3D measurement of cervical and thoracic postural dynamism in sitting: a pilot study

by

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DECLARATION

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Abstract

The aim of this study was to improve the measurement of postural dynamism in the sitting position using a three-dimensional (3D) motion analysis system. The primary objective was to describe pilot data for postural dynamism of the cervical and thoracic spines while working at a desktop computer. The secondary objective was to refine the process of posture measurement and analysis by decreasing data processing time.

Certain factors in 3D motion analysis can lead to an increase in gaps in data collected during trial capture, which in turn will lead to a longer time of data processing. In the first phase of this study, a number of such factors were identified and altered. A series of pilot studies was performed to test the improvement of data processing time when altering these factors. In the first two pilot studies, camera and tripod positionings were explored and refined, workstation layout and anatomical landmark marker placement were investigated, and optimal capture frequency was established. In both these pilot studies, outcomes were established by means of trial and error by experimenting with a variety of different options for the different outcomes. In the third pilot study, computer software which provides computer tasks for the participant during primary trial capture was tested. Two independent computer users performed all the activities as per software, after which they were required to give oral feedback and suggestions on improvement in terms of user friendliness. The objective of the fourth and final pilot study was to include all of the outcomes from the preceeding pilot studies and attempt a trial run of the actual data collection process. A study participant with no affiliation to the research project was used and a complete trial run was performed after which the measurement process was deemed feasible.

In the primary study, 18 student volunteers completed a sequence of computer tasks, including keyboard, mouse and reading activities. Prior to data capture, full range of motion of the thoracic and cervical spines were measured in three dimensions for every participant. Data capture took place for the full duration of performance of all computer activities. Outcome parameters for postural dynamism included true range of motion (degrees), proportional range of motion (percentage) and motion frequency (movement per minute) in all three planes of motion of the cervical and thoracic spines. Typing tasks were associated with biggest movement ranges and motion frequencies. Mouse activity was associated with the most stationary posture, exhibiting the least frequent movement as well as the smallest ranges of motion.

The results from this study allow us to better understand the dynamic nature of posture, as well as postural dynamism associated with different computer tasks. This study provides a baseline for future research of 3D motion analysis of the sitting posture. It also marks the

need for further research regarding ergonomics, use and potential alternatives in the computer workstation and input devices.

Oorsig

Hierdie studie het ten doel gehad om die meting van posturale dinamisme in die sitposisie te verbeter deur middel van ‘n drie-dimensionele (3D) bewegingsanalisesisteem. Die primêre doelwit was om loodsdata te beskryf vir posturale dinamisme van die servikale en torakale werwelkolomme terwyl op ‘n rekenaar gewerk word. Die sekondêre doelwit was om die proses van postuurmeting en analise te verfyn deur die dataprosesseringstyd te verminder.

Sekere faktore van 3D bewegingsanalise kan ‘n vermeerdering van gapings in ingesamelde data tot gevolg hê, wat weer kan lei na ‘n verlengde tydperiode van dataprosessering. In die eerste fase van hierdie studie is sulke faktore identifiseer en aangepas. ‘n Reeks loodsstudies is uitgevoer om die verbetering van dataprosesseringstyd te toets namate aanpassings aan hierdie faktore gemaak is. Tydens die eerste twee loodsstudies is verskillende kamera en driepoot posisionering ondersoek en verfyn, werkstasie uitleg en anatomiese baken merker plasing is ondersoek en die optimale dataversamelingsfrekwensie is vasgestel. In beide hierdie loodsstudies is die uitkomste vasgestel op grond van toets- en fouteer deur te eksperimenteer met ‘n verskeidenheid opsies soos van toepassing op die betrokke uitkomste. Tydens die derde loodsstudie is rekenaarsagteware getoets wat die rekenaaraktiwiteit vir die studiedeelnemers verskaf het tydens primêre data-insameling. Twee onafhanklike persone het al die aktiwiteite volgens die sagteware voltooi en het verbale terugvoer en aanbevelings gegee oor hoe om die program te verbeter. Die vierdie en finale loodsstudie het gepoog om al die uitkomste van die eerste drie loodsstudies in te sluit en ‘n toetsmeting te doen van die ware dataversamelingsproses. ‘n Onafhanklike studiedeelnemer met geen affiliasie tot die navorsingsprojek nie het ‘n toetslopie van die hele versamelingsproses gedoen en die metingsproses is haalbaar verklaar.

Tydens die primêre studie het 18 student-vrywilligers ‘n reeks rekenaartake gedoen (insluitend sleutelbord en muisaktiwiteite sowel as ‘n leesopdrag). Voor die aanvang van dataversameling is die volle bewegingsomvange van die torakale en servikale werwelkolomme van elke deelnemer gemeet. Dataversameling is vir die volle durasie van die uitvoer van rekenaaraktiwiteite gedoen. Uitkomsparameters vir posturale dinamisme het die volgende ingesluit: Omvang van beweging (grade), proporsionele omvang van beweging (persentasie) en bewegingsfrekwensie (bewegings per minuut) in al drie bewegingsvlakke van die servikale en torakale werwelkolomme. Sleutelbord-aktiwiteite is geässosieer met die grootste bewegingsomvange en die meeste bewegingsfrekwensie. Muisaktiwiteit is geässosieer met die mees stasionêre postuur en het die heel minste gereelde beweging getoon in die algemeen.

Die resultate van hierdie studie help om die dinamise natuur van postuur beter te verstaan, sowel as posturale dinamisme wat met verskillende rekenaartake verbind word. Die studie bied ‘n basislyn vir die toekomstige navorsings wat posturale dinamisme met verskillende rekenaartake meet. Dit merk ook die behoefte aan verdere navorsing aangaande ergonomika, gebruik en alternatiewe tot rekenaarwerkstasie en –toerusting.

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CHAPTER 1 : INTRODUCTION

1.1 Background

Sitting is one of the most common positions in workforces worldwide. An estimated 75 % of all workers in industrialised countries spend their working days in sedentary positions (Pynt et al., 2008). Much of sitting in the workplace is committed to computer use (IJmker et al., 2007). In 2007, more than 40 % of all employees in the European Union were working on a daily basis at sedentary workstations with visual display units (Ellegast et al., 2012). According to an American time-use survey, workers in sedentary occupations spend as many as 11 hours per day in the sitting position. Developing countries have also shown an increase in daily computer use. A South African-based study found a median of 8.5 computing hours per week in a school-going population, with more than 50 % of children not having daily computer access (Smith et al., 2009). No literature is available to report on the prevalance of computer use in the adult South African population.

Sitting for prolonged periods is associated with a variety of musculoskeletal disorders of the spine (Caneiro et al., 2010; Claus et al., 2009; Kuo et al., 2009; Lis et al., 2007; Mork and Westgaard, 2009; Prins et al., 2008; Smith et al., 2009). Prolonged sitting often results in a static posture, with infrequent involuntary postural changes (termed as postural dynamism) during the time period of sitting (Geldhof et al., 2007). Decreased postural dynamism whilst sitting is associated with increased pressure on intervertebral discs, leading to spinal musculoskeletal pain and long-term disc degeneration (Pynt et al., 2008). Prolonged periods of sitting are also associated with end-range angles of the vertebral column (Annetts et al., 2012), which may result in back pain due to spinal muscle imbalances (O'Sullivan et al., 2006) and soft tissue strain (Callaghan and Dunk, 2002). Frequent sitting for prolonged time periods therefore puts the individual at high risk for frequent spinal pain and discomfort, which may result in longstanding musculoskeletal disorders.

Frequent musculoskeletal pain decreases quality of life for several reasons. Apart from the physical discomfort, the incidence of pain can hold significant occupational time and cost implications (Stewart et al., 2003). Pain is known to contribute to decreased productivity (McDonald et al., 2011) and increased absenteeism with subsequent loss of productive time in the workplace (Goetzel et al., 2004; Stewart et al., 2003). The identification and elimination of risk elements for musculoskeletal pain can thus add significant value to the financial welfare in the workplace.

Accurate sitting posture analysis may provide information about specific postural aspects that contribute to pain associated with sitting. Clinical postural measurement is commonly based on observational methods such as the use of a grid and plumb line (Gadotti and Biasotto-Gonzalez, 2010).   Posture analysis by observation is not based on concrete, quantitative data and is therefore not considered to be sound for scientific measurement. Also, a comprehensive representation of postural dynamism over time is not represented. For research purposes, the use of a reliable and valid objective posture measuring tool is imperative. Opto-electical 3D motion analysis systems are currently the measuring tools of choice in epidemiological motion analysis studies worldwide (Culmer et al., 2009). These systems allow for the analysis and description of human movements in all three planes of motion; they can provide an accurate and comprehensive representation of motion from the precise positional data measured (Brink et al., 2011) and can operate over ranges of several meters in size (Culmer et al., 2009). The Vicon Motion Analysis System (Oxford, United Kingdom) is currently used for human movement analysis studies at the Stellenbosch University FNB 3D Motion Analysis Laboratory. However, a number of limitations restrict the use of 3D motion analysis systems in the clinical field. These include inaccessibility in the field (studies need to be laboratory-based due to the size of the system), expensive operation, the need for specialised technicians and complexity of data processing.

The prolonged time period required for data processing was identified as a limiting factor in an ongoing series of posture studies at the Stellenbosch University. Data processing time refers to the total time needed to process camera input data in the software used for processing into raw anthropometric data. Poor camera visibility of reflective anatomical surface markers may account for much of the time consumption of data processing. Momentary occlusion of markers during trial capture leads to gaps in the data. The accommodation and correction of these gaps, which is manually performed by the technician during data processing, is a very time-consuming process. Therefore, the optimisation of marker visibility during the entire trial capture would minimise the amount of gaps in the data, resulting in shorter time periods necessary for data processing.

The limitations mentioned above should continuously be improved in order to increase the validity and reliability of 3D motion analysis systems as measurement tools in epidemiological studies and, ultimately, in the clinical setup. By improving the feasibility of posture analysis, we strive to obtain a more accurate and valid replication of posture in the every-day environment. These methods may then reinforce investigation into musculoskeletal pain related to prolonged sitting.

1.2 Aim of the study

This study served as the third phase in a series of posture studies done at the Stellenbosch University FNB Motion Analysis Laboratory. The aim of the study was to improve the 3D measurement of postural dynamism using a camera-based motion analysis system.

1.3 Objectives of the study

The primary objective of this study was to process, analyse and describe pilot 3D spinal kinematic data for postural dynamism by performing typical computer tasks on a desktop computer.

The secondary objective was to optimise the assessment of postural dynamism while sitting at a computer workstation by improving marker visibility and reducing data processing time by:

- strategic positioning of the Vicon cameras during data capture;
- setting up the computer workstation in such a manner to avoid obstruction of marker visibility.

1.4. Outline of dissertation

Below is a flowchart of the dissertation outline (Figure 1.1). The contents will be discussed in two separate sections, which will focus on the feasibility of 3D posture measurement and postural dynamism in various computer tasks.

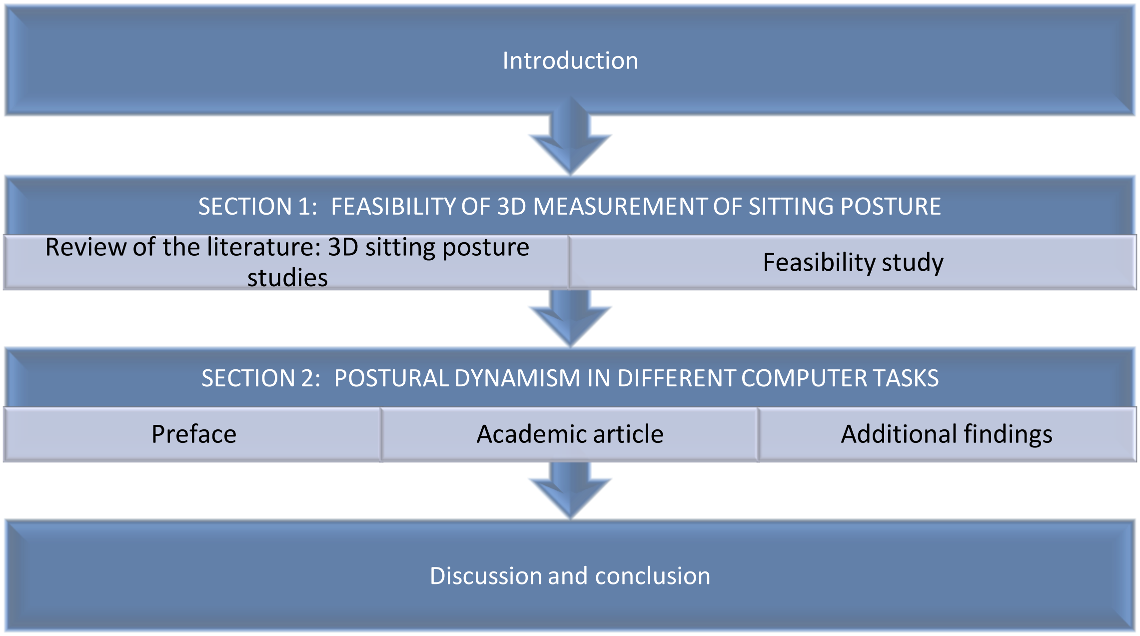


Figure 1.1: Outline of dissertation

CHAPTER 2 : LITERATURE REVIEW

Musculoskeletal pain is often associated with postural impairments (Fortin et al., 2011). Sitting posture has been identified as a possible risk factor for musculoskeletal pain when sustaining the position for a prolonged period of time (Caneiro et al., 2010; Claus et al., 2009; Kuo et al., 2009; Lis et al., 2007). Evaluation of posture plays an important role in the physical examination process of patients with musculoskeletal pain and can provide useful information about the potential pain-promoting factors exhibited in the sedentary position (Bullock-Saxton, 1993). Accurate and objective posture evaluation also aids in establishing an objective parameter to monitor the effectiveness of treatment (Fortin et al., 2011). Currently, clinical posture evaluation is mostly based on subjective measurements; a well-known example being the postural grid and plumb line (Gadotti and Biasotto-Gonzalez, 2010). However, subjective measurements as such cannot be quantified as reliable and valid (Fortin et al., 2011), and by implication, are not scientifically suitable for facilitating diagnosis or montoring patient response to treatment (Brink et al., 2011).

Three-dimensional motion analysis systems (3DMAS) are laboratory-based measurement tools that can accurately analyse human movement in all three planes of motion (i.e. saggital, horizontal and frontal). These motion analysis systems are renowned for their precision of measurement (Brink et al., 2011) as well as their ability to detect subtle task differences, integrate display and measurement, and provide information that allows the user to differentiate between pathological and healthy movements (Culmer et al., 2009).These systems are increasingly being used in clinical and research trials for a variety of human movement studies (McGinley et al., 2009).

The aim of this review is to investigate the different methodologies and outcomes in sitting posture studies using 3DMAS as measuring tools. A literature seach was done using the search engines Pubmed, CINAHL and Scopus. Keywords used included combinations of ‘sitting posture’, ‘posture’, ‘motion analysis’ and derivitaves of ‘measure’ – and they excluded the terms ‘gait’ and ‘walk’. A total of 150 hits were made. These results were manually filtered to only include studies in which opto-electrical motion analysis systems were used to measure three-dimensional sitting posture. A number of relevant articles were also found by means of pearling.

Ten sitting posture analysis studies were identified for review. The selected papers report on studies that are closely related to the current study and are used to guide this study in the different domains of measures used. The methodologies used in these studies are discussed in terms of aims and objectives, activities during trial capture, specific motion analysis systems used, experimental setup, marker placement, data processing and statistical analysis. The review is concluded with a summary of limitations and recommendations identified in the various studies.

2.1 Study aims, designs and activity during trial capture

The aims and objectives of measurement studies can determine the rest of the methodological structure of a study to a great extent. Table 2.1 illustrates the wide variety of observational research studies in which opto-electrical motion analysis systems have been used. These range from a case study (Hansson and Oberg, 1996) and feasibility study (Lissoni et al., 2001) to cross-sectional (Sheeran et al., 2012, Szeto et al., 2005), repeated measures (Edmondston et al., 2007; Gold et al., 2012; Preuss and Popovic, 2010; Straker et al., 2009, 2008) and a single-session concurrent validation (O'Sullivan et al., 2012b) study designs. No randomised control trials could be found for 3D sitting posture studies using an opto-electrical motion analysis system, this is possibly due to the the cost-implication and practical limitations of laboratory-based research on a bigger, more representative sample. Good quality observational studies can serve as pilot trials in the formulation of future normative research or randomised control trials studying 3D sitting posture.

Time periods of trial capture in all of these studies were rather short, the highest being three minutes per single capture (Gold et al., 2012). Trial capture of longer time periods results in excessive amounts of data to be processed, which may decrease the cost- and time-efficiency of the research study. However, by capturing only relatively short trial captures per task, the chances for a realistic representation of the task is limited. Also, the continuous effect that a prolonged time period per task may have on the posture will not be represented in short sequences of data. In the studies performed by Straker et al. (2008) and Szeto et al. (2005), short trial captures were done at different time periods within the activity in order to gain data that may be more representative of kinematics associated with the activity. In contrast, O'Sullivan et al. (2012) and Gold et al. (2012) captured data only in the middle of the activity, wheras Straker et al. (2009) did trial capture in the last two minutes of the activity. Data as such can be collected to study a specific time period within a given task, but may not provide an accurate and comprehensive picture of the task as a whole.

