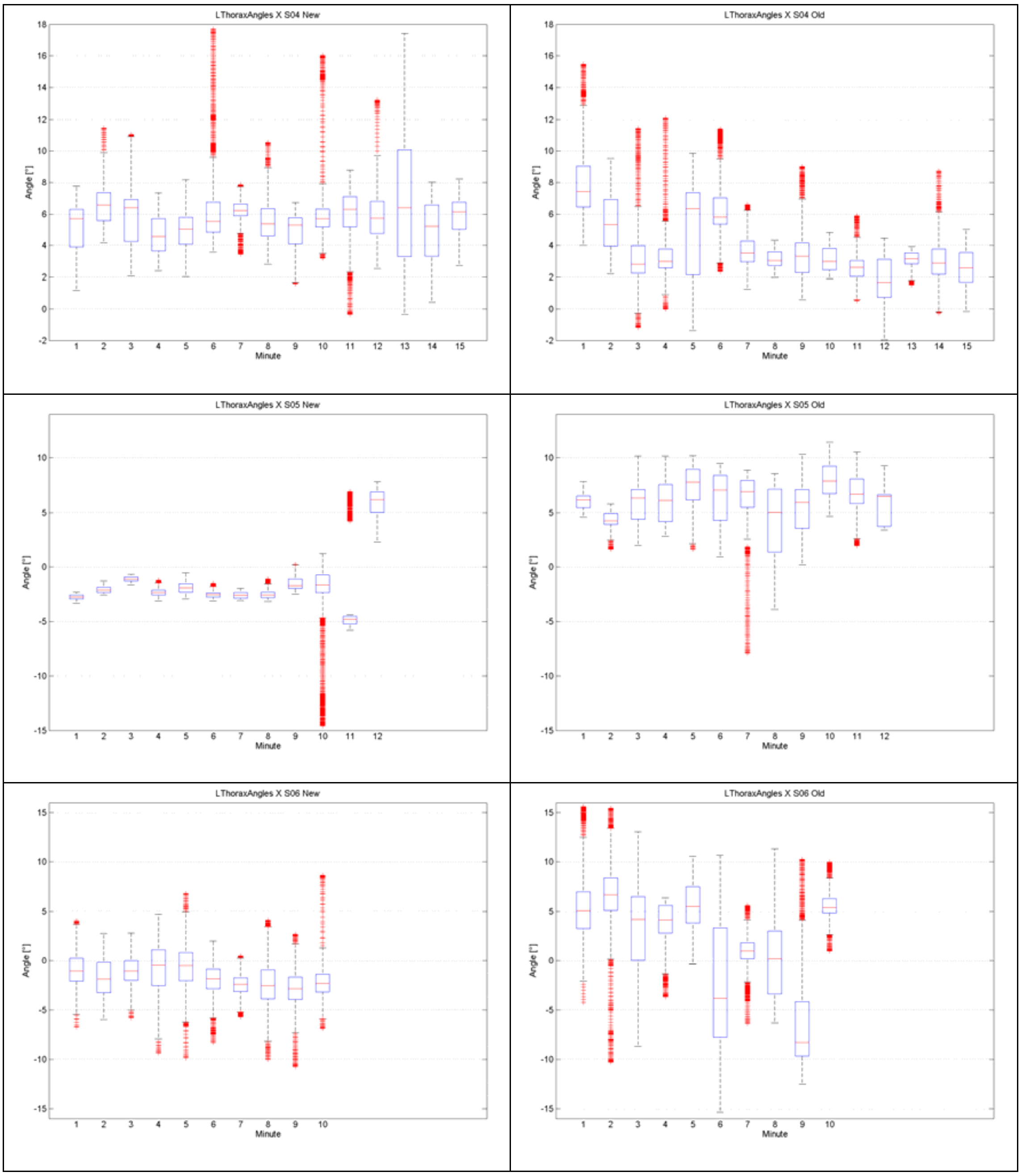
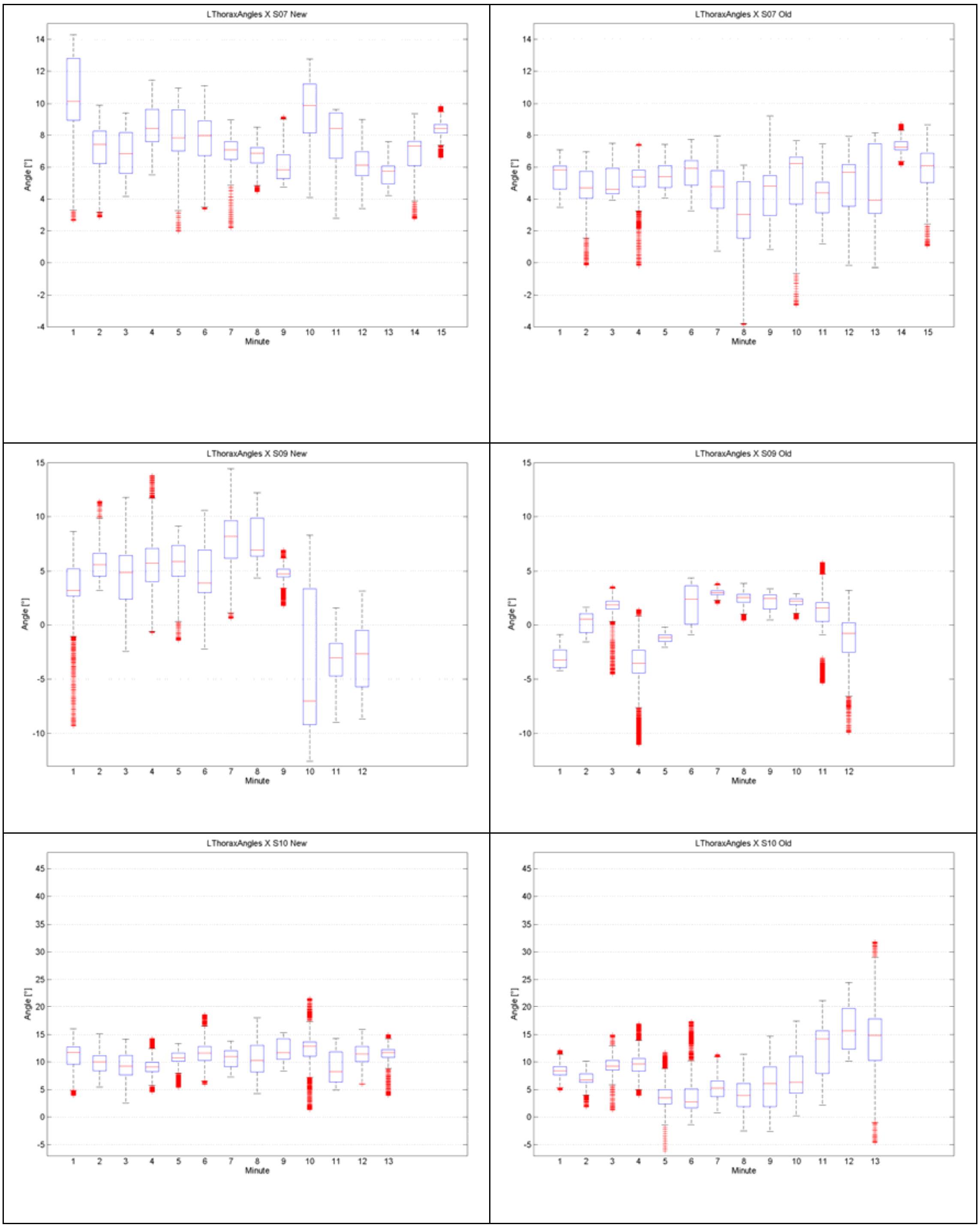
LPelvisAngles Z S10 New
LPelvisAngles Y S10 Old
Angle [°]
Minute


LPelvisAngles Z S11 New
LPelvisAngles Z S11 Old
LPelvisAngles Z S12 New
LPelvisAngles Z S12 Old
Angle [°]
Minute

Thoracic angle X-axis (flexion/extension)




LThoraxAngles X S04 New
LThoraxAngles X S04 Old
LThoraxAngles X S05 New
LThoraxAngles X S05 Old
LThoraxAngles X S06 New
LThoraxAngles X S06 Old
Angle [°]
Minute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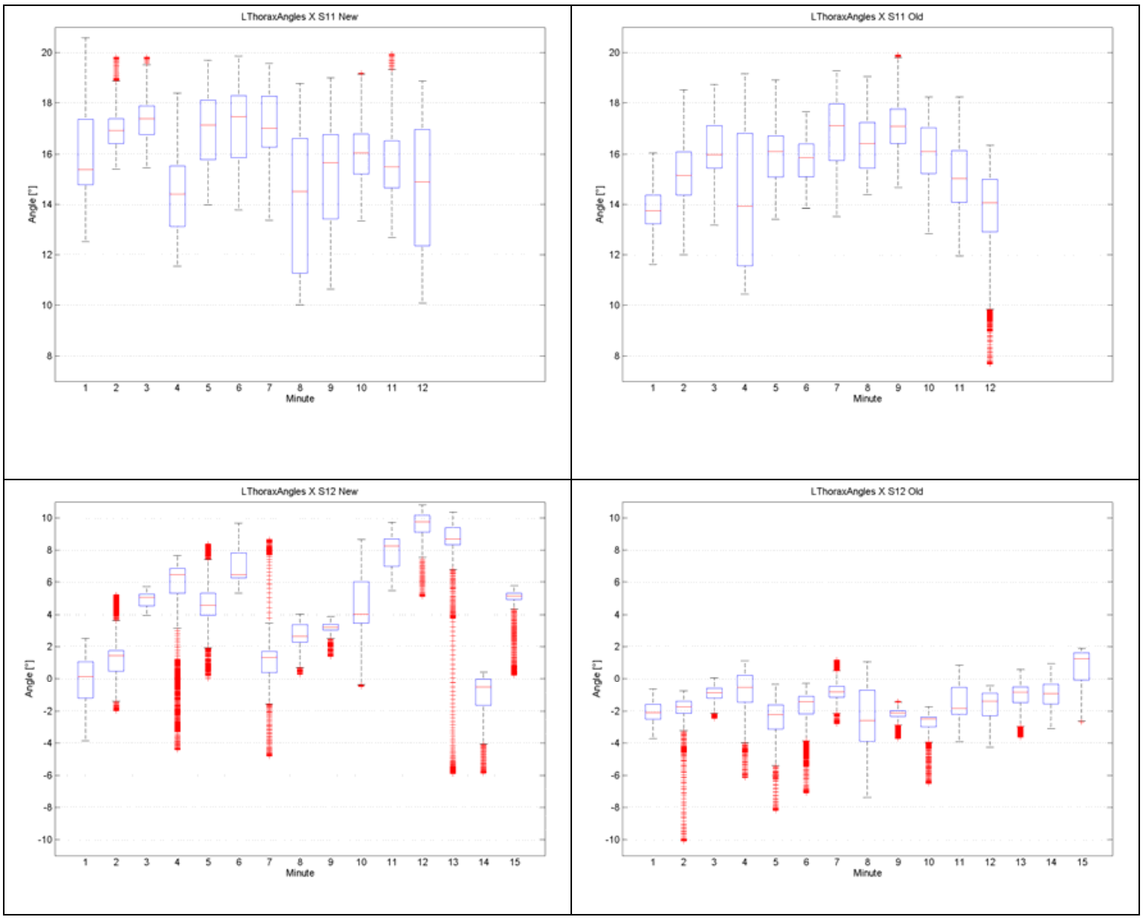
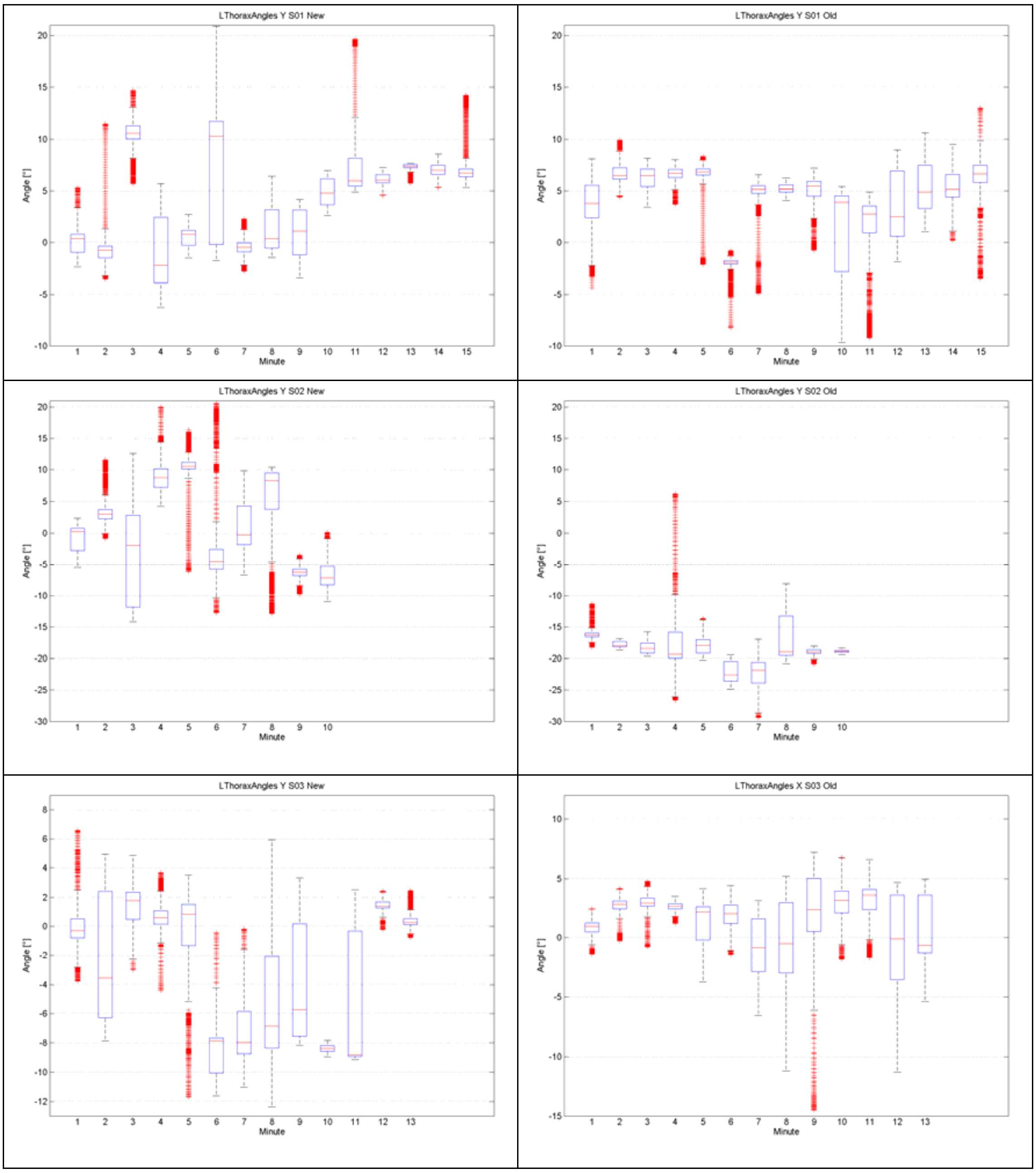
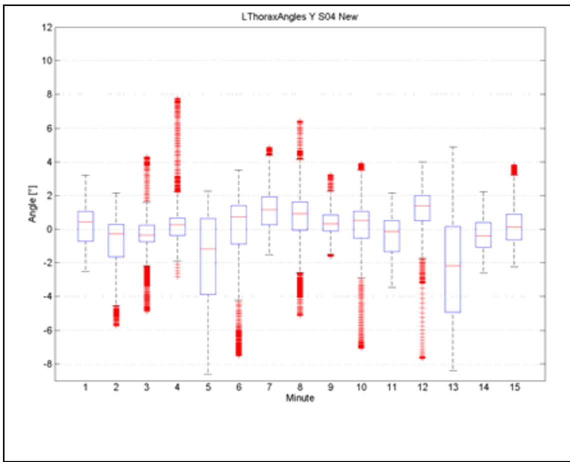
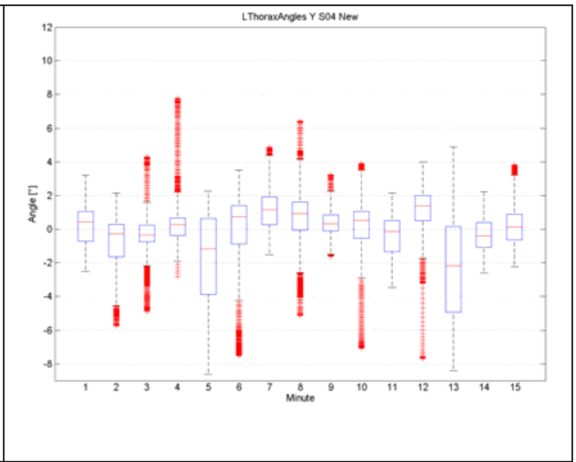
LThoraxAngles X S07 Old
LThoraxAngles X S09 New
LThoraxAngles X S09 Old
LThoraxAngles X S10 New
LThoraxAngles X S10 Old
Angle [°]
Minute


LThoraxAngles X S11 New
LThoraxAngles X S11 Old
LThoraxAngles X S12 New
LThoraxAngles X S12 Old
Angle [°]
Minute

Thoracic angle side-flexion (Y-axis)