Table 2.1: Aims, activity and data capture

Author	Aim of study and sample size (n)	Activity	Time period of data capture
Edmondston et al., 2007	Examining the effect of posture on thoracic rotation and coupled flexion (n = 52).	Moving from a neutral sitting position to full thoracic flexion, then full thoracic extension and then full range of rotation to alternating sides.	Each movement was captured entirely through full range of motion, with the starting point at neutral thoracic position.
Gold et al., 2012	Quantitatively defining sitting posture when working on a laptop computer, NOT being deskbound (n = 20).	Typing and editing tasks on the computer for the duration of seven minutes per task, in the following three positions: • seated on the couch with the feet supported on the floor • long-sitting on the couch with feet supported on a footrest • prone puppy position.	Data capture took place for three minutes (starting at the 3rd minute) in every task.
Hansson and Oberg, 1996	Developing a method for sitting posture analysis (n = 1).	Performing two different actions in sitting in a simulated tractor cockpit: • manoeuvring a gear lever with the right hand • manoeuvring the steering wheel with the right hand.	Not specified
Lissoni et al., 2001	Developing a model and protocol for the 3D measurement of sitting posture (n = 15).	Active full range of motion of inclination and rotation of the pelvis, shoulder and head	Each movement was captured entirely through full range of motion.
O'Sullivan et al., 2012	Testing the validity of a wireless posture monitor (n = 12).	Reading, typing and writing (30 seconds spent per task).	Five seconds were captured 'around the middle' of each task.

Preuss and Popovic, 2010	Assessing 3D spinal motion during multi-directional target-directed trunk movements (n = 11).	Retro=reflective markers suspended from the roof hanging around subject at different subject-specific heights; subject was required to attempt to touch target markers with his/her head.	Three trials captured at different heights per target distance, captured entirely through full range of motion.
Sheeran et al., 2012	Comparing of position sense and trunk muscle in two positions, in patients with non-specific chronic lower back pain (for this review, focusing only on sitting-related trial capture) (n = 90).	Subjects were blindfolded and positioned on a chair, with the following tasks requested: • move through the full spinal range of motion in the sagittal plane of motion for three consecutive times • subject positioned in a neutral lumbothoracic position and requested to memorise the position in five seconds • reposition from relaxed position to neutral lumbothoracic position – four trials, five-second rest periods in between.	Not specified
Straker et al., 2008	Assessing the effect of the height of a visual display unit as well as forearm support on the postures of the shoulder, neck and head, using both computer and paper technologies (n = 36).	Reading, mouse work and typewriting or filling out a form as well as active, directed movements. Six tasks performed – ten minutes each with a five-minute break between tasks.	Data capture done for 120 seconds at three different intervals, starting on the 2nd minute, the 5th minute and the 9th minute.
Straker et al., 2009	Comparing the effect of the use of computer and paper word-processing technology on the posture of children (n = 24).	Reading from an encyclopaedia and filling out a form, either manually or electronically – three tasks of ten minutes each.	Data capture took place in the last two minutes of each task.
Szeto et al., 2005	Determining the relationship between the kinematics, muscle activity and muscle fatigue of the neck and the shoulder in sedentary office workers (n = 43).	One hour of typing on a desktop computer.	A 60-second data capture was done at the 5th, 20th, 35th, 50th and 60th minutes of the typing task.

2.2 Motion Analysis Systems

Opto-electrical motion analysis systems are currently the measuring tools of choice in many epidemiological motion analysis studies (Culmer et al., 2009). Retroreflective markers are attached to anatomical landmarks on the body of the subject. Infrared-emitting cameras reflect light upon the markers and camera views are combined to derive three-dimensional positions of each marker in a system-based cartesian plane. Table 2.2 offers a summary of the motion analysis systems used in the different studies as well as a brief description of the basic principal of operation for each system as stated in each research paper. Different models of the Vicon and Peak Motus motion analysis systems were the most commonly used systems in these studies. No standard numbers of camera units were used per system. According to Ehara et al. (1995), the Vicon 370, Elite and the Peak Motus systems can accommodate a maximum of 30, 100 and 35 camera units respectively. The number of cameras used in these studies may have been determined either by the number of cameras available in the study setting or the specific segments studied as per study aim. Conversely, capturing frequencies are often determined by predefined system frequencies. For example, according to the study by Ehara et al. (1995), the Vicon is set to capture at frequencies of 50, 60, 120 or 200 Hz (refer to the studies by Preuss et al. (2010) and Szeto et al. (2005) in Table 2.2). Similarly, the Elite is preset to capture at frequencies of either 50 or 100 Hz (in the studies discussed, Lissoni et al. (2001) captured data at 100 Hz). The higher the capture frequency, the better the quality of the data; however, higher frequency implies a higher data load. When slower movements are studied (such as movement in the sitting posture), data captured at lower frequencies will still be sufficient for accurate analysis.

Table 2.2 Opto-electrical motion analysis systems used

Author	Opto-electrical system	Basic description of operation	Nr. of cameras	Software used	Capture frequency
Edmondston et al., 2007	Peak Motus (Peak Performance TechnologiesInc., Centennial, CO, USA)	Infrared-emitting cameras were used, reflecting upon markers adjusted to the subject.	Four	Peak Motus version 8.2	50 Hz
Gold et al., 2012	Qualysis AB (Gothenburg, Sweden)	Infrared-emitting cameras were used, reflecting upon markers adjusted to the subject.	Five	Qualysis track manager version 2.0; MaxTRAQ version 2.21; MaxMATE 3.6E	60 Hz
Hansson and Oberg, 1996	Mac-Reflex (Qualysis, 1993 – place of manufacture not stated)	Infrared-emitting cameras were used, reflecting upon markers adjusted to the subject.	Two	Mac-Reflex; Matlab (The Mathworks Inc.)	50 Hz
Lissoni et al., 2001	ELITE (BTS Milan)	Infrared emitted by CCD TV cameras was used, reflecting upon markers adjusted to the subject.	Six	Not specified	100 Hz
O'Sullivan et al., 2012	Cartesion Opto-electronic Dynamic Anthropometer (CODA) (Charnwood Dynamics Ltd, Leicestershire, UK)	Pre-calibrated motion analysis system, using a laboratory-based coordinate system.	Two	CODA	200 Hz
Preuss and Popovic,	Vicon 512 (Vicon Motion System Ltd., Oxford, UK)	No further specifications provided.	Six	Vicon Bodybuilder	120 Hz

2010					
Sheeran et al., 2012	Vicon 512 (Vicon Motion Systems Ltd., Oxford, UK)	No further specifications provided.	Not specified	Matlab 7.0	Not specified
Straker et al., 2008	Peak Motus passive reflector analysis system (Chattanooga, USA)	Infrared-emitting cameras used, reflecting upon markers adjusted to the subject.	Seven	Not specified	50
Straker et al., 2009	Peak Motus (Peak Performance Technologies Inc., Centennial, CO, USA)	Infrared-emitting cameras used, reflecting upon markers adjusted to the subject.	Seven	Not specified	50 Hz
Szeto et al., 2005	Vicon 370, Version 3.1 (Oxford Metrics, UK)	Infrared-emitting cameras were used, reflecting upon markers adjusted to the subject.	Six	Vicon Bodybuilder; Labview	60 Hz

2.3 Experimental setup

The experimental setup is summarised according to subject setup and camera positioning (Table 2.3). A brief review of camera calibration is also included. The experimental setup is often performed in the context of the aims and objectives of the study. For example, Hansson and Oberg (1996) studied movement and forces generated by a tractor driver; therefore, for the experimental setup, an artificial tractor cockpit was devised. Similar trends are seen in the studies by Gold et al. (2012), Lissoni et al. (2001), Straker et al. (2009, 2008) and Szeto et al. (2005). Simple and undetailed subject setups are described in the validity study by O'Sullivan et al. (2012) as well as movement studies that were not performed specific to context (Edmonston al., 2007; Preuss and Popovic, 2009: Sheeran et al., 2012).

Table 2.3: Subject setup, camera positioning and calibration

Author	**Subject setup**	**Camera positioning and calibration**
Edmondston et al., 2007	Subject positioned on stool with hips and knees at 90 degrees flexion, 90 degrees glenohumeral abduction with hands on the shoulders and the pelvis secured to chair by means of a seatbelt.	Cameras positioned in dual ring setup, four cameras at 2-meter height in an 8-meter diameter ring around subject and three cameras in a 4-meter ring overhead. No note on calibration.
Gold et al., 2012	Trials performed in three positions: 1) long-sitting on a couch, feet supported; laptop on lap; 2) sitting on a couch, feet on floor, laptop on lap; 3) prone, supporting on elbows; laptop on surface in front of subject.	Cameras positioned and average of 2.53 meters away from subject. All cameras passed calibration, but detail of calibration process not specified.
Hansson and Oberg, 1996	Laboratory-based simulated tractor cockpit (no further specifications mentioned).	Two cameras mounted in front of subject at 45 degrees to horizontal plane and ± 30 degrees to sagittal plane. Calibration done by means of calibration frame with six markers with known internal distances.

Lissoni et al., 2001	Subject sat on a modified chair with no backrest, clamps supporting around the trunk, adjustable footrest and tiltable seat.	Three cameras behind and three in front of subject. Calibration done prior to capturing by moving one-meter bar with two markers on each end through calibration volume (1.8 m x 1.8 m x 1.4 m) for a duration of 30 seconds.
O'Sullivan et al., 2012	Subject positioned on stool (no further specifications).	Two cameras placed 80 cm apart, 2.2 m posteriolateral to subject. Calibration process not noted.
Preuss and Popovic, 2010	Subject sat on an elevated rigid surface, thighs supported to 75% of the distance from the greater trochanter to the femoral lateral epicondyle; legs hanging freely; no further support or constraints.	No specifications on either camera position or calibration.
Sheeran et al., 2012	Subject positioned on a stool with legs shoulder-width apart and hands on thighs.	No specifications on either camera positioning or calibration.
Straker et al., 2008	Compared two workstations: 1) height of surface 3 cm below elbow at 0 degrees shoulder flexion. 2) Horse-shoe shaped desk, curved, height of surface 3 cm below elbow. Trial capture done at different visual display unit (VDU) heights. Chair adjusted to popliteal height..	Camera position not specified. Calibration done with 916 mm rod and a standard deviation of < 5 mm was found. No further detail on calibration process.
Straker et al., 2009	Height-adjustable office chair, adjusted to popliteal height; common desk (measurements not specified).	No specifications on either camera position or calibration.
Szeto et al., 2005	Common desk (measurements not specified), chair, VDU and keyboard; subject was instructed to adjust screen, keyboard and chair to comfortable level.	Static and dynamic calibration done prior to study in order to orientate the cameras with the laboratory coordinate system. No exact detail on camera positioning or calibration.

2.4 Marker placement

The appropriate and accurate placement of anatomical markers is very important in order to effectively and accurately define segmental movement. Furthermore, standardised marker placement over a series of studies will assure good reliability of the measuring tool. The dependence on a clear line-of-sight between the cameras and markers is identified as a drawback in the use of opto-electrical motion analysis systems, which can be improved by means of accurate marker placement (Culmer et al., 2009). Marker placement in the different studies is summarised in Table 2.4. The marker placement as performed in the studies by O'Sullivan et al. (2012) and Hansson and Oberg (1996) were according to a standardised model for the specific motion analysis systems used. In other studies, the markers were positioned as to define the specific body segment studied, as summarised in Table 4 (Edmontston et al., 2007; Gold et al., 2012; Lissoni et al., 2001; Preuss and Povovic, 2009; Szeto et al., 2009). Marker positioning can thus rely on a number of factors, including a system-specific protocol, research protocol or the definition of a specific body segment studied.

Table 2.4: Marker placement

Author	Marker placement	Determinants of marker placement
Edmonston et al., 2007	Transverse process of T6 (bilateral) and costochondral junction at 6th rib (bilateral)	Defining anterior and posterior midpoints of the thorax
	Spinous processes of T6, T10 and T12	Assisting with differentiation between anterior and posterior aspects of thorax
Gold et al., 2012	Trachus (right); suprasternal notch; acromion process (bilateral); lateral humeral epicondyle (right), midway between radial and ulnar styloid process (right); ulnar styloid process (right); head of 5th metacarpal (right); greater femoral trochanter (bilateral)	Defining head-neck segment, trunk, right shoulder and right elbow to describe kinematics of the different segments
Hansson and Oberg, 1996	Proximal and distal thigh (bilateral), proximal and distal lower leg (bilateral), dorsum of hand (bilateral), lateral humeral epicondyle (bilateral); acromion process (bilateral), anterior superior iliac spine (ASIS) (bilateral);	Markers positioned according to the 3DSSPP model (University of Michigan, 1993)

	midpoint between ASIS	
Lissoni et al., 2001	Posterior superior iliac spines (PSIS)	Defining pelvic segment
	Acromion processes	Defining shoulder segment
	Zygomatical arches	Defining head segment
	Occiput and top of the head	Defining movement of head in sagittal plane
O'Sullivan et al., 2012	PSIS (bilateral); spinous processes of L1 and L3; sacro-iliac joint (SIJ) (bilateral)	Markers positioned according to customised CODA marker protocol
Preuss and Popovic, 2010	22 markers, placed over and lateral to the spinous processes of L3, T12, T9, T6, T3 and C7	Defining seven spinal segments consecutively: Lower lumbar; Upper lumbar; Lower thoracic; Mid-lower thoracic; Mid-upper thoracic; Upper thoracic
Sheeran et al., 2012	Spinous processes of C7, T12 and S1; Spinal wheel used to measure spinal curvature	Defining thoracic spine and lumbar spine segments
Straker et al., 2008	Outer canthi (bilateral), trachus (bilateral), acromion process (bilateral), posterior mid-humerus (bilateral), lateral humeral epicondyle (bilateral), midway between radial and ulnar styloid process (bilateral); distal end of 3rd metacarpal (bilateral); greater femoral trochanters (bilateral); spinous processes C7 and T5	Defining head, neck, torso and upper limbs as segments
Straker et al., 2009	Outer canthi (bilateral), trachus (bilateral), acromion process (bilateral), posterior mid-humerus (bilateral), lateral humeral epicondyle (bilateral), midway between radial and ulnar styloid process (bilateral); distal end of 3rd metacarpal (bilateral); greater femoral trochanters (bilateral); spinous processes C7 and T3; suprasternal	Defining head, neck and trunk (including gaze, cranio-cervical angle and cervico-thoracic angle), scapula, arm and wrist as segments

	notch	
Szeto et al., 2005	Lateral to outer canthi of eyes; mastoid processes	Defining head/neck segment
	Inferior to suprasternal notch; C7 and T8 spinous processes	Defining thoracic segment
	Acromioclavicular joint, lateral humeral epicondyle, midpoint of the posterior shaft of the humerus	Defining upper arm segment

2.5 Data Processing and Statistical Analysis

Data was processed using different methods and systems, as outlined in Table 2.5. Raw data from the motion analysis system were reconstructed to produce concrete values (predefined according to desired outcome parameters), which were then statistically analysed for interpretation. In the majority of the studies, ranges of motion (degrees) of defined joints were used either as primary outcomes (Gold et al., 2012; Lissoni et al., 2001; Straker et al., 2009, 2008; Szeto et al., 2005) or used to calculate secondary parameters. Secondary parameters included the percentage of spinal range of motion in relation to its full available range (O'Sullivan et al., 2012); the absolute and relative ranges of motion in studies of coupled movements (Edmondston et al., 2007); absolute, variable and constant errors to report on spinal position sense (Sheeran et al., 2012); and loading moments calculated from ranges and directions of motion (Hansson and Oberg, 1996).

Table 2.5: Data Processing

Author	**Data processing procedure**
Edmondston et al., 2007	Low pass filtering (4 Hz) of 3D coordinate data was performed using a second order Butterworth filter. Data processing was performed using the PEAK Motus 8.2 software package (PEAK Performance Technologies Inc Centennial, CO, USA) facilitated in an IBM compatible computer (Intel Pentium 4 CPU 2 GHz, AT/AT compatible).
Gold et al., 2012	Low pass (6 Hz) filtered data from each participant was exported to MaxMATE version 3.6E (Innovision Systems, Inc.; Columbiaville, MI), through which all joint kinematics were analysed.

Hansson and Oberg, 1996	Gaps in data were filled with linear or cubic regression by means of an unidentified computer program; Matlab Software (The Mathworks Inc. 1993) was used to calculate body segment angles from 3D marker positions, transcribing these to body posture angles and force vectors by means of formulae from 3D Solid Geometry.
Lissoni et al., 2001	None specified
O'Sullivan et al., 2012	Low pass filtering (16 Hz) of data was performed using a fourth order Butterworth filter, after which mean flexion was exported for analysis.
Preuss and Popovic, 2010	Low pass filtering (2 Hz) using an eighth order Butterworth filter
Sheeran et al., 2012	Matlab 7.0 was used to subdivide the Spinal Wheel curvature into 19 equidistant points and calculating an angle between the lines interconnecting the adjacent points. Target and repositioning data were used to calculate absolute error, variable error and constant error.
Straker et al., 2008	Not specified
Straker et al., 2009	Filtering (4Hz) of data was performed using a Butterworth filter
Szeto et al., 2005	Reconstructed marker trajectories were processed using the Vicon Bodybuilder (Oxford Metrics, UK) to produce Euler's angles (X; Y; Z); data was exported to a Labview (National Instruments TM, Austin, USA). The 10th percentile, 50th percentile and 90th percentile of APDF were calculated.

In all the studies specified, statistical analysis was done to determine measures of central tendency. For this reason, means and standard deviations were calculated after which analysis was done by means analysis of variance (ANOVA) with/without configurations. Table 2.6 provides a summary of outcome parameters used and the relevant statistical analysis procedures.