LThoraxAngles Y S04 New
Angle [°]
Minute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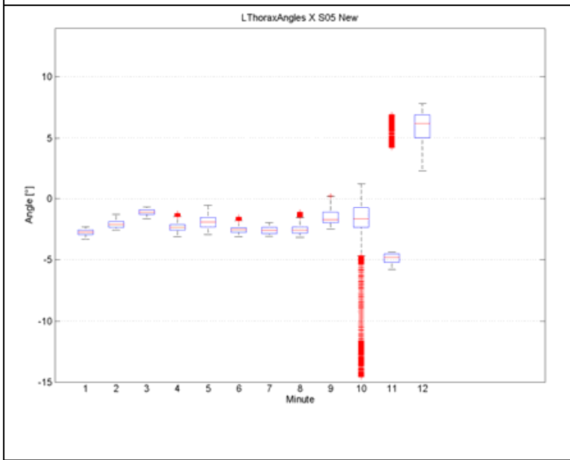
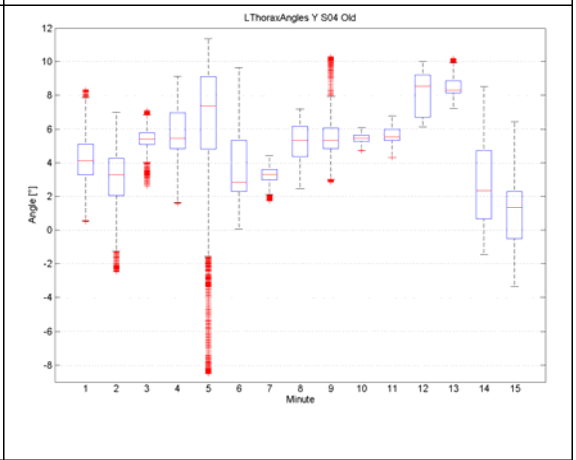
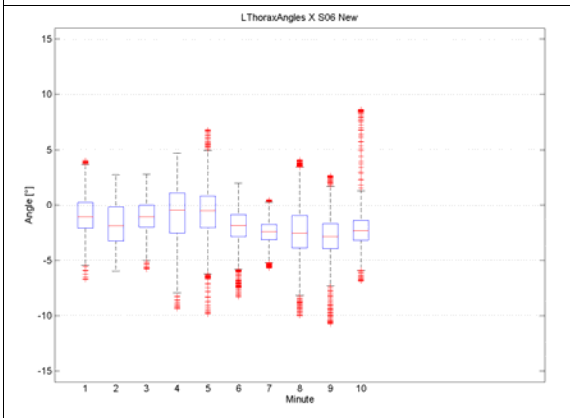
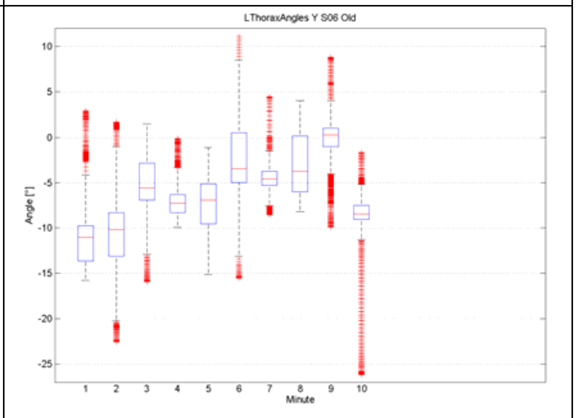
Angle [°]
Minute


LThoraxAngles X S05 New
Angle [°]
Minute


LThoraxAngles Y S04 Old
Angle [°]
Minute


LThoraxAngles X S06 New
Angle [°]
Minute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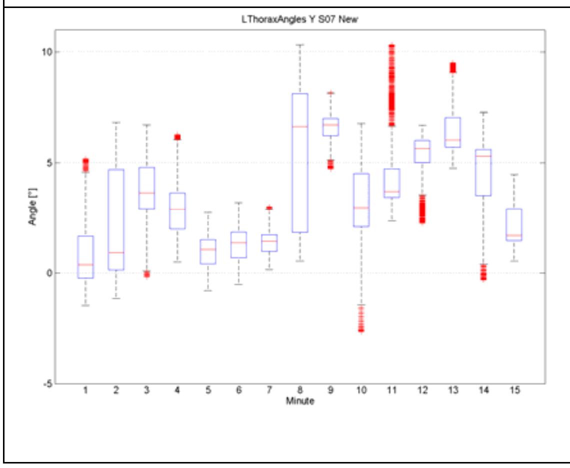
Angle [°]
Minute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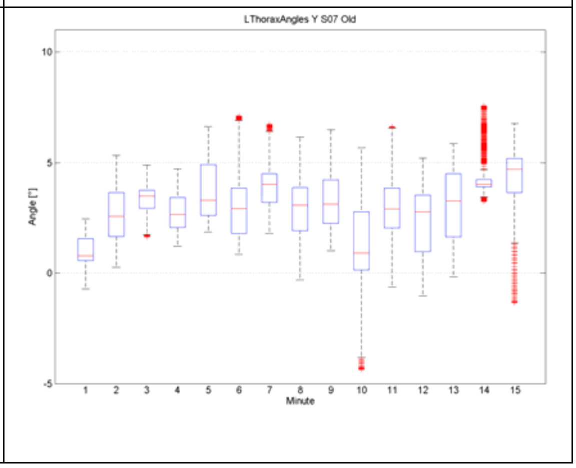
Angle [°]
Minute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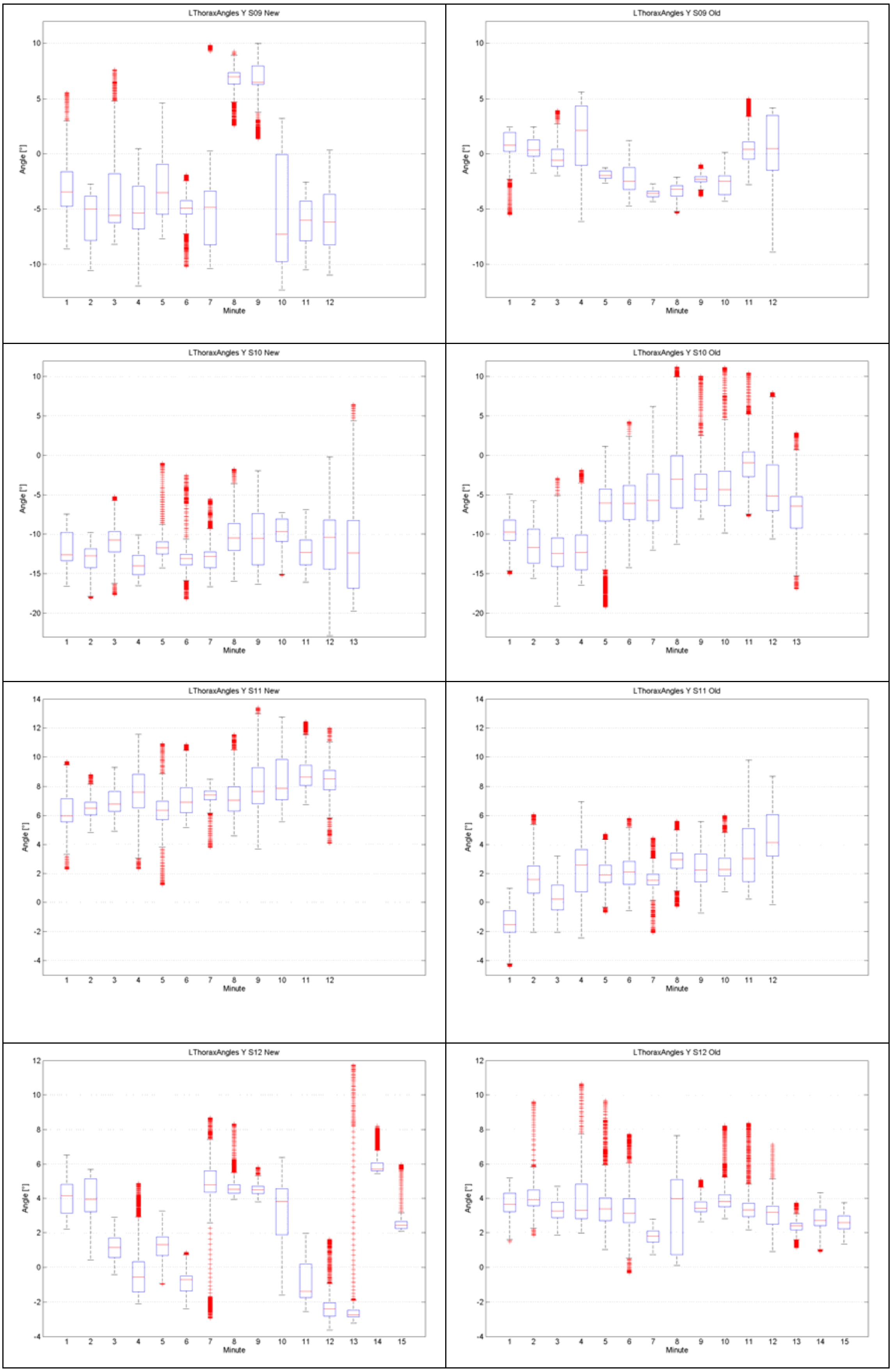
Angle [°]
Minute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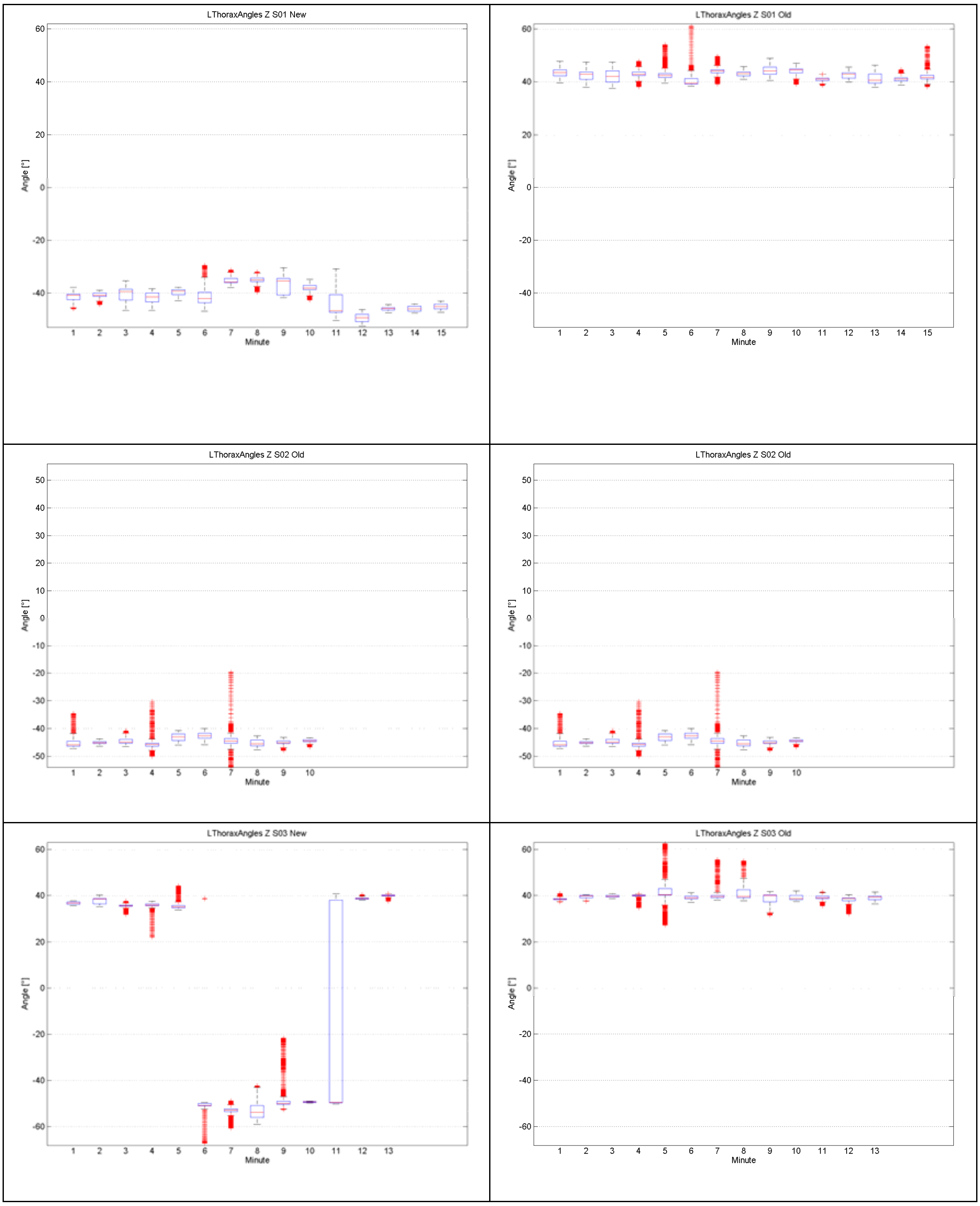
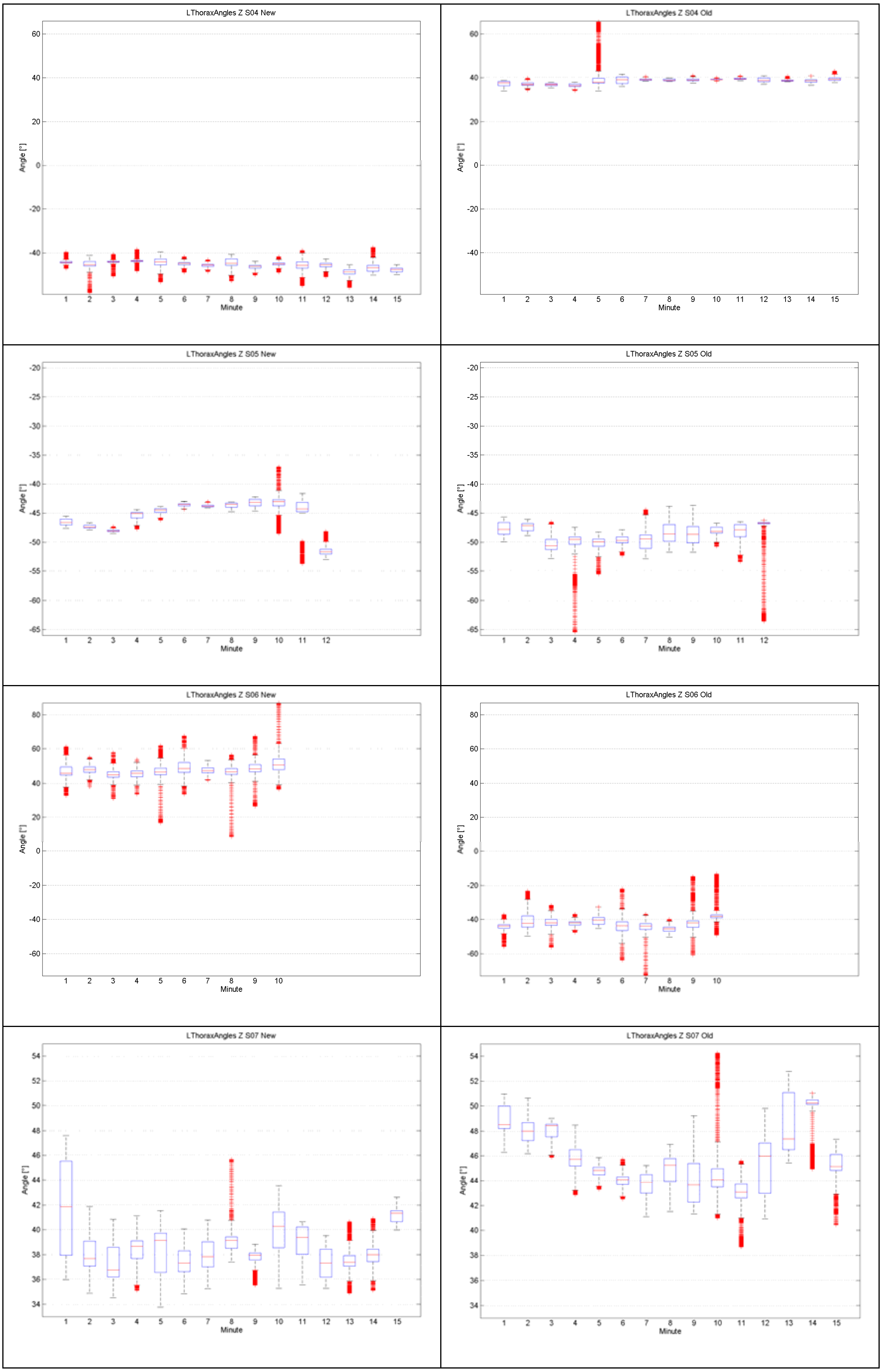
LThoraxAngles Y S10 New
LThoraxAngles Y S10 Old
LThoraxAngles Y S11 New
LThoraxAngles Y S11 Old
LThoraxAngles Y S12 New
LThoraxAngles Y S12 Old
Angle [°]
Minute

Thoracic angle rotation (Z-axis)