Table 2.6: Outcomes and statistical analyses

Author	**Outcome parameters**	**Statistical analysis**
Edmondston et al., 2007	3D *ranges of motion* (degrees) of rotation and coupled lateral flexion in neutral, extended and flexed postures; changes in ranges for rotation and coupled lateral flexion when compared to neutral.	Means and standard deviations; RANOVA (α < 0.05).
Gold et al., 2012	3D *ranges of motion* (degrees) of the neck, trunk, shoulder, elbow and wrist, in three different posture setups.	Means and standard deviations; RANOVA with Bonferroni adjustments.
Hansson and Oberg, 1996	Position of the body relative to *exertion load* (nanometres) during the performance of a heavy-load task (turning a tractor steering wheel) in static sitting. Load was calculated from joint angles (degrees) of 3D movement of the shoulder and lumbar spine.	None specified
Lissoni et al., 2001	Maximum 3D *range of motion* (degrees) of the pelvis, shoulder and head.	Means and standard deviations
O’Sullivan et al., 2012	Lumbopelvic *range of motion* (% range of motion relative to maximum range of motion) during different tasks.	Means and standard deviations; Spearman’s rank correlation coefficient, the coefficient of determination.
Preuss and Popovic, 2010	3D *range of motion* (degrees) for both total trunk motion and intersegmental trunk motion.	Means and standard deviations; three-way ANOVA with Bonferroni adjustments (α < 0.05).
Sheeran et al., 2012	Repositioning errors (absolute, variable and constant errors): subjects were to return from a relaxed position, to a facilitated starting position. Errors were calculated from ratios between target repositioning and actual repositioning (degrees).	Means and standard deviations; univariate ANOVA with Bonferroni adjustments; SPPS 14 (α < 0.05).

Straker et al., 2008	3D *joint angles* (degrees) of head, neck and upper limb while doing tasks at different desk setups.	Means and standard deviations; univariate RANOVA (α < 0.01).
Straker et al., 2009	3D *joint angles* (degrees) of the head, neck, scapula, arm and trunk, comparing input to old IT with new IT, in different desk setups. Variability analysed using APDF and EVA.	Means and standard deviations; repeated measures RANOVA (α < 0.01); Amplitude Probability Distribution Function (APDF); Exposure Variation Analysis (EVA).
Szeto et al., 2005	3D *joint angles* (degrees) in the head, thorax and bilateral shoulders over a prolonged typing task.	Medians, means and standard deviations; MANOVA (α < 0.05).

2.6 Limitations and recommendations

The authors in all the studies discussed reported limitations to their studies and recommendations for future research based on their findings. Certain recommendations were quite specific to the particular research process followed in the respective studies and cannot be applied in different contexts. For the purpose of this paper, only the limitations and recommendations that are universally applicable to a broad spectrum of posture analysis studies will be discussed.

The relative motion of the skin below the marker has been identified as potentially compromising reliability of marker positions relative to the Cartesian plane. Preuss and Popovic (2010) suggested the use of X-rays, MRI, video fluoroscopy and raster stereography as alternatives, although these tools will hold limitations of their own. Lissoni et al. (2001) implemented and recommended the selection of bony prominences as anatomical landmarks to place surface markers, in order to minimize the potential movement of the marker via movement of the skin. For future studies, O'Sullivan (2012) suggested a bigger sample, especially when validating the relevant measuring tool in a clinical population. Szeto (2005) recommended more extensive studies on sitting posture in subjects with musculoskeletal pain, specifically focusing on different subgroups within the population. Gold (2012) and Straker (2008) both suggested longer periods of exposure in different positions as well as a bigger variety of tasks. Straker (2008) also suggested field studies with a long-term follow-up. Gold (2012) explored the possibility of a tendency to assume a specific position for each particular task and suggested the investigation of preferred tasks in relation to the sitting position. Sheeran (2012) suggested that the thoracic flexion and extension patterns as measured in the laboratory should also be measured in a variety of functional tasks. Straker (2008) identified the multifactorial relationship between posture and pain and suggested furhter investigation on possible factors of posture which may lead to pain.

2.7 Conclusion

The study design, aims and objectives play a very important part in the methodology and data analysis of a research study. The availability of suitable research facilities is also a prominent contributing factor. Such facilities may include a research location, a motion analysis system with applicable software, trained technicians and assistants as well as possible existing models or protocols to be used. This review provides an insight in the relationship between the methodology, aims and objectives and research facilities in different studies of 3D sitting posture.

CHAPTER 3 : TESTING FEASIBILITY

The current study serves as the third phase in a series of posture studies done at the Stellenbosch University FNB 3D Movement Analysis Laboratory. Based on the technical challenges encountered during the initial posture studies in the laboratory, evaluation of postural dynamism using a camera-based system was deemed to be unfeasible as further development of the methodological protocol was thus required.

The prolonged time periods required for data processing was problematic as it took an average of 90 minutes to process a single trial. Data processing time refers to the total time needed to process input to Nexus (the software used for processing) via the Vicon cameras, into raw data. Difficulty and time consumption of data processing have previously been identified as a universal limiting factor in the use of a 3D motion analysis system for posture evaluation (Fortin et al., 2011).

The visibility of the anatomical surface markers plays a prominent role in the data processing time. These spherical retro-reflective markers are attached to certain anatomical landmarks of the study participant prior to data collection. The markers reflect infrared rays from the Vicon camera units during trial capture, enabling the cameras to detect the position of the markers. Views from all cameras used are combined and a 3D position of each marker is derived (Culmer et al., 2009), thereby defining the shape of the image captured. Poor visibility of the markers by the cameras may account for much of the time consumption and complexity of data processing. When a marker is momentarily concealed during trial collection, good quality lines of vision from a sufficient number of cameras in the 3D motion analysis system are interrupted, leading to gaps in the data. The accommodation and correction of these gaps are done manually by the technician during data processing. This process can be very time-consuming; therefore an increase in the frequency of gaps will lead to an increased time period of data processing.

3.1 Feasibility pilot studies

A number of specific technical difficulties were encountered during the initial pilot studies, including laboratory layout, system calibration, marker visibility and regulation of activity performed by the subject. Prior to official data collection, a number of feasibility pilot studies were performed to address these technical shortcomings. The aim of the pilot studies was to improve the experimental setup and system operation of the Vicon in an attempt to reduce gaps in movement data. A series of three pilot studies were performed, of which only the last one was formally conducted with a subject with no affiliation to the research study.

3.1.1 First Pilot Study

The specific objectives of the first pilot study were: to assess the optimal position of the tripods/cameras and to determine a suitable calibration frequency.

3.1.1.1 Methodology

Two of the eight Vicon cameras were removed from their mountings, and placed on tripods. Marker visibilitiy was tested with the two tripods in different positions, thereby establishing the ideal position of these tripods by means of trial and error. A basic workstation set-up was done. Calibration was performed at different frequencies (80 Hz, 50 Hz and 25 Hz), in order to gauge the influence of camera and workstation setup on calibration.

3.1.1.2 Outcome

The ability to manipulate the two tripod-mounted camera units significantly more than was possible with the wall-mounted cameras led to greater possibilities in optimal positioning. However, we were still unable to position the cameras such that there was sufficient visibility of all markers at any given stage on a subject positioned at a basic workstation. This highlighted the need to place more of the camera units on tripods and reattempt positioning in a follow-up pilot study.

The effect of calibration frequencies as tested by the laboratory technician showed that the volume calibration needed to be performed at 200 Hz or more. This was due to the movement speed of the calibration needing to suitably cover the entire capture volume. The faster the calibration capture, the more accurate the calibration, as there is a finer covering of the capture volume. However, the faster the capture, the larger the amount of data captured. Fortunately, calibration is usually only 20 to 40 seconds worth of captured data representing five wand markers and therefore is a relatively small amount of data.

3.1.2 Second Pilot Study

The objectives of the second pilot study were: to reassess and determine optimal camera positioning with all eight the units mounted on tripods; to investigate different options for workstation layout; and to investigate the possible challenges with regards to marker placement.

3.1.2.1 Methodology

Optimal tripod positions and camera orientations were determined by trial and error, par A laboratory layout was established in which the majority of the markers in the capture were visible to at least two cameras at any given time period. Tripod positions were marked out by means of duct tape.

The researcher was used as a model for marker positioning according to the full Plug-in-gait model (refer to Appendix B) and was positioned at the workstation engaging in computer activity. A data collection trial run was performed to monitor visibility of all the markers. Partial marker occlusion occured at the sternum and anterior superior iliac spines (ASIS) due to skin folds. The possibility of extension wands were considered for the markers at the ASIS. However, during initial posture studies, the accurate positioning of extension wands were not established.

Feasibility of the workstation was tested by identifying any of its aspects that could potentially obstruct marker visibility. The conventional desk used at the workstation had four foot pieces, with the front ones running parallel to the lower leg of the participant. These foot pieces caused occasional occlusion of lower limb markers. Also, the back rest of the typist chair that was used occluded posterior spinal markers.

3.1.2.2 Outcomes

Optimal camera positioning was established and marked off on the floor (Figure 3.1 and Figure 3.2). It was decided to use a custom-made desk with a single foot piece, which would be tested in the next pilot study. The U-shaped desk used was specifically designed with a single foot piece along the edge of the length of the desk, on the opposite side to where the subject was to be positioned (Figure 3). This design eliminated the need of a vertical foot piece on the same level of the subject’s legs and feet. This type of foot piece (often included in traditional desk design) could potentially lead to the occlusion of lower limb markers during trial capture. Furthermore, the typist chair that was used had its backrest removed in order to avoid the occlusion of posterior markers.

Although the use of marker extension wands could enhance sternal and ASIS marker visibility, it was decided to first establish valid and reliable positioning of these wands in sitting posture during an independent study. For the purpose of this study, we decided to use a convenience sample with a body-mass index and waist-hip ratio within normal limits in order to minimise the potential for skin folds. Visibility of the sternal and ASIS markers was enhanced by strategic tucking and taping of clothes.

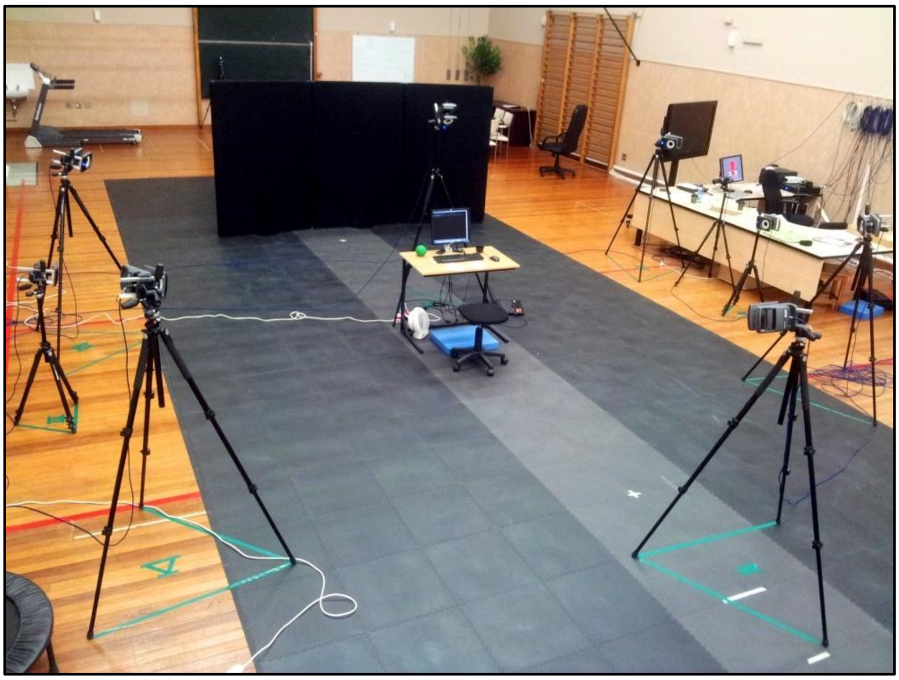


Figure 3.1: Laboratory layout (a)

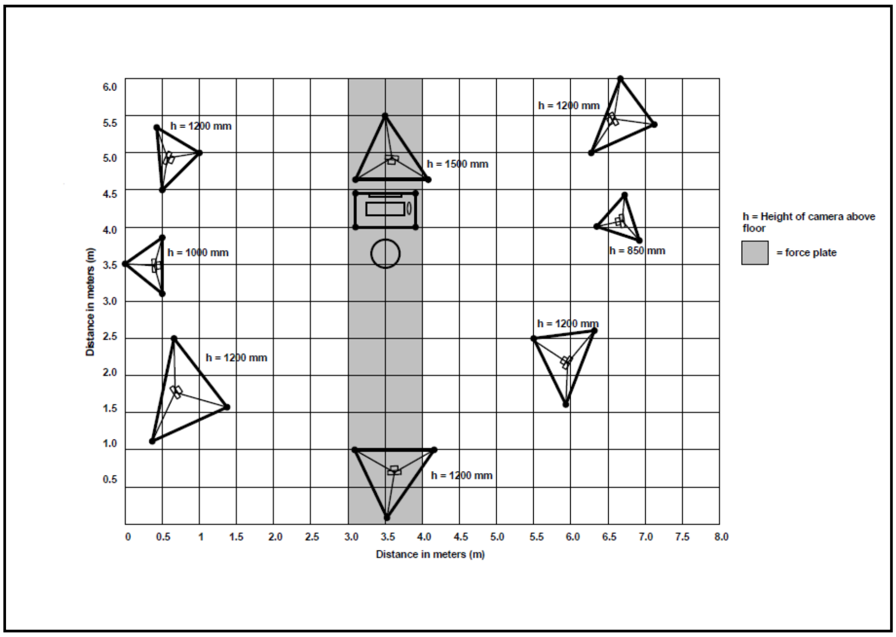


Figure 3.2: Laboratory layout (b)

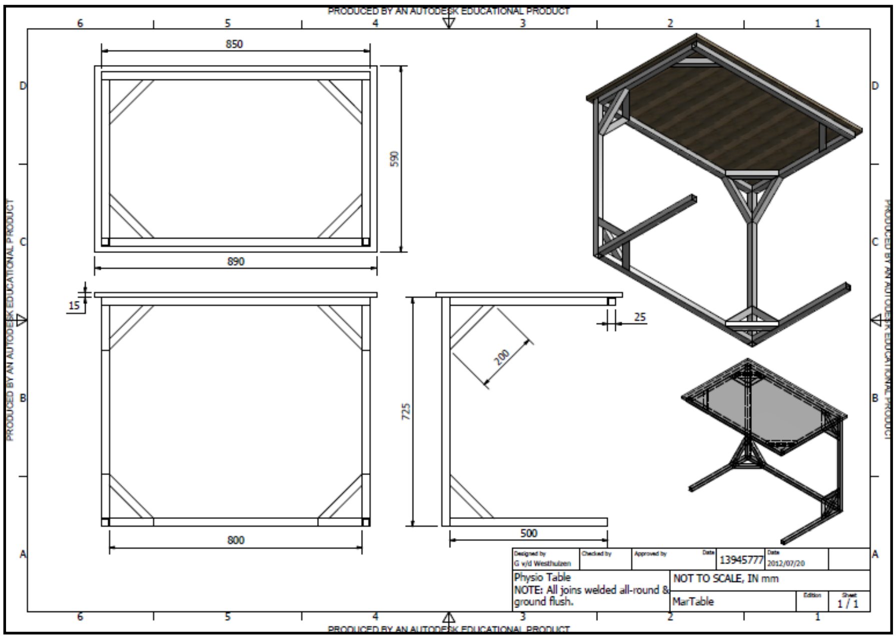


Figure 3.3: U-shaped desk

3.1.3 Third pilot study

In our previous sitting posture studies, the sequence and duration of the computer task were not controlled, nor were the unplanned movements of subjects such as touching the face or hair. Therefore the objective of this pilot study was to design and test a customised computer task in order to limit unplanned subject-specific movement and to ensure that all subjects participating in the main study would perform similar computer tasks for a specific duration. Although not directly associated with the reduction of gaps in movement data, the regulation of activity during trial capture is noteworthy. A custom-designed computer program was used to regulate a range of very simple computer activities to be done according to a time frame. Each of these activities (including mouse work, keyboard typing and reading from the screen) was based on true-life setups. The timing and performance of the activities were well controlled, resulting in relatively uniform, intersubject-comparable data for each activity. It also allowed for the observation of tendencies and movement patterns related to specific activities. The manipulation of activities may have resulted in a consciously artificial performance by the participant, which may differ from real-life movement. However, a standard series of activities regulated by a computer program tended to improve the repeatability of this study.

3.1.3.1 Methodology

Two independent computer-literate subjects were required to perform all the activities as regulated by the software program. The subjects were requested to provide feedback on the user-friendliness of the program, clarity of instructions and general difficulty of the tasks. They were also asked to share any comments or recommendations regarding improvement of the software. Feedback was given orally to the researcher and the laboratory technician who was responsible for the software design. Feedback was discussed and appropriate adjustments were made. The same subjects repeated the corrected program, after which no further recommendations for improvement were made.

3.1.3.2 Outcome

Feasibility was established for the computer software used to regulate the computer tasks to be performed by the study participants.

3.1.4 Fourth pilot study

The objective of the final pilot study was to include all of the outcomes from the preceeding pilot studies and attempt a trial run of the actual data collection process. The feasibility of the experimental setup, subject compliance, procedure prior to and during trial capture, as well as data processing were tested and varified. A model with no affiliation to the research study or the laboratory was used as a study participant.

3.1.4.1 Methodology

The entire trial capture process was performed as a trial for the main study. Prior to trial capture, final workstation adjustments were made. These included the setup of the subject at the workstation, the positioning of the computer hardware, climate control, and identifying and covering all reflective surfaces of the workstation. A computer monitor, keyboard and mouse were positioned on the surface of the workstation and marked with duct tape. Trial capture was done for 15 minutes, during which the participant perfomed the different computer tasks as regulated by the custom-designed computer software. Hereafter, the biomedical engineer completed data processing for the trial. Raw data was processed by means of Matlab analysis and statistical processing and analysis was done. Both of these processes were performed in about ten minutes, as opposed to the previous phase of the study where data processing for the same trial capturing time took about 90 minutes.

3.1.4.2 Outcome

Methodology for this study was deemed feasible as marker visibility was improved; this was evidenced by the shorter processing time required per trial. On average, each trial took about ten minutes to process compared to 90 minutes prior to instigation of the improved methodological procedures as described above.

3.2 Proposed methods for improving data processing time

Prior to this study, aspects were investigated that may have influenced data processing time, either directly or as a cause of poor marker visibility. Methods for improving these aspects were proposed and will now be discussed.

3.2.1 Marker visibility

The improvement of marker visibility contributed considerably in reducing data processing time. The amount of gaps in the data was much decreased from the previous phase to the current phase of the posture study series. The laboratory technician responsible for data processing reported a decrease in data processing time from an average of 90 minutes for every 15 minutes of collected data to an average of ten minutes for every 15 minutes of collected data. Strategical workstation setup as discussed in the pilot study contributed significantly to improve marker visibility.

Skin folds of the study participants could have potentially lead to marker occlusion, thereby increasing the potential for gaps in the data. For the purpose of this study, the use of subjects within normal boundaries of body mass index (BMI) and hip waist ratio (HWR) was useful in order to investigate the feasibility of the 3D measurement of sitting posture. However, for follow-up studies, optimal marker placement strategies for a more representative variety of human body shapes need to be investigated.

3.2.2 Camera units

The Vicon motion analysis system used in the Stellenbosch University FNB Gait Laboratory is equipped with eight camera units. These cameras detect the positions of the reflective markers, and by combining all camera views a 3D position of each reflector can be determined. Good lines of vision from at least two cameras at any given point in time are important in order to portray an accurate image and location of all surface markers. Strategic camera positioning can optimise these lines of vision without compromising marker visibility.

In the previous phase of the posture study series, the cameras were mounted in fixed positions on I-beams suspended from the roof. In the current study, all camera units were mounted on adjustable tripods, enabling the researcher to determine the exact positions and angulations of the camera in relation to the body. The positioning of the tripods in relation to the capture volume was established during the pilot studies (3.1.2). The positioning and setup of the tripods were marked on the floor by means of coloured tape (Figure 3.1) and was replicated in a sketch (Figure 3.2).

3.2.3 System preparation

Calibration is a crucial part of the preparation process prior to trial capture; this allows the software to calculate the relative location and orientation of all the cameras. These measurements are used after trial capture to calculate accurate movement of the markers in the capture volume.

In this study, calibration was done at a frequency of 250 Hz; however, trials were captured at a frequency of 25 Hz. The high frequency at which calibration was done enhanced the accuracy of system orientation. The much lower frequency at which trial capture took place implied that less data were captured, although the data were still of adequate quality for the purpose of this study. Therefore, lower capture frequency resulted in a much shorter period of data processing than when capturing at higher frequencies. The determination of ideal capture frequency was performed during a series of pilot studies prior to the study (3.1.1).

Ghost markers are bright spots that appear on the system in the same way as anatomical markers, but are created by the camera reflecting on another reflective object (Jobbágy et al., 2002), such as reflective surfaces on clothing or the workstation. Ghost markers can also be caused when the infrared light of one camera is reflected on another. Ghost markers increase the data load on the system and also contributes to the increase in data processing time. Ghost markers were eliminated by virtual masking of the cameras in the software prior to trial capture in order to remove any reflective regions from non-critical regions of the capture volume. Covering all reflective surfaces inside and outside of the capture volume with a non-reflective object such as masking tape also reduced the occurrence of ghost markers.

3.3 Conclusion

In this chapter, the technical aspects of the use of a 3D motion analysis system that could negatively influence data processing time in sitting posture measurement studies were identified. Alternatives were devised and tested in a series of feasibility studies. Marker visibility was improved by means of adjustments to camera positioning and workstation setup. The regulation of activity performed by the subjects during trial capture contributed to the improvement of posture measurement in terms of relative control over subject behaviour as well as reliability of the research process. The improvement of 3D sitting posture measurement in terms of data processing simplified the operation and the use of this tool to study sitting posture, whilst improving the time- and cost-efficiency of the measurement tool.

CHAPTER 4 : PREFACE TO ARTICLE

This chapter presents a succinct literature overview, which is relevant to the article. The association between prolonged sitting and musculoskeletal pain is presented. Thereafter, the need and complexities of siting posture analysis is discussed.

4.1 Introduction

Valid and reliable measurement techniques are very important in order to accurately link exposures with outcomes in epidemiology. The measurement of physical exposures where posture is concerned are difficult and complex to describe (Bruno Garza and Catalano, 2012). For this reason, measurement tools for posture analysis should continuously be improved in terms of operation and psychometric properties.

The accurate and reliable measurement of the sitting posture can be complex. The human body is never entirely static, as it is continuously adjusting to its surroundings. The dynamic nature of posture should be considered and appreciated when attempting to measure sitting posture. In the clinical setup, posture evaluation techniques are mostly based on observation with or without the use of a postural grid and plumb line (Gadotti & Biasotto-Gonzalez, 2010:141). Apart from displaying poor psychometric properties, observational posture measurement tools cannot take constant spinal dynamism into account.

3DMAS's have been proposed as reliable and valid tools for the measurement of dynamic sitting posture (Brink et al., 2011). Data obtained can provide comprehensive information on spinal kinematics during the entire course of trial capture. This enables the researcher to systemically analyse all aspects of sitting in order to identify the potential risk factors that may be related to neuromusculoskeletal abnormalities.

4.2 Incidence of sitting-related musculoskeletal pain

The relationship between the sitting posture and musculoskeletal pain has been explored in various studies. Prolonged periods spent in a relatively static sedentary position have been identified as a risk factor for sitting-related musculoskeletal pain in various body segments, including the shoulder and upper limb (Claus et al., 2009; Kuo et al., 2009; Prins et al., 2008; Smith et al., 2009), the cervical spine (Caneiro et al., 2010; Kuo et al., 2009), as well as the lumbar spine (Lis et al., 2007; Mork and Westgaard, 2009). Increase in frequent involuntary postural changes in the sitting posture (termed ‘postural dynamism’) has been shown to decrease lumbar pain in scholars (Geldhof et al., 2007). Enhancing this theory, associations have also been found between decreased postural dynamism in sitting and musculoskeletal pain of the upper quadrant (Prins et al., 2008) and the lumbar spine (Pynt et al., 2008). Two possible explanations for musculoskeletal pain associated with relatively static sitting are discussed below.

Sustaining *end-range spinal angles* for a prolonged period of time in the sedentary position is proposed to be a possible causative factor for musculoskeletal pain (Murphy et al., 2007). Moving into and holding spinal curves in these extreme angles leads to sustained soft tissue strain of the spine, often resulting in reactive forces exerted in the ligamentous system (Annetts et al., 2012). This occurrence may be explained by the flexion-relaxation phenomenon, a theory that was originally studied only in terms of the standing posture. According to this theory, active end-range lumbar flexion in the healthy subject results in myographic silencing of the lumbar extensor musculature when measured via electromyography. It is hypothesised that this reduction of electrical signal is due to a load shift of moment-support from the erector spinae muscle group, to the passive structures in the lumbar spine. Passive structures include vertebral bones and intervertebral discs, ligaments and tendons (Colloca and Hinrichs, 2005). Studies investigating the flexion-relaxation theory in sitting have found a similar tendency, specifically in the superficial lumbar multifidus, the internal obliques (O’Sullivan et al., 2006) and the thoracic erector spinae muscle group (the latter being tested during a short duration of lumbar sitting) (Callaghan and Dunk, 2002). It is therefore suggested that prolonged sustaining of a slumped position will lead to the relaxation of the spinal stabilisers (O’Sullivan et al., 2006), resulting in increased loading and subsequent tissue failure of the passive structures, eventually causing back pain (Colloca and Hinrichs, 2005).

The link between a prolonged, fairly *non-dynamic sitting posture* and musculoskeletal pain can also be discussed from a biomechanical and physiological piont of view. The sustained load on the spine produced by prolonged sitting may lead to an increase in the hydrostatic pressure within the nucleus of the relevant intervertebral disc (Lis et al., 2007; Pynt et al., 2008); it also increases the risk for the compromise of the cartilaginous endplates of the vertebral bodies, the latter being the primary source of nutrition to the intervertebral disc. Damage to these endplates leads to a decrease in proteoglycan production and a reduction in the pH of the disc; this in turn leads to progressive degeneration of the nucleus and a subsequent decrease in the nucleus volume. The decrease in volume of the nucleus results in a greater transference of load from the nucleus to the posterior annulus fibrosis leading to broadening of the latter structure. At this stage, the annulus fibrosis has become weight bearing and cannot optimally function to restrain pressure. Further high-stress loading on the structure may cause the annulus to collapse into the nucleus leading to a decrease in disc space and subsequent long-term disc degeneration. Considering the aforementioned, the correlation between frequent periods of sustained static posture and disc degeneration is evident (Pynt et al., 2008).

Students (Torsheim et al., 2010) and office workers (Tudor-Locke et al., 2011) worldwide are spending an increasing amount of time in the sedentary position, much of which is committed to computer use. A relationship has been established between computer use and musculoskeletal pain in both adolescent (Brink and Louw, 2013; Smith et al., 2009; Torsheim et al., 2010) and adult populations (J. H. Andersen et al., 2011; Dennerlein and Johnson, 2006; Marcus et al., 2002). Frequent musculoskeletal pain has also been linked with a decrease in productivity (McDonald et al., 2011) and a loss of productive time in the workplace (Goetzel et al., 2004; Stewart et al., 2003). The investigation of possible risk factors for sitting-related musculoskeletal pain may assist to formulate workable solutions to eliminate these risk factors, both as a health hazard and as an occupational limitation. Objective posture analysis measurement tools with well-established psychometric properties can aid in gaining a better understanding of the association between pain, human movement and the sitting posture.

4.3 Measurement of posture

Three-dimensional motion analysis systems (3DMAS) are used for the measurement and analysis of the sitting posture in many laboratory-based human movement studies (Brink et al., 2011). A 3DMAS allows for the analysis and description of human movements in all three planes of motion. These biomechanical measurement tools can provide an accurate representation of motion from precise positional data measured (Brink et al., 2011). Various types and models of 3DMAS, used in research centres globally (Brink et al., 2011) are generally categorised into five measuring instrument groups: mechanical; optical; magnetic; inertial; and graphical. Currently, the majority of experimental movement studies are done using optical/opto-electrical systems such as the Vicon Motion Analysis (Oxford, United Kingdom) (Culmer et al., 2009). The Vicon, which is currently used for human movement analysis studies at the Stellenbosch University FNB 3D Motion Analysis Laboratory, has demonstrated high accuracy and reliability (Ehara et al., 1995) and has also demonstrated that it has less than a 1.5-degree error (Richards, 1999).

Due to its size and complexity of use, a motion analysis study using a 3DMAS can only be conducted in a well-equipped laboratory. Other limitations contribute to the general inaccessibility of a 3DMAS in the clinical field. These may include the difficulty and time consumption of data processing; major financial implications; and the need for specially-skilled technicians (Fortin et al., 2011). Such limitations should be addressed continuously in order to increase the efficacy of a 3DMAS as a measuring tool for human movement analysis. The need for further research in this area is great, especially in terms of feasibility.

4.4 Summary

Office workers, students and adolescents, spend long periods of time every day in the sitting posture, specifically whilst engaging with computer work. Prolonged sitting is a risk factor for musculoskeletal pain and can potentially be a health and occupational hazard. Objective posture analysis may provide information on human movement in the sitting posture, from which possible causes for sitting-related pain can be derived. The use of a 3DMAS is proposed as an accurate and precise measurement tool that can provide information on spinal kinematics in all three planes of motion. However, the need exists for the continuous improvement of the factors that may limit the use of a 3DMAS as a realistic and effective measurement tool.

CHAPTER 5 : ARTICLE

Spinal kinematics in computer mouse and keyboard use: A pilot study

5.1 Introduction

Prolonged periods spent in a sedentary position are considered to be a health risk when performed regularly (Alkhajah et al., 2012). Typical areas of pathology that are linked with sustained sitting include the shoulder and upper limb (Claus et al., 2009; Kuo et al., 2009; Prins et al., 2008; Smith et al., 2009), the cervical/thoracic spines (Caneiro et al., 2010; Kuo et al., 2009; Straker et al., 2009) and the lumbar spine (Caneiro et al., 2010; Lis et al., 2007; Mork and Westgaard, 2009). Frequent musculoskeletal pain is also linked with a decrease in productivity (McDonald et al., 2011) as well as a loss of productive time in the workplace (Stewart et al., 2003). Similar findings have been obtained from a university student population studied by Chang et al. (2007), who reported musculoskeletal pain associated with prolonged computer with subsequent limitation of activity and performance. Sitting-related musculoskeletal pain is a common condition that limits the performance of daily activity for many individuals.

Nowadays, many people spend the greater part of their day in a sitting position while working at a computer (Tudor-Locke et al., 2011). According to an estimate by Internet World Stats, 1.8 billion people are internet users, and by implication, also computer users (Andersen et al., 2011). In addition to frequent prolonged sitting, interaction with computer technology has also been identified as a risk for the development of musculoskeletal disorders, although the specific human-computer related risk factors remain unclear (Bruno Garza et al., 2012). Since the computer keyboard and mouse are commonly used as computer input devices, the effects of these devices in relation to musculoskeletal disorders have been widely studied (Andersen et al., 2011)

Descriptive studies have been conducted to describe muscle activity, posture and force exerted on the upper limb associated with the use of a computer mouse and keyboard. When compared to keyboard use, regular mouse use is associated with a decreased posture variation of the wrist and shoulder (Dennerlein and Johnson, 2006) together with a decrease in variability of muscle effort in these segments (Bruno Garza et al., 2012). Mouse work is also associated with sustained non-neutral postures of the shoulder (external rotation) and the wrist (extension and/or radial deviation) (Bruno Garza et al., 2012). Regular mouse use has been identified as a risk factor for the development of musculoskeletal disorders of the lower arms and hands and less so in the neck and shoulder area (Arvidsson et al., 2008; IJmker et al., 2007). In contrast, regular keyboard use has been associated with an increase in dynamic contraction of the forearm muscles (Dennerlein and Johnson, 2006) as well as a less fixated upper arm posture (Dennerlein and Johnson, 2006). Although regular keyboard use has been associated with a possible increased risk for hand and arm pain (Marcus et al., 2002), it does not appear to be a pertinent risk factor for musculoskeletal pain in epidemiologic literature (Bruno Garza et al., 2012). However, prolonged sub-optimal upper limb positioning in both keyboard and mouse use is associated with the development of musculoskeletal pain.

The association between spinal kinematics during keyboard and mouse use has not been studied extensively. Spinal kinematics concerns the types and quantity of motion that the human spine undergoes during its normal physiological movements (White and Panjabi, 1978). According to a systematic review by Andersen et al. (2011), studies investigating the role of keyboard or mouse use as a risk factor for cervical pain have been inconclusive. However, there is ample literature available on the posture and kinematics of the spine during computer work in general. Literature as such includes research on workstation ergonomics and posture (Ellegast et al., 2012; Straker et al., 2008), field studies on spinal kinematics (Mork and Westgaard, 2009), observational posture studies (Callaghan and McGill, 2001) and case-control comparison studies (Szeto et al., 2005). Limited literature is available in which posture and spinal kinematics are specifically discussed in terms of mouse use versus keyboard use. In a study of upper extremity forces, muscle efforts and postures across different computer activities, Bruno Garzia et al. (2012) included postural measurement of the head, neck and torso. Results showed increased ranges of motion only with cervical extension during keyboard use, with a more neutral angle of head tilt. Spinal kinematics was not exclusively studied, but formed part of a bigger set of postural data.

There are no standard parameters with which to measure and express the sitting posture in terms of spinal kinematics. Some authors have reported posture purely in terms of true range of motion of the specific spinal segments and/or peripheral joints under investigation (Gold et al., 2012; Lissoni et al., 2001; Straker et al., 2009, 2008; Szeto et al., 2005). In other studies, ranges of motion of spinal segments and/or peripheral joints were measured and used to calculate other parameters. Examples of such parameters included: the percentage of spinal range of motion in relation to the full available range of the individual (O’Sullivan et al., 2012); the absolute and relative ranges of motion in studies of coupled movements (Edmondston et al., 2007); absolute, variable and constant errors to report on spinal position sense (Sheeran et al., 2012); and loading moments calculated from ranges and directions of motion (Hansson and Oberg, 1996). Frequency of direction change during a specific movement has also been used as a parameter to describe spinal kinematics (Van Niekerk, 2013).

Valid and reliable measurement is very important in order to accurately link exposures with outcomes. The measurement of physical exposures such as kinematics is considered exceptionally difficult and complex to describe (Bruno Garza and Catalano, 2012). Three-dimensional (3D) motional analysis systems have been proposed as reliable and valid tools for the measurement and analysis of postural kinematics (Brink et al., 2011) in a laboratory as they are able to measure the size and frequency of movement very precisely. The current study forms part of a research project to improve the 3D measurement of the sitting posture. This study aims to investigate the 3D kinematics of the cervical and thoracic spinal regions whilst performing a seated mouse and keyboard task.

5.2. Methods

5.2.1 Participant recruitment and selection

Freshman physiotherapy students were recruited as participants. A total of 18 volunteers were screened in order to exclude participants with a history of spinal or neurological pathology. In order to limit potential marker obstruction by means of skin folds, volunteers with a high body-mass ratio (> 25) and/or a high waist-hip ratio (<0.8 in females, <0.9 males) were excluded from the study. A convenience sample (n = 12, 1 male and 11 females) was selected as study participants. All participants met the inclusion criteria and were regular computer users. The Health Research Ethics Committee of Stellenbosch University, South Africa, approved the study (Appendix C). Participants all gave written informed consent to participate in the study.

5.2.2 Motion analysis system

The Vicon Motion Analysis system (Vicon, Oxford, United Kingdom) consists of eight (either wall-mounted or tripod-mounted) T-10 MX cameras. Nexus software was used during this study. The Vicon system has demonstrated high accuracy and reliability (Ehara et al., 1995) and has less than a 1.5-degree error (Richards, 1999).

The Vicon system detects retro-reflective markers in a capture volume and reconstructs their positions in three dimensions. Thereafter, a biomechanical model uses these markers to calculate anthropometric angles, which define the skeletal pose and movements of the subject being captured. The system requires careful planning of the experiment set-up, selection of marker landmarks, relevant biomechanical model and system calibration in order to capture accurate and appropriate anthropometric measurements.