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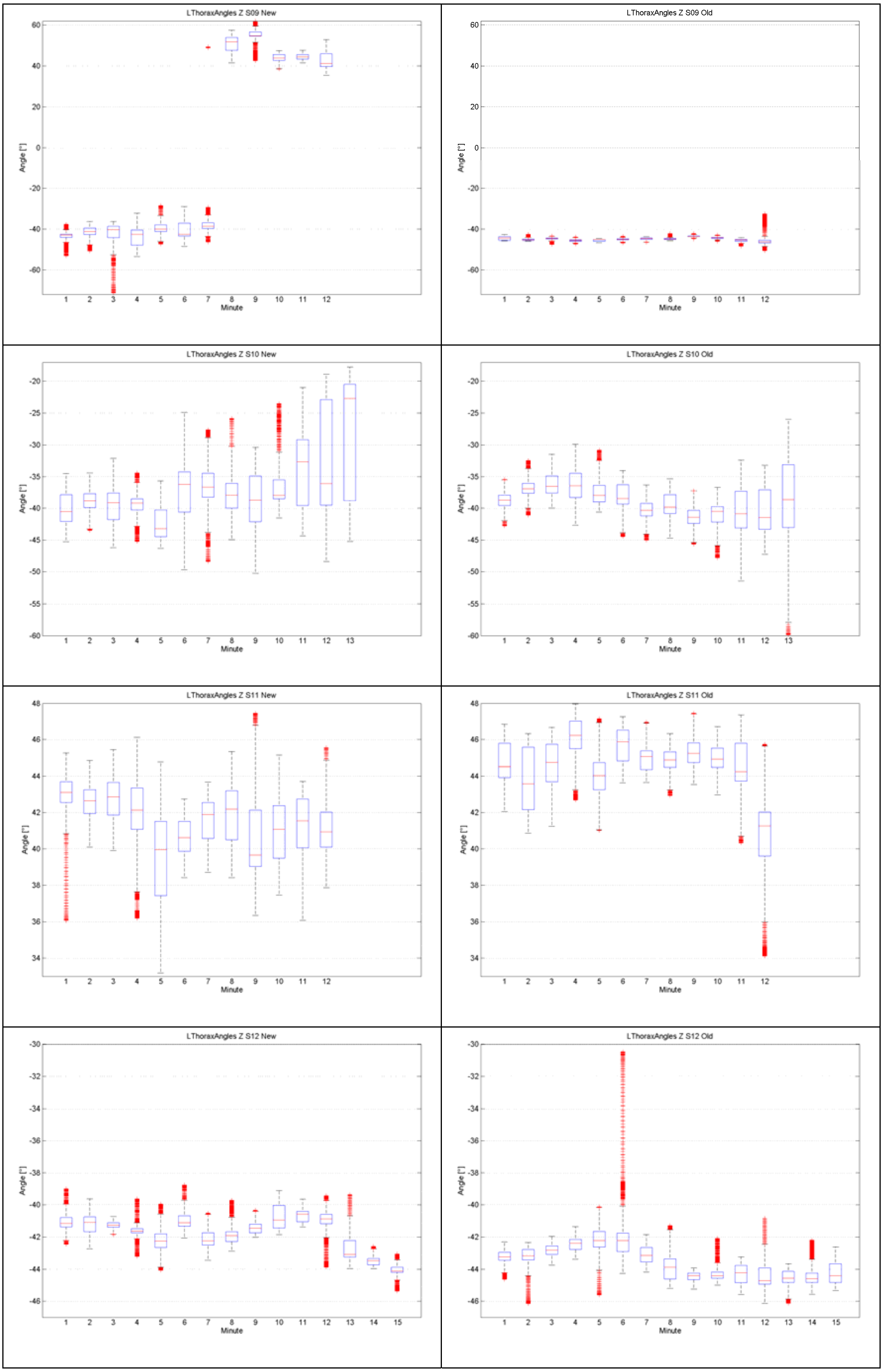
LThoraxAngles Z S04 Old
LThoraxAngles Z S05 New
LThoraxAngles Z S05 Old
LThoraxAngles Z S06 New
LThoraxAngles Z S06 Old
LThoraxAngles Z S07 New
LThoraxAngles Z S07 Old
Angle [°]
Minute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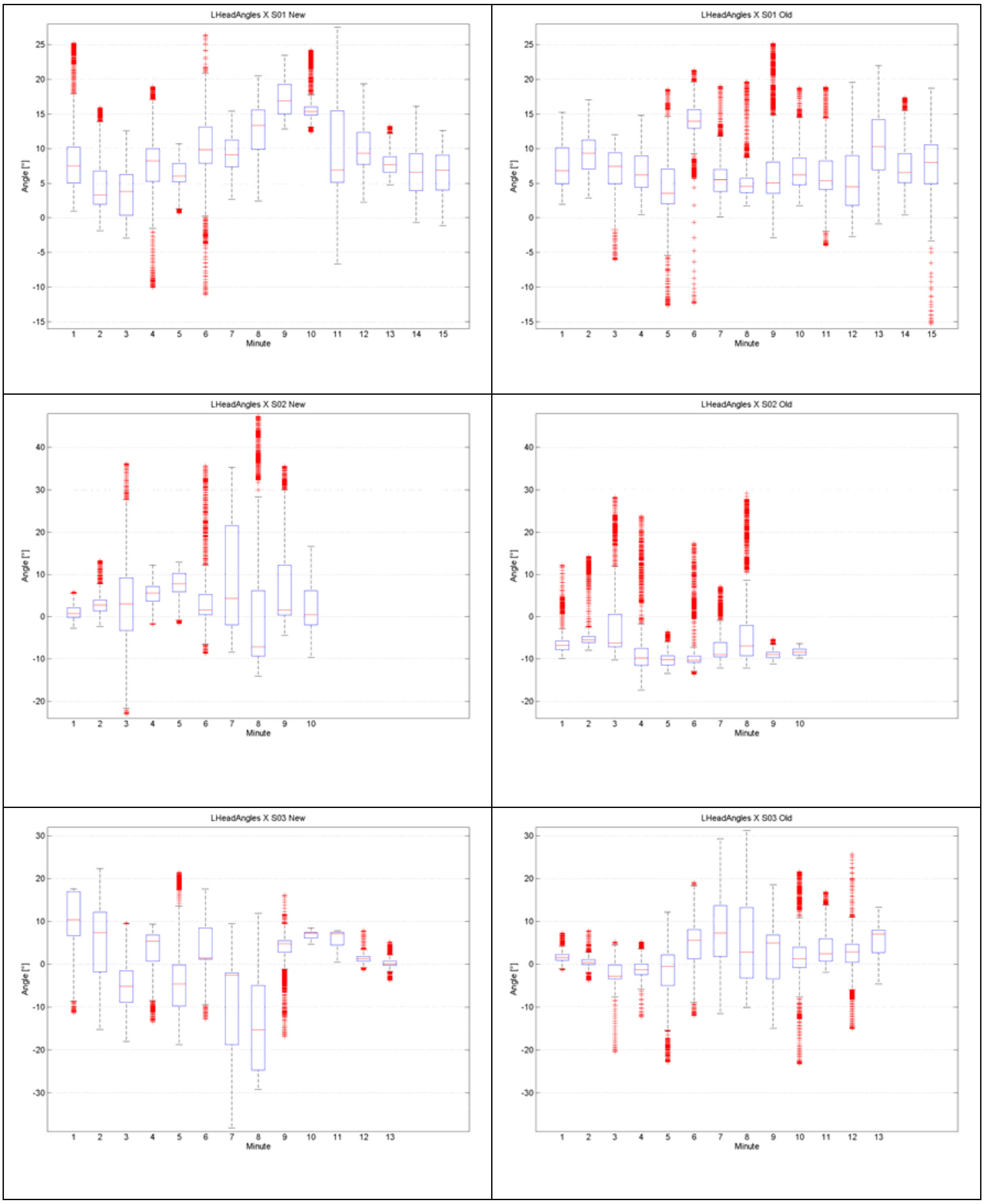
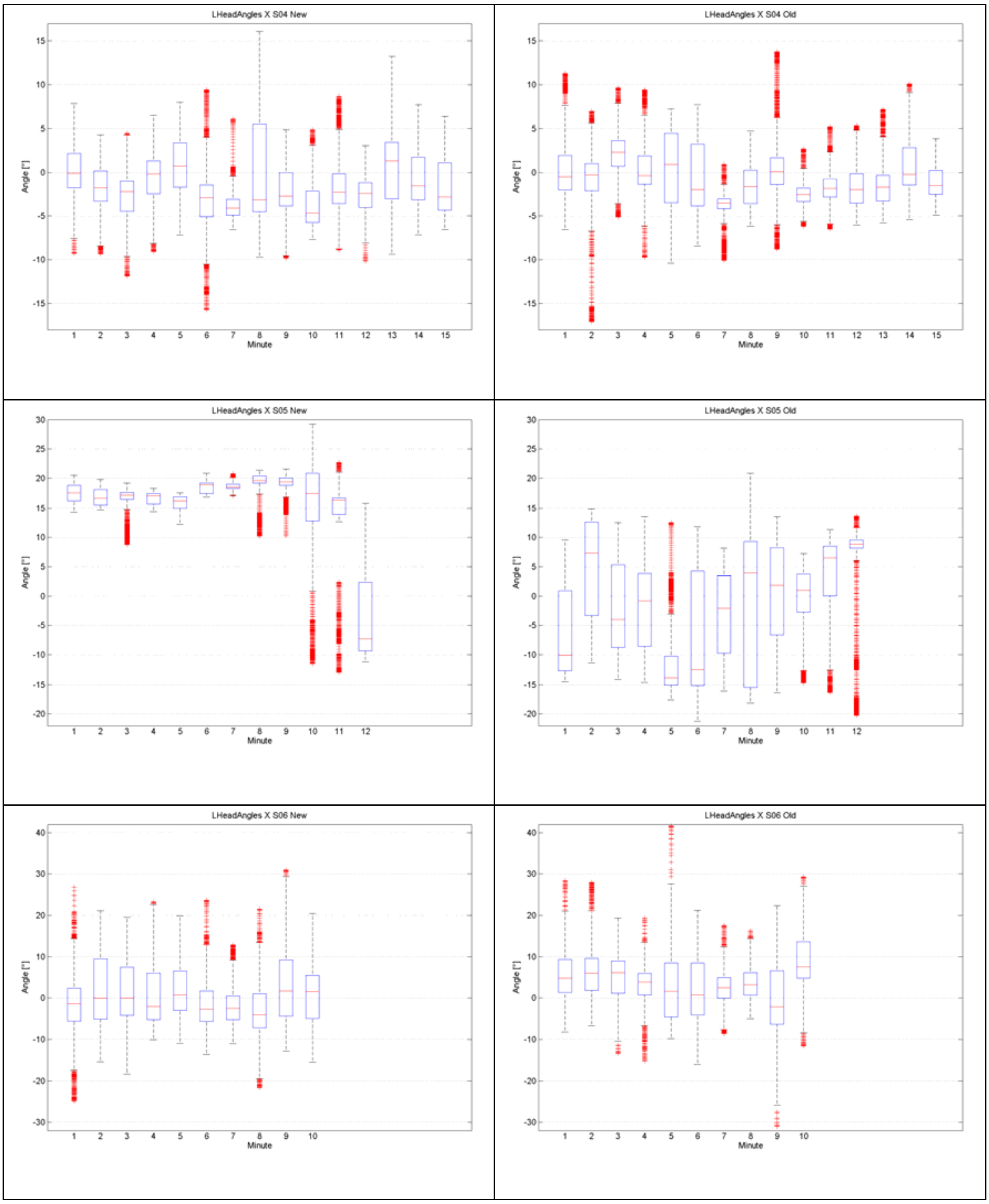
LThoraxAngles Z S10 New
LThoraxAngles Z S10 Old
LThoraxAngles Z S11 New
LThoraxAngles Z S11 Old
LThoraxAngles Z S12 New
LThoraxAngles Z S12 Old
Angle [°]
Minute