5.2.3 Laboratory setup and preparation

A custom-made desk with a U-shaped foot piece was used to optimise marker visibility (Figure 5.1). The participant was seated on a regular typists chair with the back support removed to ensure visibility of the posterior anatomical landmark markers. A flat-screen monitor, computer mouse, computer keyboard and a ball and cup were positioned at marked areas on the desk. The height of the chair and/or monitor was adjusted for each individual participant as to facilitate approximate right angles at the hips and knees, with a gaze angle of approximately 30 degrees to the horizontal. A footrest was used where necessary (Figure 5.2).

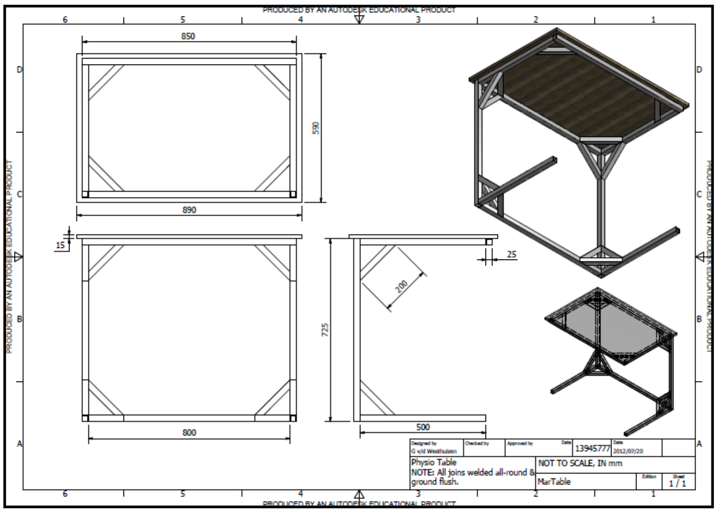


Figure 5.1: U-shaped desk

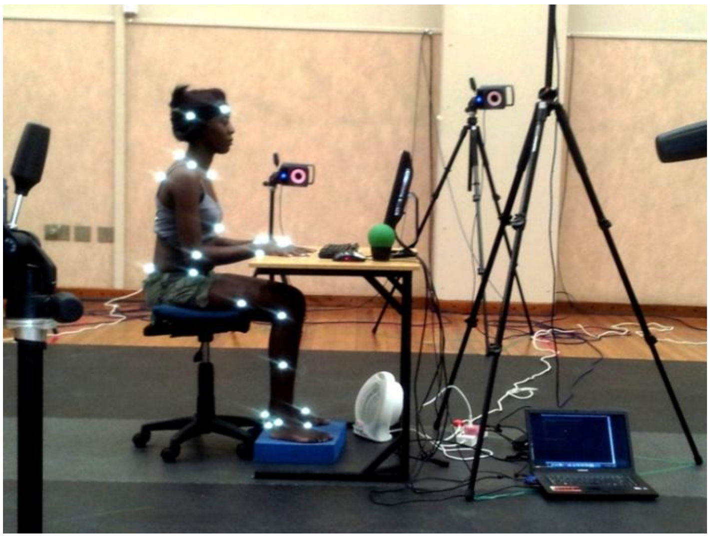


Figure 5.2: Subject positioning

Eight cameras mounted on tripods were positioned around the workstation. Cameras were positioned (as predetermined during a pilot study) in order to ensure visibility of each marker by at least two cameras at any given time. All reflective regions in the capture volume were covered with masking tape and camera masking was done in order to reduce ghost markers. The camera positions were clearly marked on the floor by means of duct tape, as illustrated in Figure 5.3.

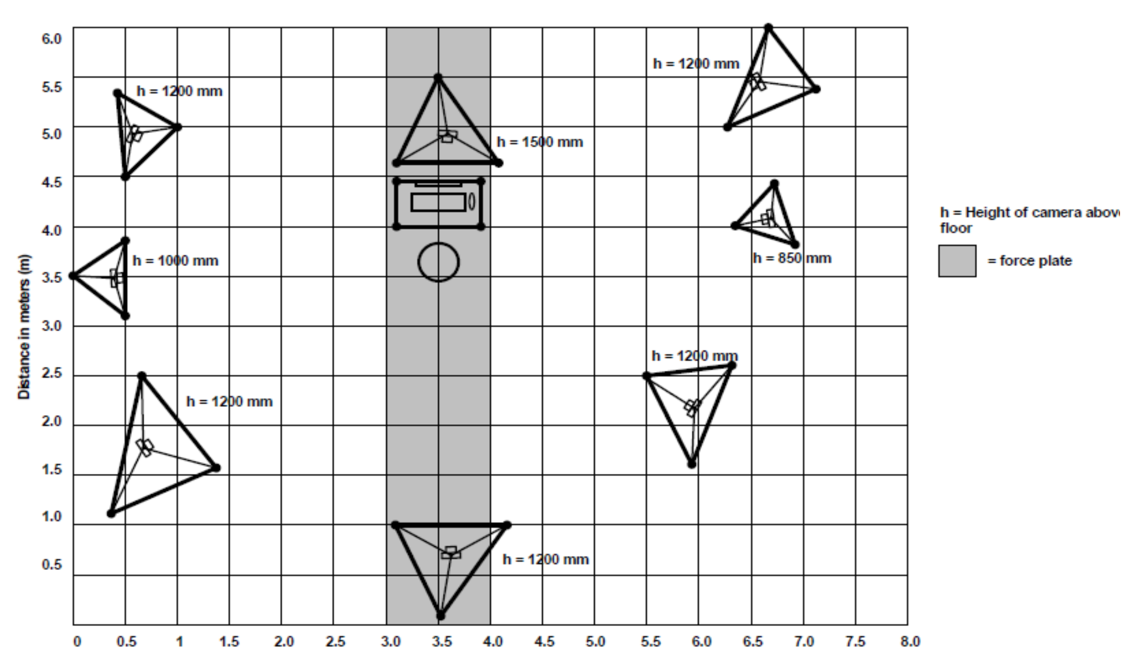


Figure 5.3: Laboratory lay-out

5.2.4 Anthropometric measurements and marker placement

Prior to trial capture, anthropometric measurements were done according to the Plug-in-Gait model, currently an industry standard in motion analysis (Lind et al., 2013; Van der Krogt et al., 2012). These measurements included the height, weight, leg length, shoulder offset as well as the widths of the ankle, knee, elbow and wrist. Marker placement was done according to the Full-body Plug-In Gait Marker Placement Protocol of the Stellenbosch University FNB-3D Movement Analysis Laboratory (Appendix B). All anthropometric measurements and marker placements were done by a physiotherapist with training and experience in marker placement and a sound understanding of the full Plug-in-Gait model.

5.2.5 Experimental protocol and data capture

During calibration (Appendix A), the system captured at 250 Hz; however, due to the planned duration of the experiment, the trials were captured at a frequency of 25 Hz. Per implication, movement occurring at 25 times per second or faster was neglected. Since sitting posture does not involve high-frequency movement, this capture frequency is sufficient for the purpose of this study.

During the initial part of the trial-capturing process, the participants were requested to move through their full available ranges of motion of the spinal segments whilst sitting at the workstation (Table 5.1). These movements were first explained and facilitated by the researcher, after which they were actively performed by the participants and captured. The ranges measured defined the full ranges of motion in the specific planes and segments for each participant.

Table 5.1: Verbal instructions for full ranges of motion

Segmental Movement	Verbal command
Cervical Flexion/Extension	'Look up to the ceiling as far as possible, then move your chin towards your chest as far as possible.'
Cervical Lateral flexion	'Without rotating your head, drop your left ear in the direction of your left shoulder as far as you can. Repeat this movement to right.'
Cervical Rotation	'Without moving your shoulders, look over your left shoulder as far as possible, then repeat to the right.'
Thoracic Flexion/Extension	'Slump forward as far as you can, without bending your lower back.'
Thoracic Lateral flexion	'Reach down with your left hand towards the floor as far as you can without lifting up your right foot. Repeat to right.'
Thoracic Rotation	'Cross your arms in front of your chest and while keeping the hips facing to the front, rotate the body sideways as far as you can. Repeat to both sides.'

Following the range of motion captures, the participants performed a series of computer tasks that were briefly explained to them prior to capture. A custom-designed computer program was used to give detailed commands and vary the different tasks according to a specific time frame (Table 5.2). Tasks were performed consecutively with short breaks in between during which the participants read commands and familiarised themselves with the task to follow. These breaks were marked with a beep sound at the end of a task. As soon as the participants started with the next task, another beep sound followed.

Table 5.2: Tasks performed as per computer software

Task (T) number	Description of task	Time duration (minutes)
T01	Warm-up: randomly pressing specific keys using specified hands	1
T02	Short questions: answering questions with one-word responses	5
T03	Mouse-clicking randomly clicking specified locations on the screen	1
T04	Reading: reading a portion of text, with an indicated interruption to do a specified diagonal movement across the table using the ball and cup on the workstation	5 (interrupt at 2)
T05	Long questions: answering questions with full sentences	5
T06	Cool-down: fixing gaze onto the monitor screen	0.33

The trial capture took place for the entire duration of each task. The beeps gave an indication to the researcher as when to stop trial capture at the end of one task, and when to start again at the beginning of the next task.

5.2.6 Data processing

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. The data of four subjects could not be used due to technical errors. A trained laboratory technician performed the data processing. Where gaps still occurred in the captured data , these were by preference filled by means of the Pattern fill option in the Nexus 1.7 software, which was patterned to a marker on the same rigid body segment (e.g. right wrist A and right wrist B, or toe and heel). The pattern fill function was that of a spline fill, the latter corrected at discontinuities therein in order to follow the pattern of the second marker. After all the data were processed, the data were exported to Microsoft Excel (Microsoft, USA) for analysis.

5.2.7 Biomechanical parameters

5.2.7.1 Range of motion

Range of motion (degrees) in both the cervical and thoracic spines was the first parameter used in this study. This parameter was defined by the true range of motion as a percentage of the full available range of motion. True range of motion was captured in three planes, namely sagittal (*x*-axis), frontal (*y*-axis) and horizontal (*z*-axis) planes. Neutral was defined by the starting position and all motion away from neutral was captured in the three separate planes of motion. Total range of motion was obtained by calculating the difference between the furthermost points of movement in relation to the starting position. The range of motion obtained during trial capture was then expressed as a percentage of the full available range of motion (the latter measured during the initial range of motion capture).

5.2.7.2 Frequency of motion

Frequency of motion was defined and calculated as described by Van Niekerk et al. (2013). Frequency of motion indicates the number of postural changes within the measured ranges and was used as the second parameter. 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. The absolute differences were grouped between 0 degrees and 180 degrees in increments of one degree. Totals of these movement groups were calculated to indicate the total amount of postural change. All 'movements' smaller than two degrees were disregarded as system errors (McGinley et al., 2009). The totals of the movement groups in each plane and segment were converted and expressed as movements per minute.

5.2.8 Data analysis

For the purpose of this paper, descriptive statistics of the mouse clicking task (T03) and the typing task (T05) were selected for interpretation in order to illustrate the tendencies in the kinematics of the cervical and thoracic spinal segment of these two tasks in relation to each other. True ranges of motion were considered in terms of the difference between the lowest and highest value of angles measured, and outliers were corrected by using only the values between the 10th and 90th percentile of data collected. Percentage of range of motion was determined by calculating the relationship between true range of motion (corrected) and the full available range of motion as measured prior to trial capture. The frequencies of movement per minute in the two spinal segments were tallied and represented by means of line graphs.

5.3 Results

5.3.1 Range of motion

The true ranges of motion (ROM) (90th to 10th percentile) and percentage of full available range (% ROM) in all participants (S01 to S08) were measured and tabulated (Table 5.3). The values representing % ROM are all remarkably low, with only one value exceeding 12%. Overall, the magnitude of motion was generally bigger (mostly by a considerable margin) in the typing task than in the mouse task. In isolated cases, bigger movement was recorded with the mouse use than with keyboard use (indicated by an asterix in Table 5.3).

Table 5.3: Range of motion

a) Mouse clicking task

Segment	Thoracic F/E[a]		Thoracic LF[b]		Thoracic Rot[c]		Cervical F/E[a]		Cervical LF[b]		Cervical Rot[c]	
	True ROM[d]	% ROM	True ROM	% ROM	True ROM	% ROM	True ROM	% ROM	True ROM	% ROM	True ROM	% ROM
S01	0.569	1.111	0.285	0.432	0.454	0.614	2.311	1.604	2.014	2.326	1.806	1.016
S02	0.334	0.771	0.618	0.853	0.530	0.646	2.931	2.314	1.186	1.879	1.275	0.850
S03	1.028	2.379	2.292	3.023	0.760	1.001	3.194	2.723	1.545	1.877	2.730	2.202
S04	1.048	1.795	*1.561	2.772	1.139	2.000	*10.261	*8.587	2.252	2.819	*4.130	*3.115
S05	0.568	0.905	1.338	2.267	0.574	1.145	1.960	1.904	0.812	0.996	1.761	1.130
S06	0.979	1.507	0.335	0.573	0.627	0.871	3.049	2.279	3.299	3.835	3.703	2.516
S07	2.543	4.342	1.050	1.698	1.082	2.272	3.007	1.929	*4.354	*5.370	4.413	3.226
S08	1.306	2.741	0.731	1.376	0.523	0.636	1.687	1.123	2.353	2.949	3.806	2.464

b) Typing task

Segment	Thoracic F/E[a]		Thoracic LF[b]		Thoracic Rot[c]		Cervical F/E[a]		Cervical LF[b]		Cervical Rot[c]	
	True ROM	% ROM	True ROM	% ROM	True ROM	% ROM	True ROM	%ROM	True ROM	% ROM	True ROM	% ROM
S01	3.034	5.926	1.969	2.984	2.546	3.442	6.146	4.262	2.687	3.104	4.021	2.263
S02	2.624	6.062	2.598	3.587	2.665	3.248	7.140	5.637	4.711	7.467	4.059	2.705
S03	4.668	10.806	3.437	4.534	3.215	4.236	10.600	9.036	2.794	3.394	4.247	3.424
S04	5.998	10.276	*1.301	2.310	1.176	2.057	*9.422	*7.885	3.069	3.842	*3.720	*2.805
S05	10.565	16.813	6.617	11.210	6.001	11.976	9.309	9.044	9.038	11.090	6.101	3.914
S06	5.225	8.041	2.011	3.445	8.454	11.731	6.601	4.934	3.623	4.212	7.067	4.802
S07	3.067	5.236	1.915	3.096	3.286	6.898	7.860	5.041	3.273	4.036	5.809	4.246
S08	5.645	11.847	2.457	4.623	2.647	3.218	6.121	4.073	3.307	4.144	4.095	2.652

*Indicator of movement range in the mouse task larger than that in the typing task

[a] F/E = Flexion/Extension

[b] LF = Lateral Flexion

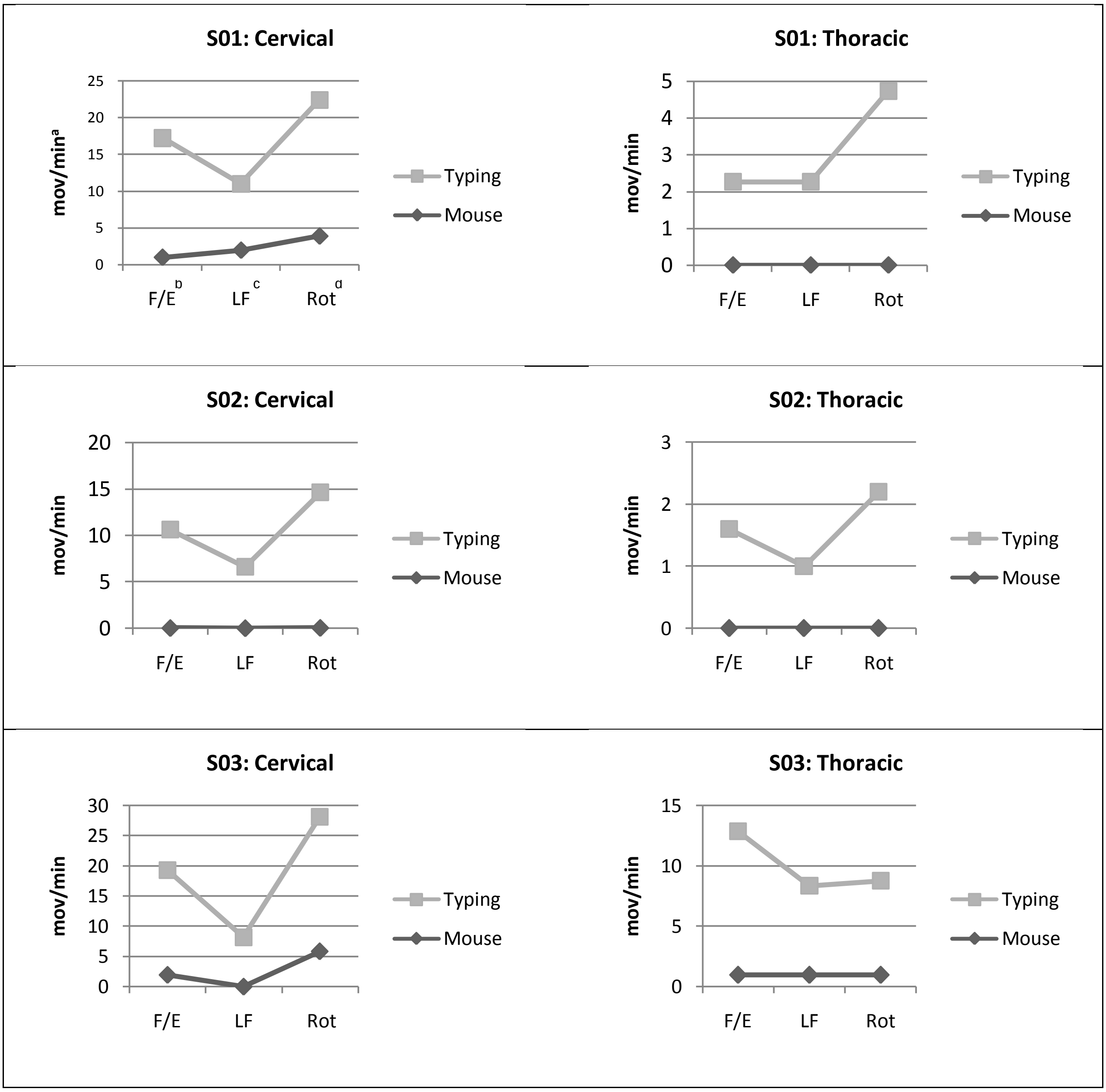
[c] Rot = Rotation

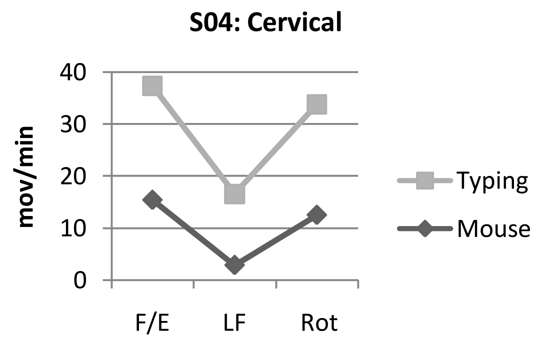
[d] ROM – Range of motion

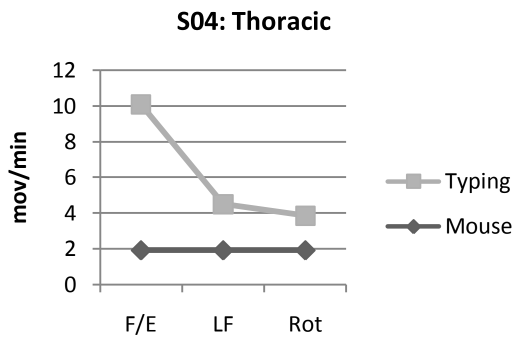
5.3.2 Frequency of motion

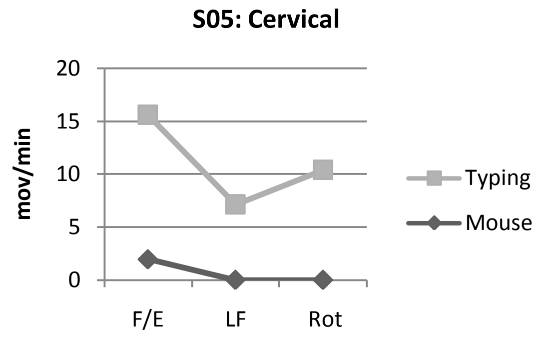
Frequency of motion in the three planes of motion for every participant (S01 to S08) was represented by means of line graphs (Table 5.4). Frequency of motion in the cervical spine is represented separately from the thoracic spine. Without exception, frequency of movement in all three planes was considerably less in the mouse task than in the typing task. No subject-specific or task-specific tendencies regarding variance or movement patterns were noted.

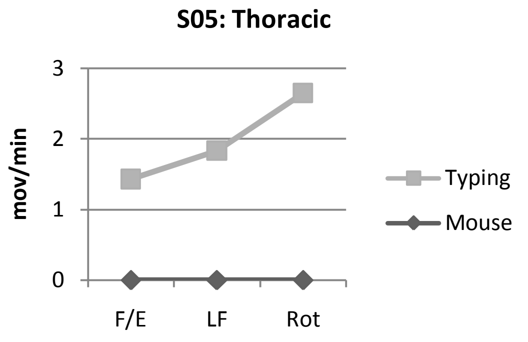
Table 5.4: Frequency of motion

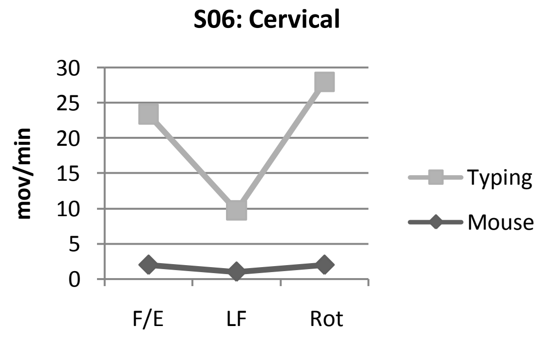


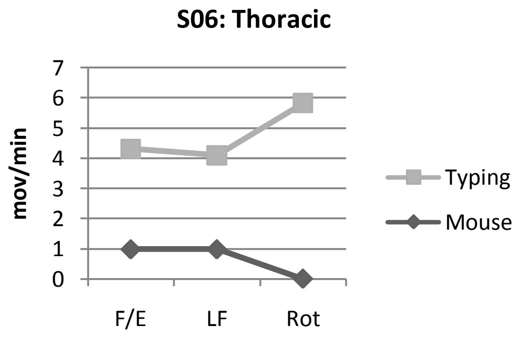

S04: Cervical
mov/min
40
30
20
10
0
F/E
LF
Rot
Typing
Mouse

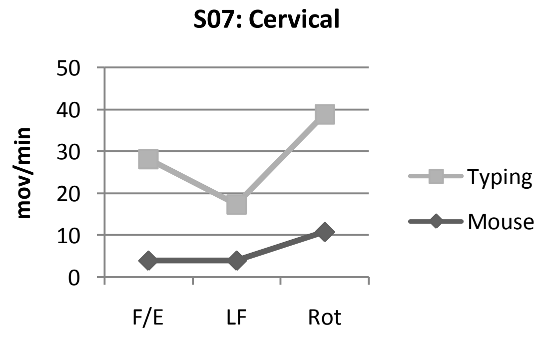

S04: Thoracic
mov/min
12
10
8
6
4
2
0
F/E
LF
Rot
Typing
Mouse

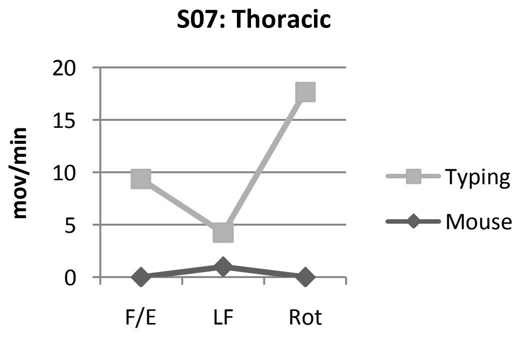

S05: Cervical
mov/min
20
15
10
5
0
F/E
LF
Rot
Typing
Mouse

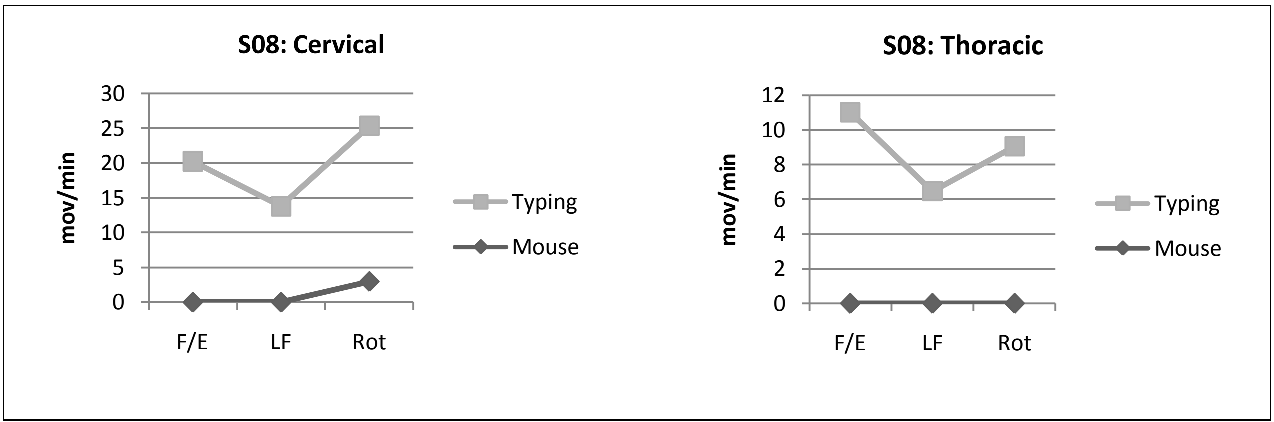

S05: Thoracic
mov/min
3
2
1
0
F/E
LF
Rot
Typing
Mouse


S06: Cervical
mov/min
30
25
20
15
10
5
0
F/E
LF
Rot
Typing
Mouse


S06: Thoracic
mov/min
7
6
5
4
3
2
1
0
F/E
LF
Rot
Typing
Mouse


S07: Cervical
mov/min
50
40
30
20
10
0
F/E
LF
Rot
Typing
Mouse


S07: Thoracic
mov/min
20
15
10
5
0
F/E
LF
Rot
Typing
Mouse



[a]Mov/min: Movements per minute
[b]F/E: flexion/extension, i.e. sagittal plane
[c]LF: lateral flexion, i.e. frontal plane
[d]Rot: Rotation, i.e. horizontal plane

5.4. Discussion

This is the first study that describes the 3D kinematics of the cervical and thoracic spines during keyboard and mouse use. The findings illustrate that the cervical and thoracic spines are more fixated while using a computer mouse compared to using a keyboard.

Range of motion describes the *magnitude* of the angle covered when moving a body segment through a specific plane of motion. The true range of motion may give us an idea about the physical size of the motion performed. However, we do not have a realistic reflection on the individual's capacity to perform that specific motion, and whether the magnitude of this movement lies within normal range. Movement can be influenced by a number of intrinsic factors such as muscle tone, joint laxity, age, gender or chronic pain (Einkauf et al., 1987; Lundberg and Gerdle, 1999; McGill et al., 2003), which may differ among individual subjects. Subsequently, the true magnitude of normal, healthy movement will be different for each individual and can therefore not provide realistic values for inter-subject comparison. Previous sitting posture studies, in which only true range of motion was used as a parameter, have not described individual subjects, but have used these parameters for statistical analysis to determine measures of central tendency (Gold et al., 2012; Lissoni et al., 2001; Straker et al., 2009, 2008; Szeto et al., 2005). A more comparable parameter may be produced by calculating the true range of motion as a percentage of full available range of motion as performed in a sitting posture study by O'Sullivan (2012). The use of this parameter may allow for better and more realistic and comprehensive inter-subject comparison in future motion range studies. In normative studies, the use of this parameter may propose a common measurement to standardise the wide spectrum of subject-specific true ranges of motion in a bigger study sample.

The implication of the different reflexions provided by the true range of motion versus percentage range of available motion can be seen in the results of the present study (Table

5.3). Using an example, when comparing S03 and S04 in the mouse task for ‘Thoracic F/E’, the true range of motion differs by only 0.02 degrees, with S03 being the smaller of the two values. However, when considering the percentage range of motion, a difference of 0.58 can be seen with S03 now having the highest value. By implication, although S03 performed a *smaller movement* than S04, this subject moved through a much *bigger range available* to him than S04. This example marks the risk for obtaining inaccurate clinical information when considering only true range of motion in inter-subject comparison, thereby omitting the possible influence of subject-specific intrinsic factors on motion range.

The frequency of postural change provides information on the *amount* of spinal movement that took place per task and time period. Frequency of motion as measured by a 3D motion analysis system has been proposed as a parameter in previous posture studies (Van Niekerk, 2013). In certain studies describing keyboard and mouse use, variance in activity of selected muscles has been measured by electromyograpy (EMG). This was then used to derive general motion frequency of the relevant segments (Bruno Garza et al., 2012; Dennerlein and Johnson, 2006). Generally, keyboard use was associated with a greater variability in the muscle effort of the wrist extensors (Dennerlein and Johnson, 2006), which is suggestive of more frequent movement in the forearm. A greater variability of trapezius contraction was found with keyboard use than with mouse use (Bruno Garza et al., 2012; Dennerlein and Johnson, 2006); however, trapezius muscle effort for both the tasks was relatively low, leading to less complaints of neck and shoulder pain than lower arm pain (Arvidsson et al., 2008). It should be noted that the measurement of only a single muscle in a movement segment cannot provide a comprehensive and realistic representation of the kinematics of that segment. A motion analysis system may be able to capture more comprehensive information on various segments of the spine. No EMG studies to date have been done to determine muscle effort of any spinal muscles in keyboard and mouse use.

The findings of this study illustrate that thoracic and cervical ranges and frequencies of motion in the keyboard task exceed that of the mouse task. Bruno Garza et al. (2012) also studied the posture measurement of the torso, head and neck in relation to keyboard and mouse use – however, these measurements were done using tri-axial accelerometers and formed part of a greater set of data. In accordance with the current study, the authors associated keyboard use with more extreme postures of the head, neck and torso, especially in terms of cervical extension. Results from the current study also indicate that keyboard use exhibits much more activity in terms of spinal motion frequency than computer mouse use. Other studies on upper limb kinematics found similar results in terms of wrist (Bruno Garza et al., 2012) and shoulder movement (Dennerlein and Johnson, 2006). A more dynamic posture associated with the keyboard task may be due to the fact that keyboard use is a bilateral activity, requiring simultaneous motion from more body segments than with unilateral activity. Also, during a typing activity, many individuals will constantly alternate their gaze from the screen to the keyboard and/or to a document relevant to the keyboard activity, leading to a greater frequency of cervical movement. However, since no study to date describes 3D spinal kinematics in terms of motion frequency specific to mouse and keyboard use, further research will be needed to investigate the effect of the use of these input devices on the spine.

A possible explanation to mouse-related decreased motion frequency may be due to the fact that mouse use is a unilateral activity. Prolonged mouse use might result in a compensatory weight shift to the contralateral side in order to maintain center of gravity, which may entail the subject moving into and sustaining a fixed position. The more static posture during mouse use may also be due to the fact that mouse use requires higher demands on hand-eye coordination and visual focus, which may lead to a more constrained posture (Arvidsson et al., 2008). A possible alternative input device may be the use of a touch screen, which could potentially facilitate an increase in the frequency and magnitude of spinal motion. However, literature sources have provided contrasting findings on the association between touch screen use and musculoskeletal disorders (Toy et al., 2012). Posture related to touch screen use can be influenced by a number of factors, including the type of device used, the user’s interaction with the device and the type of task performed (Toy et al., 2012) as well as the positioning of the device (Toy et al., 2012; Young et al., 2012). Further research is necessary in order to provide more information about the effect of touch screen use on spinal kinematics, specifically in comparison to other input devices. A more futuristic approach could include the use of advanced technology similar to that of a seventh generation video game console, in which physical motion can be used as an input device. This would imply physical virtual ‘shifting’ of objects on a computer screen while positioned a distance away from the screen. The use of such technology may increase frequency and ranges of motion in the cervical and thoracic spines as well as both upper limbs, and will be a good variation for computer mouse use. Further research will be necessary to identify healthy ranges and frequencies of motion with the use of this technology.

It is noteworthy that in two subjects (Table 5.3, refer to S04 and S07), spinal motion magnitude from the mouse task exceeded that of the typing task, contrary to the rest of the sample. The mouse data in subject S04 implies a bigger motion range in the sagittal and horizontal planes than the frontal plane in the cervical spine (movement in the former two planes also exceeding those of the keyboard task). Conversely, in the thoracic spine, frontal plane movement exceeds that of the sagittal and horizontal planes (movement in the former plane also exceeds that of the keyboard task). Bruno Garza et al. (2012) suggested an increased range of sagittal plane motion of the head, neck and torso for both mouse and keyboard tasks. For this subject, a correlation with the above research exists only in cervical movement and not thoracic movement. The movement pattern observed may suggest that during the mouse task the subject gradually moved into, and sustained, a thoracic lateral weight shift with resultant bigger ranges of cervical rotation and flexion to keep the gaze fixed to the monitor. This theory is supported by the data describing frequency of movement, which shows a relatively low frequency of thoracic lateral rotation and a higher frequency of cervical flexion/extension and rotation in the mouse task. Therefore, even though certain movement ranges were generally larger with the mouse task than with the keyboard task, less frequent movement took place, suggesting a less dynamic spinal posture in the mouse task than in the keyboard task. Dennerlein et al. (2006) also found a more fixated posture during mouse use than during keyboard use; however, the author focused only on wrist and shoulder posture. A more constrained posture of the upper limb may be suggestive of a fixated posture of the cervical and upper thoracic spine, but to verify this, further research is necessary. Similarly, range of motion data in participant S07 implies a larger range of cervical lateral flexion in the mouse task than in the keyboard task. The movement pattern observed in S07 suggests movement into and sustaining lateral cervical tilt whilst engaging in the mouse task, resulting in potentially bigger and more frequent cervical rotational and flexion/extension movements to keep the gaze fixed to the monitor. This theory is once more supported by data showing a higher frequency of motion in cervical rotation and lateral flexion in the mouse task. Apart from cervical lateral rotation, the ranges of all the other spinal segments are considerably bigger in the keyboard task than in the mouse task for this subject, yet again suggesting a more dynamic posture with keyboard use than with mouse use. The findings correlate with those of Bruno Garza et al. (2012) who found more non-neutral cervical posture in the sagittal plane with less dynamic cervical rotation.

To conclude, movements of the thoracic and cervical spines tend to be considerably larger during keyboard use than during mouse use. Bigger spinal motion ranges may be suggestive of a more dynamic spinal sitting posture, thereby implying that regular keyboard use is less of a risk factor for musculoskeletal pain than the regular use of a computer mouse. This notion is supported by Bruno Garza et al. (2012), who stated that keyboard use was not found to be a pertinent risk factor for musculoskeletal disorders according to epidemiological literature. In contrast, Marcus et al. (2002) found an association between regular computer use and pain of the hand and arm. However, a number of literature sources have suggested mouse use to be an outspoken risk factor for the development of upper limb musculoskeletal pain (Arvidsson et al., 2008; Bruno Garza et al., 2012; IJmker et al., 2007). As illustrated in the above discussion, the consideration of data from both ranges and frequency of motion may provide a more comprehensive clinical picture than when considering either of these parameters in isolation.