Head flexion/extension (X-axis)




LHeadAngles X S04 New
LHeadAngles X S04 Old
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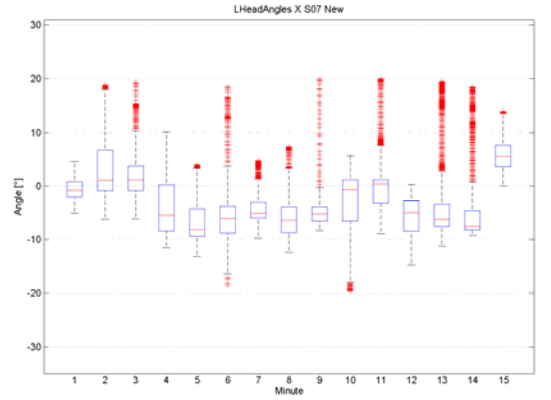
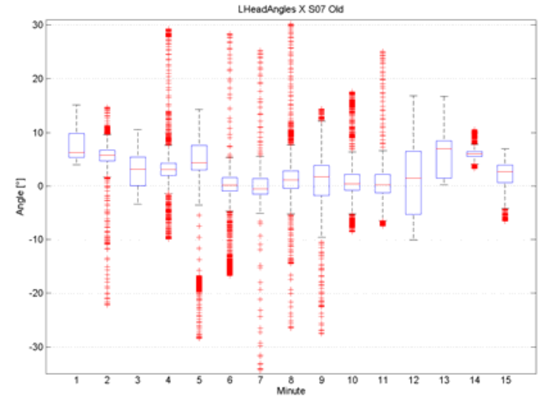
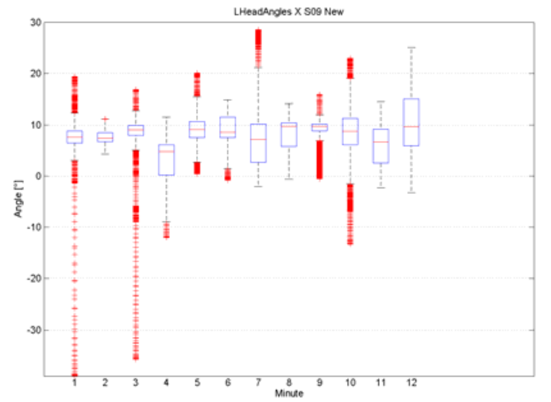
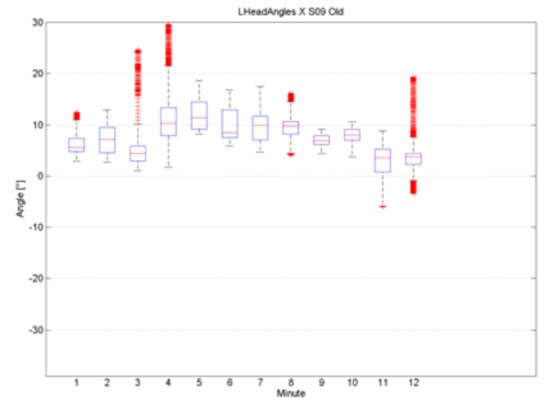
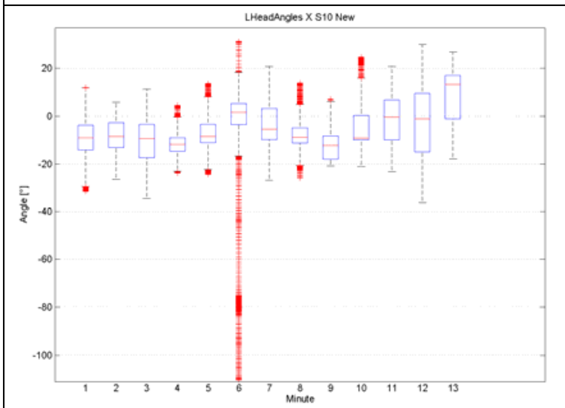
LHeadAngles X S06 Old
Angle [°]
Minute