Although mouse use is linked to decreased spinal movement when compared to keyboard use, the frequent use of both these input devices leads to a relatively monotonous sitting posture that is sustained for prolonged periods. The use of computers is inevitable in the occupational and academic environment worldwide; therefore, an alternative for the use of computer input devices needs to be established in order to increase spinal movement and subsequently decrease the incidence of pain and musculoskeletal disorders in the workplace. Simple interventions could include so-called ‘pause’ software, which briefly interrupts computer activity after a preselected time period, reminding the user to take a break from a prolonged sitting position. However, evidence for the usefulness of this intervention is poor (Slijper et al., 2007). The use of sit-stand desks has been proposed in order to facilitate the use of different postural positions for the performance of computer tasks. Studies have shown a strong association between the use of sit-stand desks and increased postural dynamism in sitting (Alkhajah et al., 2012), subsequently reducing sitting-related musculoskeletal pain. Chairs designed to facilitate spinal dynamics have also been proposed as interventions to decrease musculoskeletal pain associated with prolonged sitting. Many literature sources support the role of chair intervention in the reduction of musculoskeletal pain; however, the quality of available studies is moderate (O’Sullivan et al., 2012; Van Niekerk et al., 2012). Although all of these interventions may effectively reduce pain related to prolonged sitting, none of them facilitates reduction in the amount of keyboard or mouse activity performed.

This study had a number of limitations. The subjects were not evaluated in terms of intrinsic factors that might have influenced movement patterns considerably. The typist chair used had a limited potential for adjustment, making it difficult to position taller participants at the correct height according to methodological procedure. The analysis was mostly descriptive due to the large amount and complexity of the data. The lumbar spine was not included in the study. In future research, study of the lumbar spine together with the thoracic and cervical spines will provide a more comprehensive reflexion of spinal kinematics. The sample was also conveniently selected and was too small to be representative of the general population. However, the findings of this study can be used to determine sample sizes for larger, more representative studies.

5.5 Conclusion

Previous studies comparing posture between mouse and keyboard users have focused mainly on muscle activity of the upper limb and cervical areas as well as only upper limb posture. In this study, spinal kinematics of the cervical and thoracic spines were investigated specific to both keyboard and mouse use. Frequency and 3D motion range of cervical and thoracic spinal kinematics were measured. The main findings suggest that less frequency of movement of the thoracic and cervical spines is associated with mouse use compared to keyboard use. There was also a tendency for the range of cervical and thoracic movement to be larger with keyboard usage. This implies that keyboard use can be associated with a more dynamic cervical and thoracic spine than with mouse use. Subsequently, the regular prolonged use of a mouse may hold a bigger risk for spinal musculoskeletal disorders than the use of a keyboard. Future studies are needed for more comprehensive research on the potential association between prolonged mouse work and musculoskeletal pain, using a bigger and randomly selected sample, which is representative of the population. Such studies should include a larger variety of mouse and keyboard tasks in order to enhance the validity of real-time computer tasks.

CHAPTER 6 : ADDITIONAL FINDINGS

This chapter presents the findings that were not reported in Chapter 5. The methodological procedures described in the manuscript also apply to this section. The cervical and thoracic kinematics are described according to each computer task.

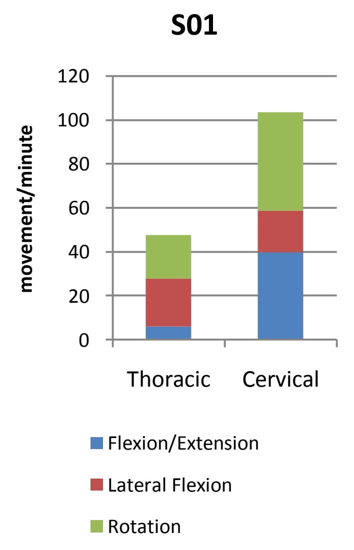
6.1 Task 1: Warm-up

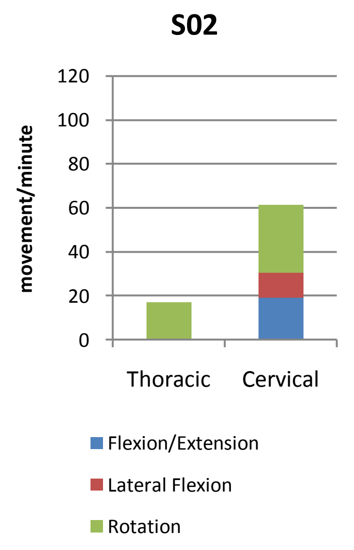
In this task, the subjects were required to strike different single keyboard keys with alternating hands. The aim of this task was to orientate the subjects with the computer program and to allow for some settling into the subject- and workstation setup.

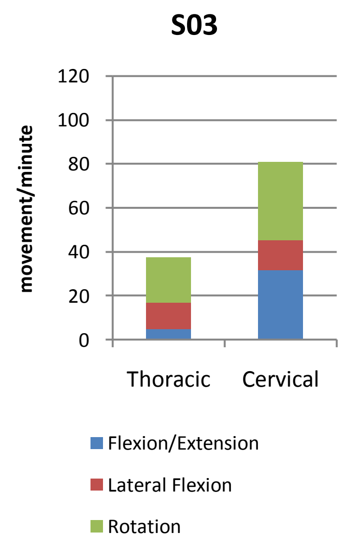
6.1.1 Frequency of motion

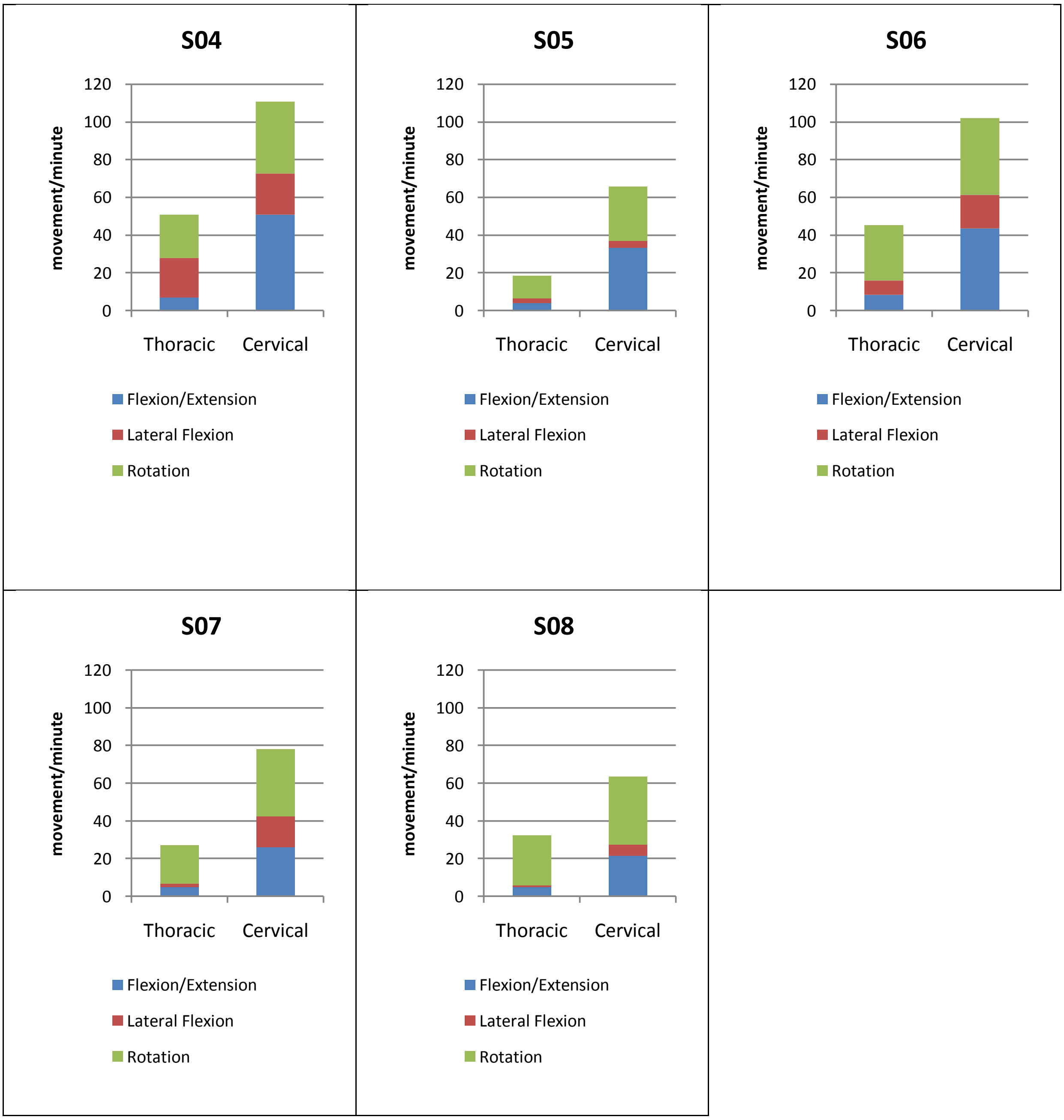
In all the subjects, cervical frequency of motion was higher than in the thoracic spine. Task 1 was also associated with the highest frequency of motion for both the thoracic and cervical spines when compared to the other tasks. Table 6.1 provides histograms in which the frequencies of thoracic and cervical motion of the study participants (S01 to S08) are presented.

Table 6.1: Task 1 - Frequency of motion









6.1.2 Range of motion

Table 6.2 summarises the Task 1 movement ranges for all subjects. Movement ranges in this task were generally small, with only one value exceeding 10 % of total range of motion.

Table 6.2: Task 1 - Range of motion

	Thoracic Spine						Cervical Spine					
	Flexion/Extension		Lateral flexion		Rotation		Flexion/Extension		Lateral flexion		Rotation	
	TRUE ROM[a]	% ROM[b]	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM
S01	2.046	3.995	4.276	6.479	4.357	5.892	6.452	4.479	2.508	2.897	4.960	2.792
S02	2.428	5.611	0.808	1.116	3.686	4.493	5.859	4.626	2.095	3.321	4.400	2.932
S03	4.059	9.395	3.118	4.113	4.562	6.011	8.825	7.522	2.024	2.459	5.054	4.076
S04	2.198	3.766	3.626	6.438	5.052	8.870	7.598	6.359	3.600	4.506	3.583	2.702
S05	1.376	2.191	2.139	3.623	3.257	6.499	5.979	5.808	2.620	3.215	10.041	6.441
S06	2.336	3.594	3.254	5.576	5.999	8.325	9.690	7.242	3.241	3.768	7.491	5.090
S07	1.416	2.418	1.241	2.006	4.912	10.310	4.767	3.057	3.340	4.119	6.354	4.644
S08	3.848	8.075	0.927	1.744	6.196	7.531	3.047	2.028	2.285	2.863	3.543	2.294
Average		4.881		3.887		7.241		5.140		3.393		3.872

[a] Range of motion (ROM) values between the 10th and 90th percentiles

[b] True ROM as a percentage of full available ROM

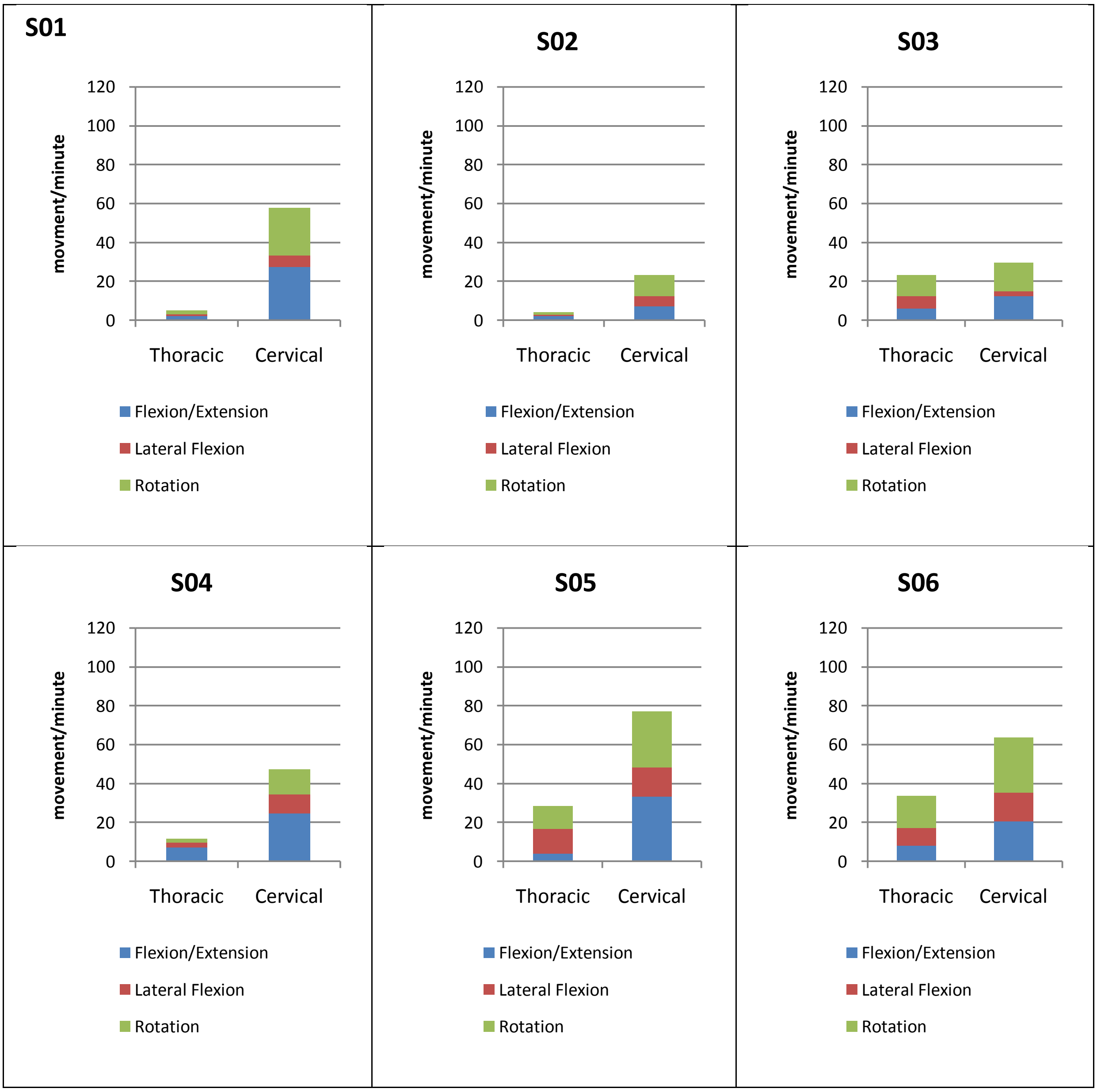
6.2 Task 2: Single keystroke typing

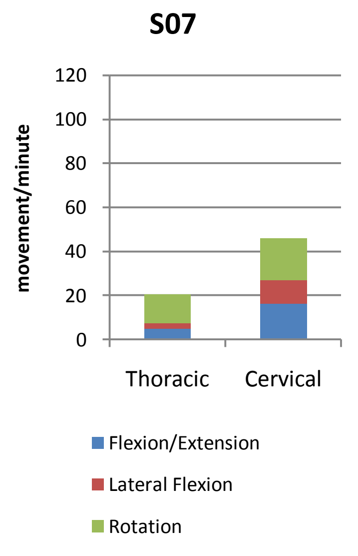
The second task was performed by striking four consecutive keys per set of questions.

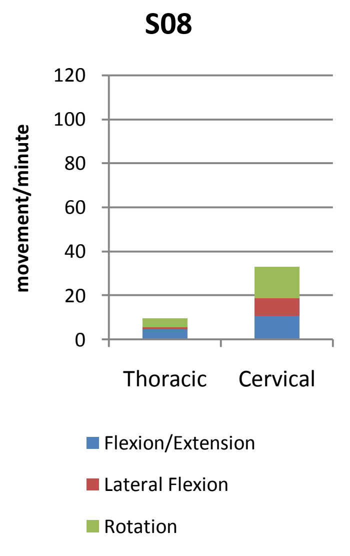
6.2.1 Frequency of motion

In all subjects, the frequency of motion in the cervical spine was higher than in the thoracic spine. It is interesting to note that for all cervical, and the majority of thoracic movement, least movement changes took place in the frontal plane. Table 6.3 shows movement frequencies of the two spinal segments by means of histograms.

Table 6.3: Task 2 - Frequency of motion







6.2.2 Range of motion

Cervical flexion/extension generally covered a bigger range than cervical rotation or lateral flexion in this task (Table 6.4).