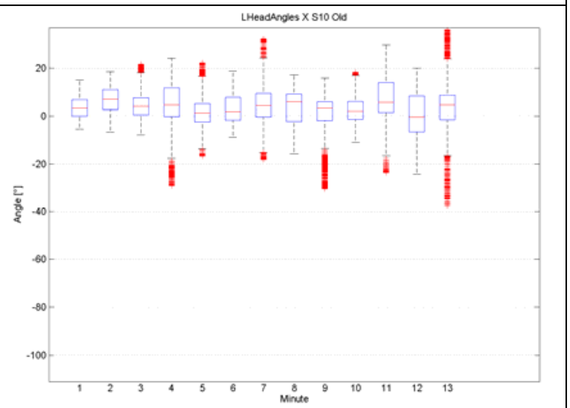

LHeadAngles X S07 New
Angle [°]
Minute

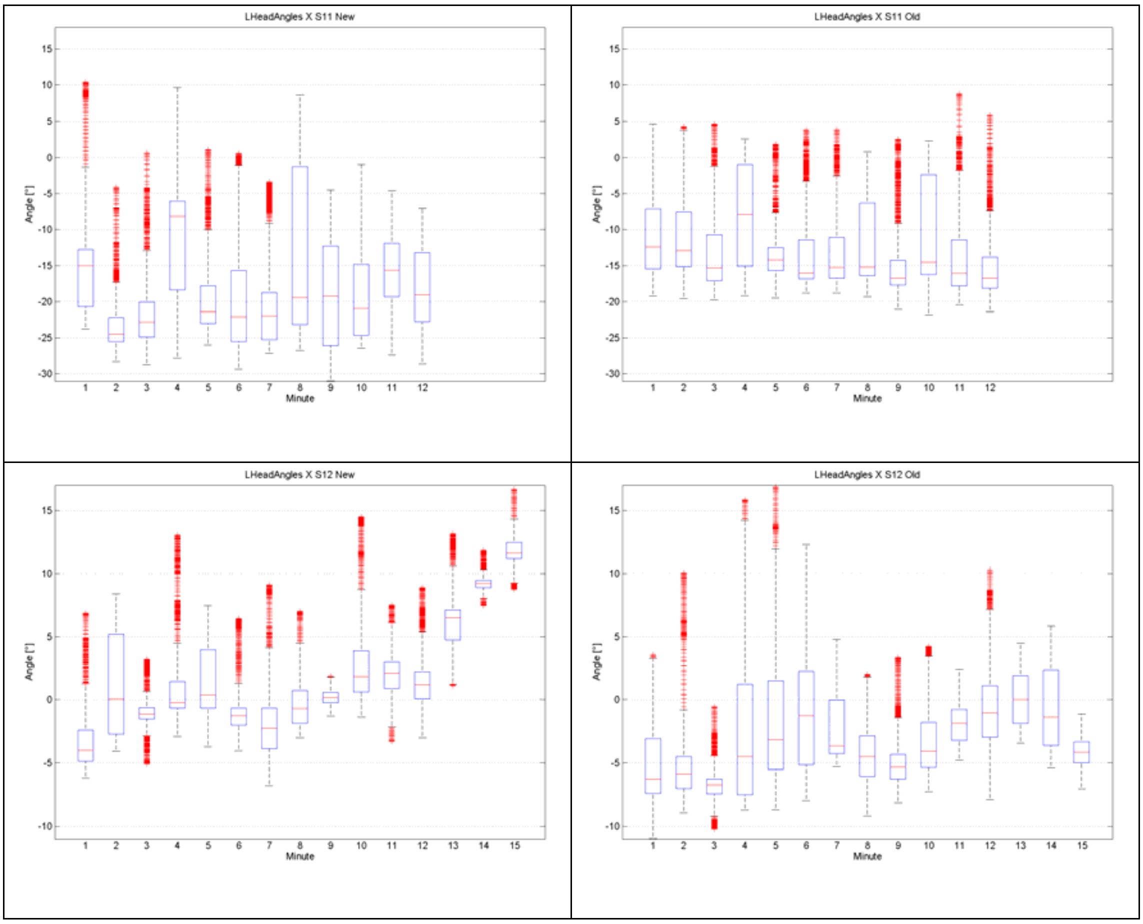

LHeadAngles X S07 Old
Angle [°]
Minute


LHeadAngles X S09 New
Angle [°]
Minute

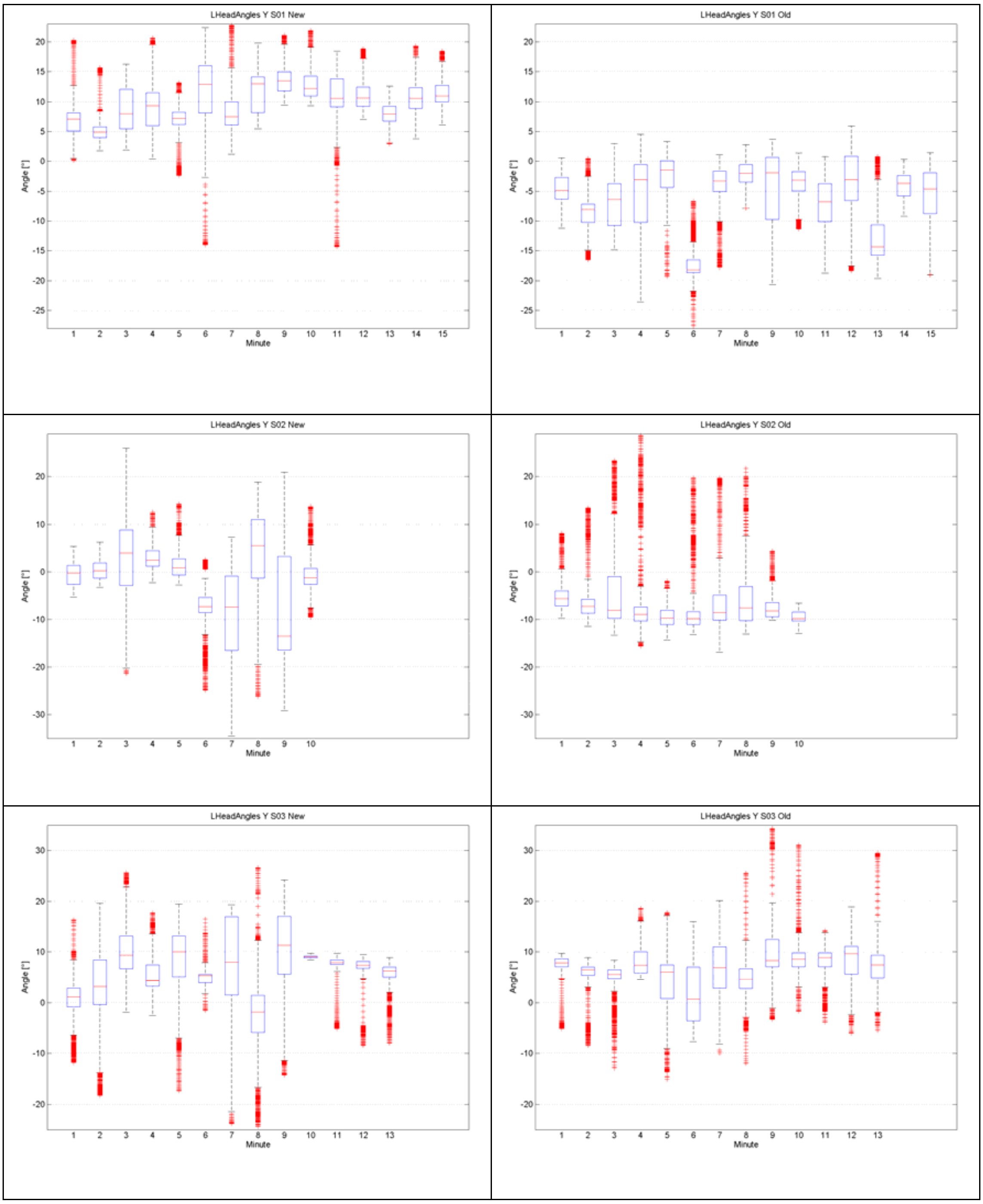

LHeadAngles X S09 Old
Angle [°]
Minute

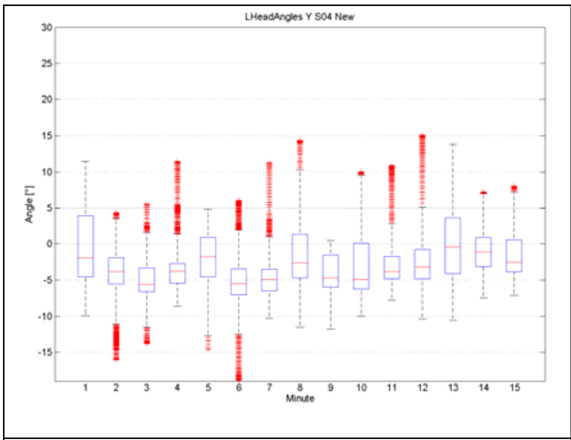

LHeadAngles X S10 New
Angle [°]
Minute

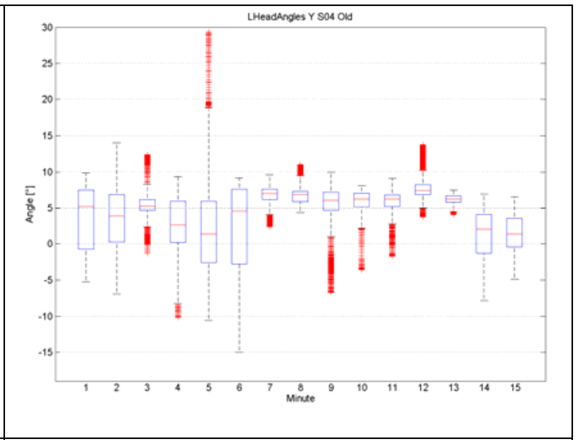

LHeadAngles X S10 Old
Angle [°]
Minute

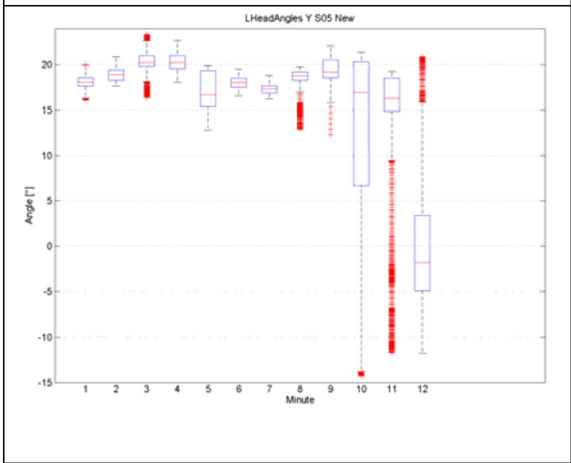

LHeadAngles X S11 New
LHeadAngles X S11 Old
LHeadAngles X S12 New
LHeadAngles X S12 Old
Angle [°]
Minute

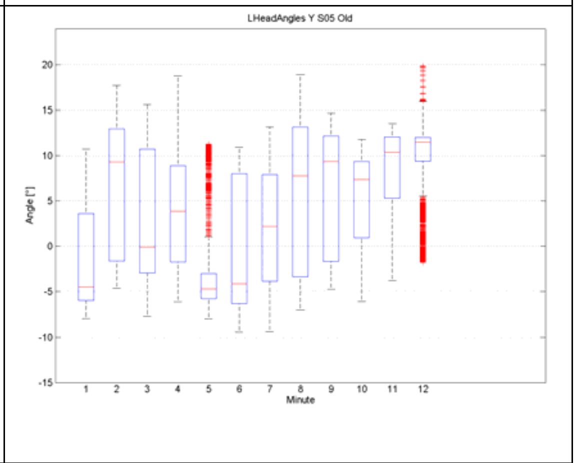
Head side-flexion (Y-axis)

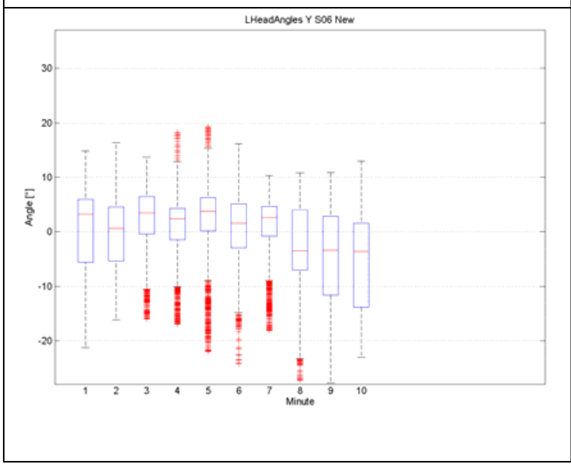


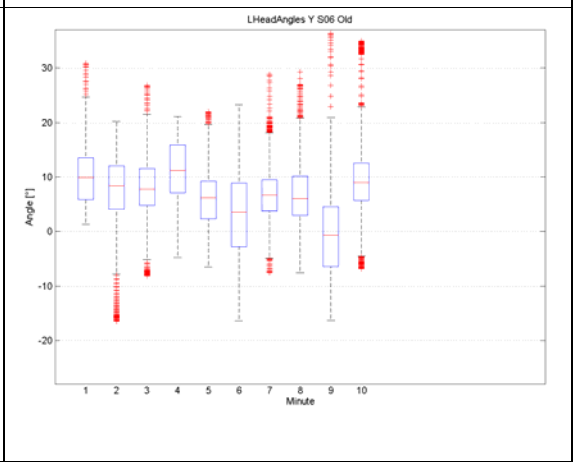

LHeadAngles Y S04 New
Angle [°]
Minute

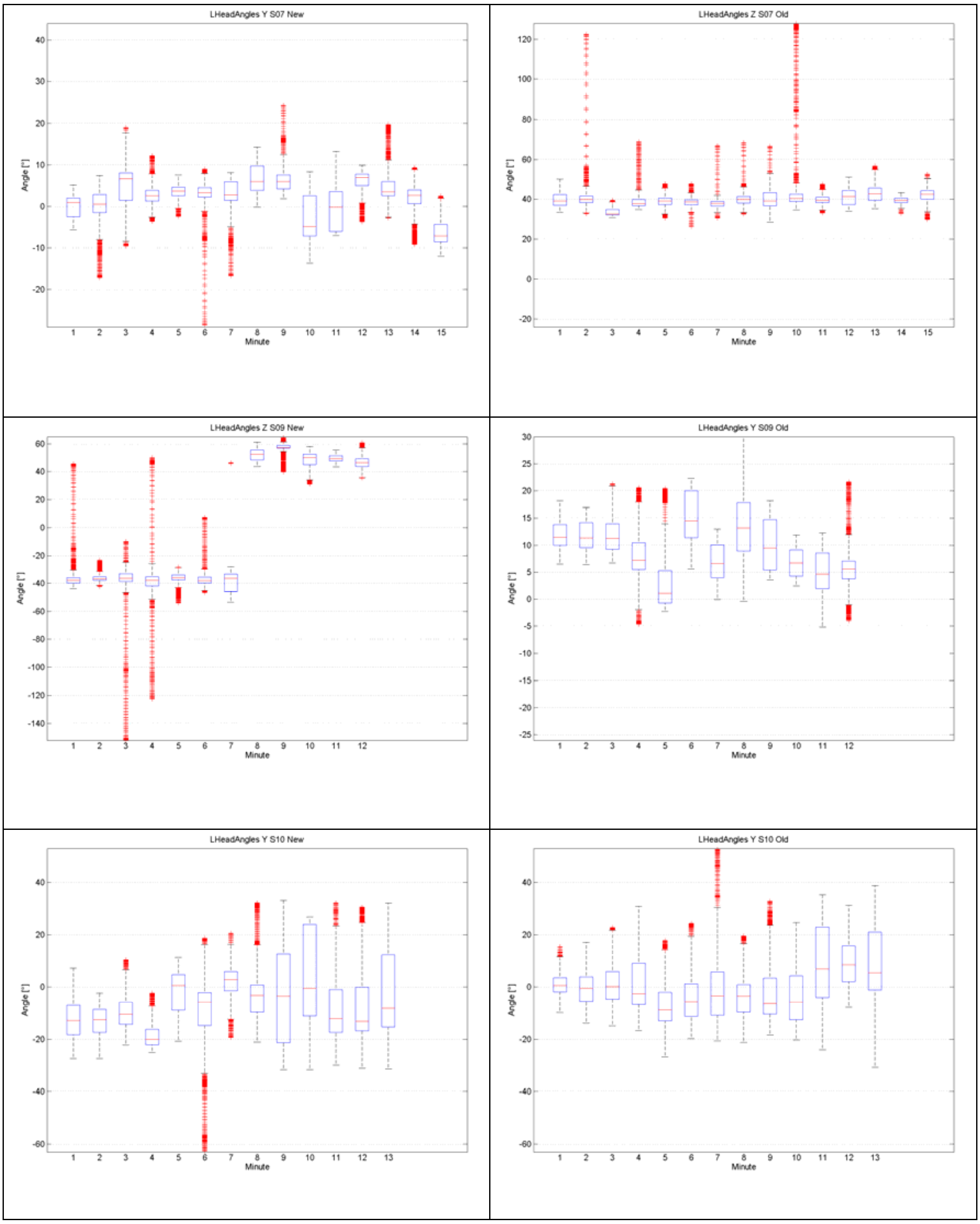

LHeadAngles Y S04 Old
Angle [°]
Minute

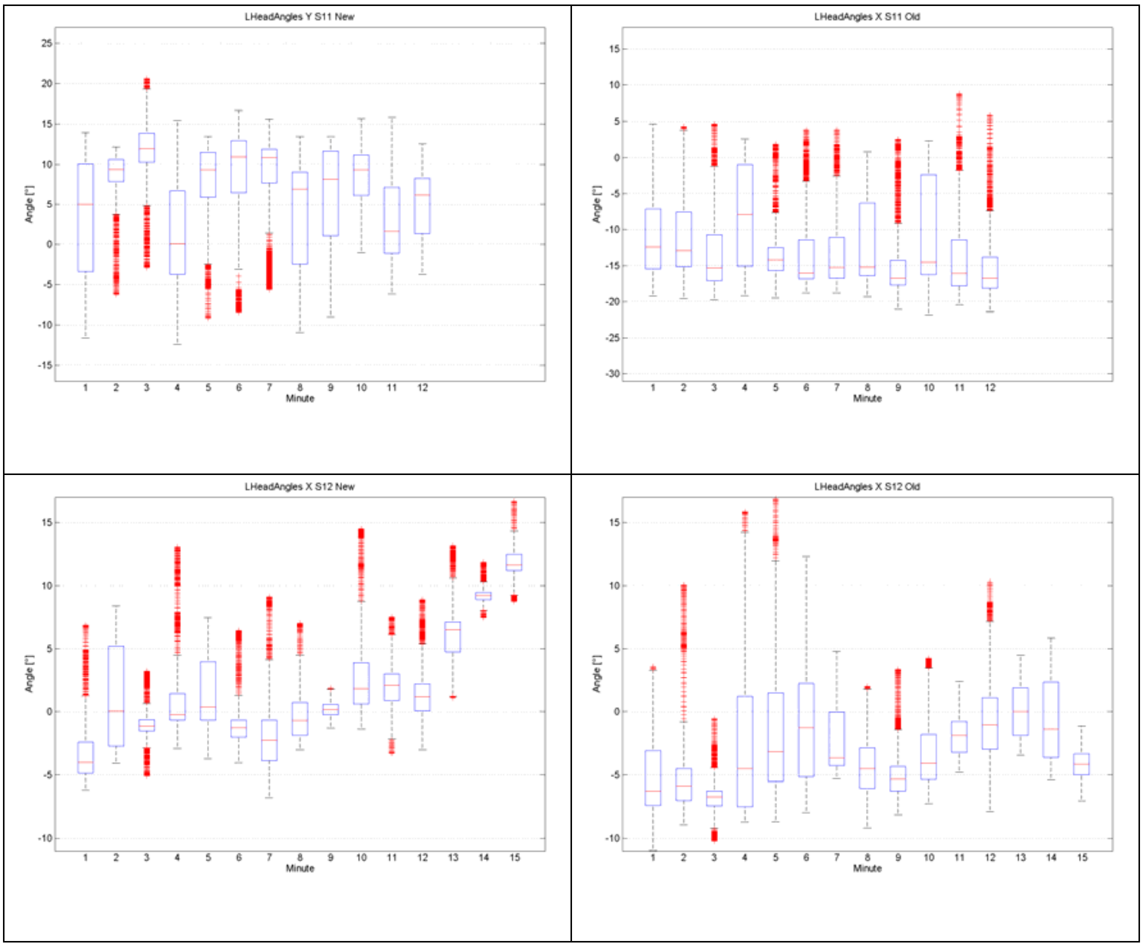

LHeadAngles Y S05 New
Angle [°]
Minute


LHeadAngles Y S05 Old
Angle [°]
Minute


LHeadAngles Y S06 New
Angle [°]
Minute


LHeadAngles Y S06 Old
Angle [°]
Minute


LHeadAngles Y S07 New
LHeadAngles Z S07 Old
LHeadAngles Z S09 New
LHeadAngles Y S09 Old
LHeadAngles Y S10 New
LHeadAngles Y S10 Old
Angle [°]
Minute


LHeadAngles Y S11 New
Angle [°]
Minute
LHeadAngles X S11 Old
Angle [°]
Minute
LHeadAngles X S12 New
Angle [°]
Minute
LHeadAngles X S12 Old
Angle [°]
Minute

Head rotation (Z-axis)