Table 6.4: Task 2 - Range of motion

	Thoracic Spine						Cervical Spine					
	Flexion/Extension		**Lateral flexion**		**Rotation**		**Flexion/Extension**		**Lateral flexion**		**Rotation**	
	TRUE ROM[a]	% ROM[b]	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM
S01	3.748	7.320	1.818	2.755	2.111	2.855	10.944	7.598	2.818	3.255	4.097	2.306
S02	3.728	8.614	0.977	1.348	1.453	1.772	5.471	4.320	3.469	5.497	2.749	1.832
S03	2.749	6.362	2.762	3.643	4.905	6.463	9.667	8.240	2.656	3.227	2.877	2.320
S04	6.862	11.757	1.800	3.196	0.950	1.667	19.239	16.101	3.363	4.209	3.522	2.656
S05	1.897	3.019	1.069	1.812	2.127	4.244	8.262	8.026	4.083	5.010	3.371	2.163
S06	6.824	10.502	4.379	7.503	6.590	9.144	8.720	6.517	4.739	5.509	7.948	5.400
S07	3.590	6.130	2.524	4.080	4.747	9.964	6.974	4.473	5.535	6.826	7.809	5.708
S08	3.018	6.334	1.282	2.412	5.702	6.931	3.290	2.189	3.039	3.808	4.328	2.803
Average		7.505		3.344		5.380		7.183		4.668		3.149

[a] Range of motion (ROM) values between the 10th and 90th percentiles

[b] True ROM as a percentage of full available ROM

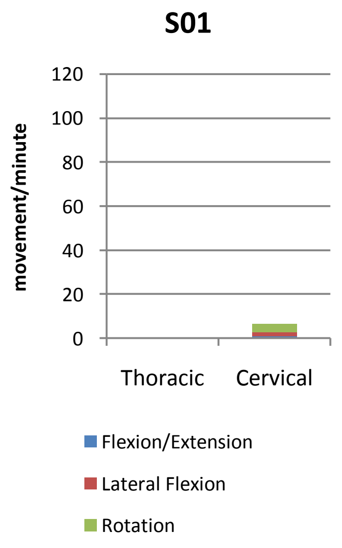
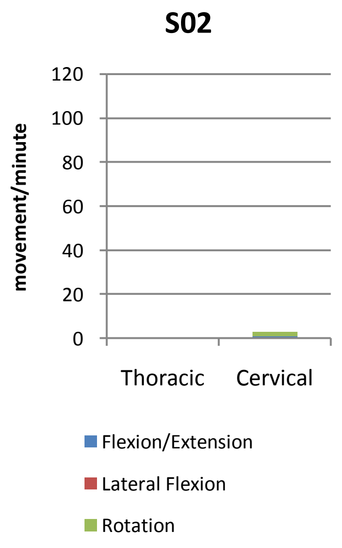
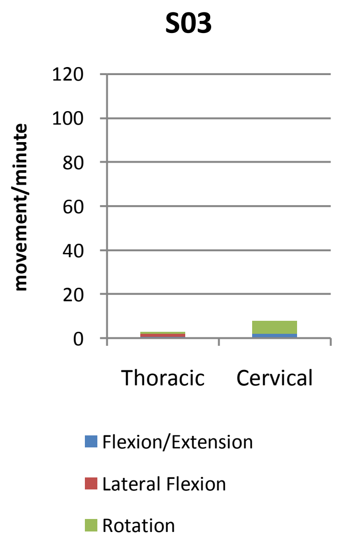
6.3 Task 3: Mouse clicking

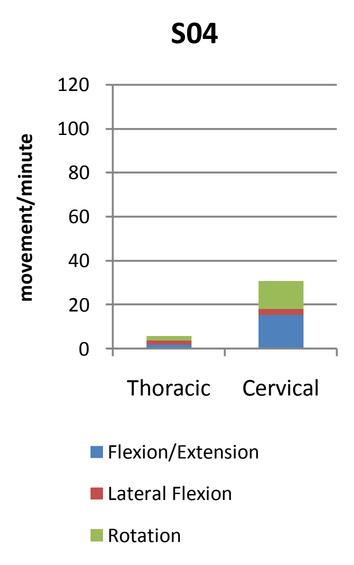
In this task, the subject was requested to click on specific areas of the screen.

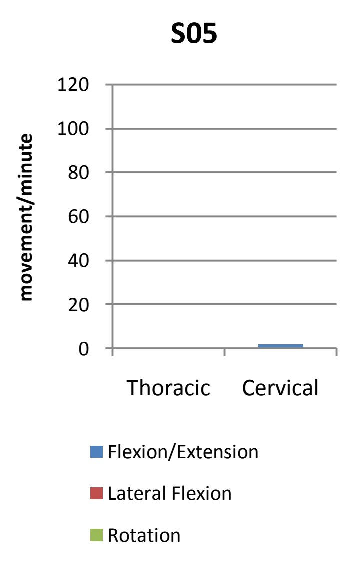
6.3.1 Frequency of motion

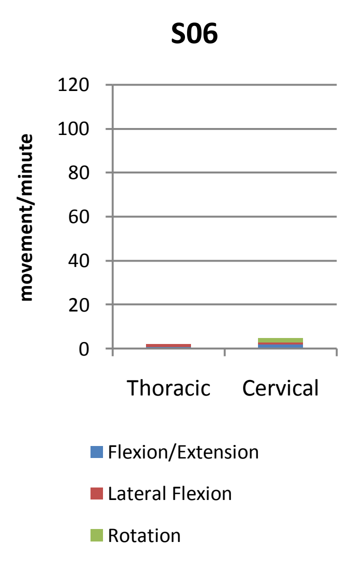
The mouse-clicking task was associated with frequencies of motions of all segments when compared with the other tasks. Table 6.5 presents motion frequencies of the two studied segments per subject. The same data is summarised in Figure 6.1 using a smaller scale for more visible representation of the various different planes of motion. It must be noted that in 50 % of the sample, no thoracic movement was recorded.

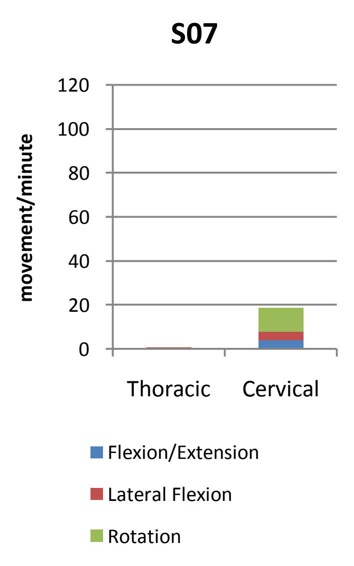
Table 6.5: Task 3 - Frequency of motion (a)


S04
movement/minute
120
100
80
60
40
20
0
Thoracic
Cervical
🟦 Flexion/Extension
🟥 Lateral Flexion
🟩 Rotation


S05
movement/minute
120
100
80
60
40
20
0
Thoracic
Cervical
🟦 Flexion/Extension
🟥 Lateral Flexion
🟩 Rotation


S06
movement/minute
120
100
80
60
40
20
0
Thoracic
Cervical
🟦 Flexion/Extension
🟥 Lateral Flexion
🟩 Rotation


S07
movement/minute
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Thoracic
Cervical
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🟥 Lateral Flexion
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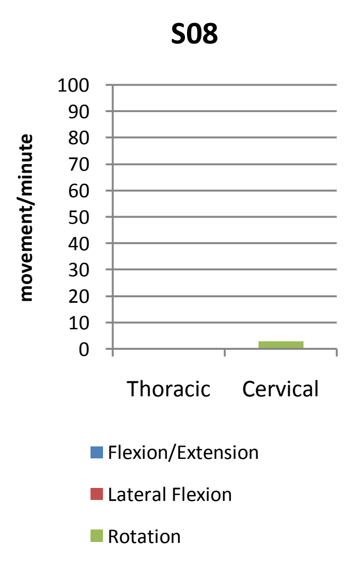
S08
movement/minute
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90
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70
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50
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30
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10
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Thoracic
Cervical
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🟥 Lateral Flexion
🟩 Rotation

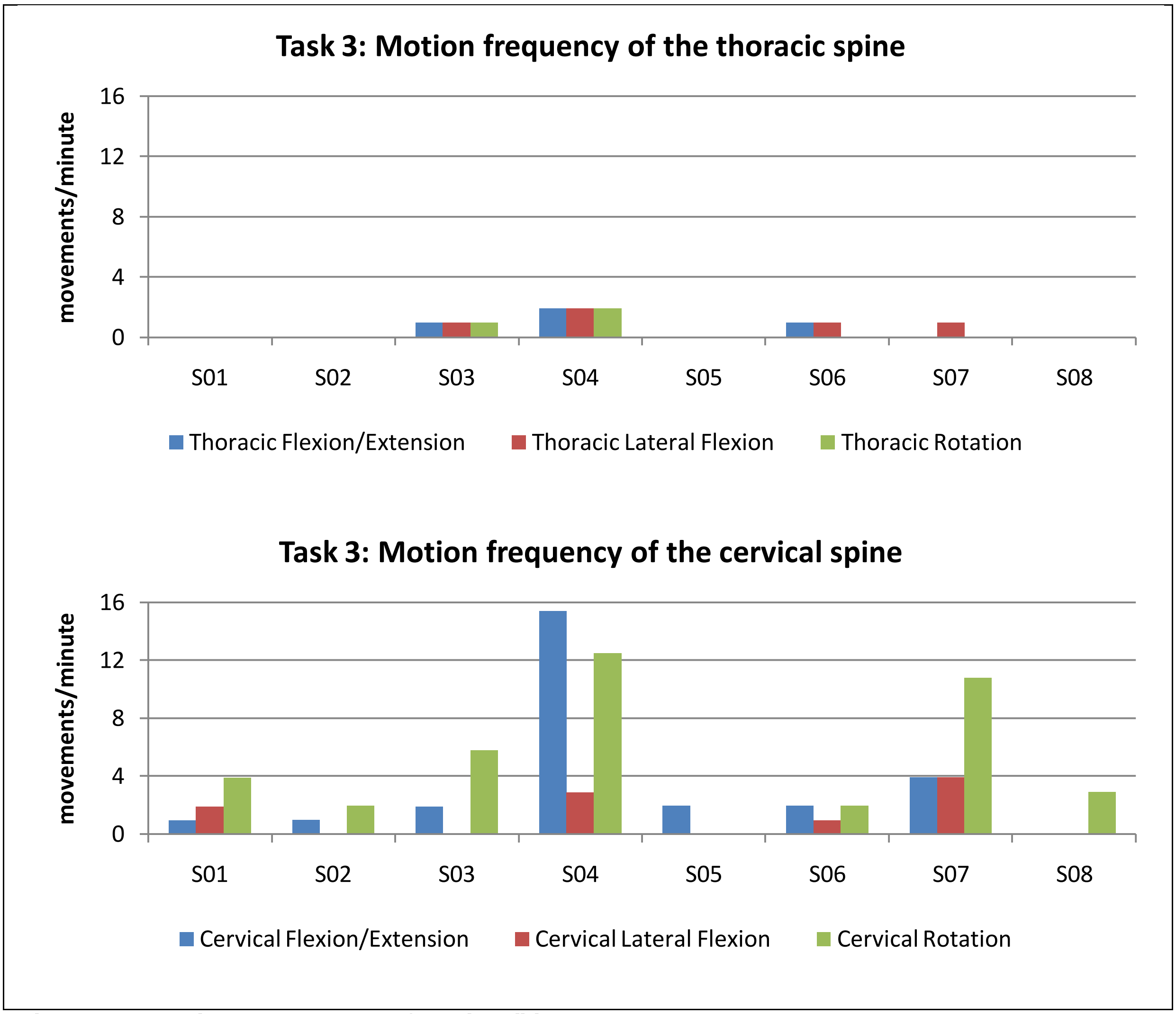


Figure 6.1: Task 3 - Frequency of motion (b)

6.3.2 Range of motion

This task is associated with generally lower ranges of motion in all spinal segments. A tabulated summary of motion ranges and further results from this task are discussed in detail in the article manuscript (see Chapter 5: 5.3.1, 5.3.2 and 5.4).

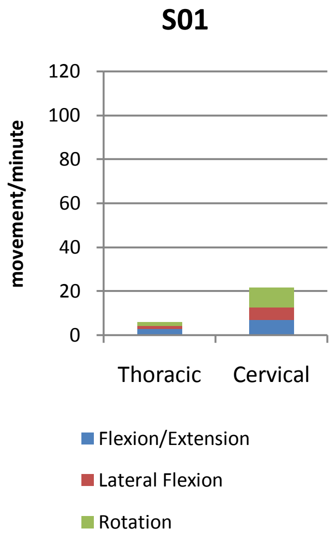
6.4 Task 4: Reading with interruption for diagonal movement over keyboard

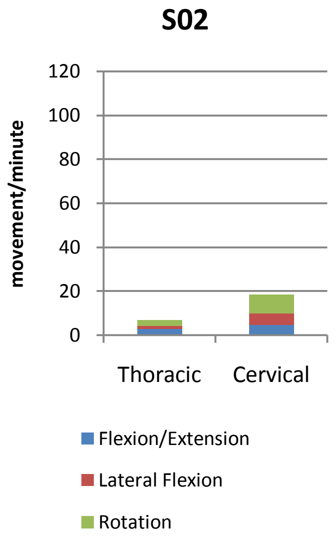
A section of fiction literature was read from the computer screen by the participant. A diagonal movement of the upper limb was performed during the course of the task.

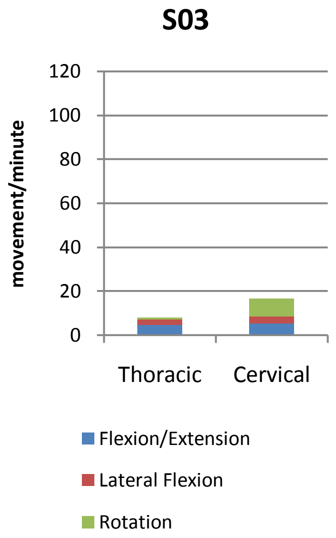
6.4.1 Frequency of motion

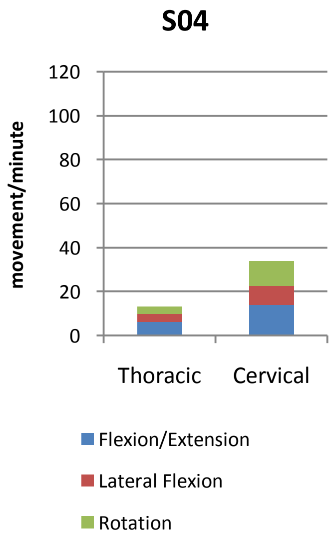
Again, more frequent movement took place in the cervical spine than in the thoracic spine. In the majortiy of subjects, frequency of thoracic movement in the sagittal plane exceeded that in the frontal and horizontal planes (Table 6.6).

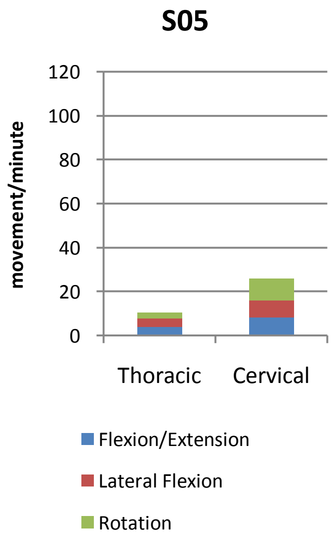
Table 6.6: Task 4 - Frequency of motion

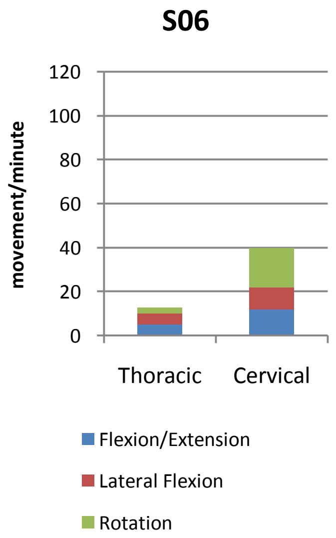


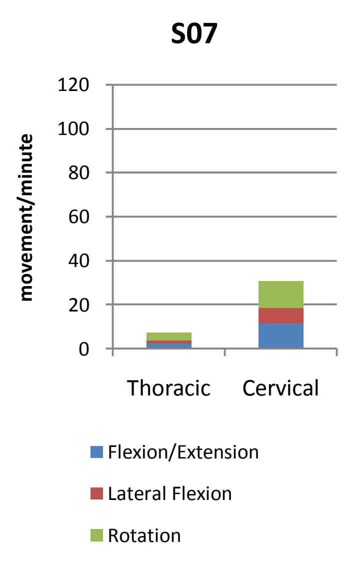


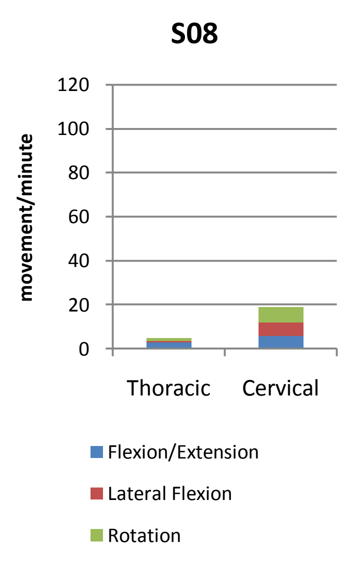












6.4.2 Range of motion

The range of motion data present the largest thoracic movement range when compared to other tasks (Table 6.7).

Table 6.7: Task 4 - Range of motion

	Thoracic Spine						**Cervical Spine**					
	Flexion/Extension		**Lateral flexion**		**Rotation**		**Flexion/Extension**		**Lateral flexion**		**Rotation**	
	TRUE ROM[a]	% ROM[b]	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM
S01	5.560	10.858	2.996	4.539	2.910	3.935	11.056	7.676	2.602	3.005	3.768	2.121
S02	2.571	5.940	1.567	2.163	5.149	6.277	6.765	5.341	4.785	7.583	5.120	3.412
S03	5.973	13.824	3.498	4.614	3.326	4.382	10.121	8.628	2.399	2.914	2.401	1.936
S04	9.486	16.253	1.588	2.819	1.102	1.935	18.251	15.274	3.838	4.804	5.934	4.475
S05	8.844	14.074	3.433	5.817	2.854	5.695	11.371	11.047	12.088	14.833	10.107	6.483
S06	5.295	8.149	3.286	5.629	5.078	7.046	7.535	5.631	6.990	8.127	7.434	5.052
S07	1.188	2.028	1.973	3.190	1.442	3.026	7.768	4.982	3.184	3.927	4.284	3.131
S08	4.282	8.986	1.027	1.932	1.382	1.679	7.661	5.098	2.740	3.433	4.219	2.732
Average		10.014		3.838		4.247		7.960		6.078		3.668

[a] Range of motion (ROM) values between the 10th and 90th percentiles

[b] True ROM as a percentage of full available ROM

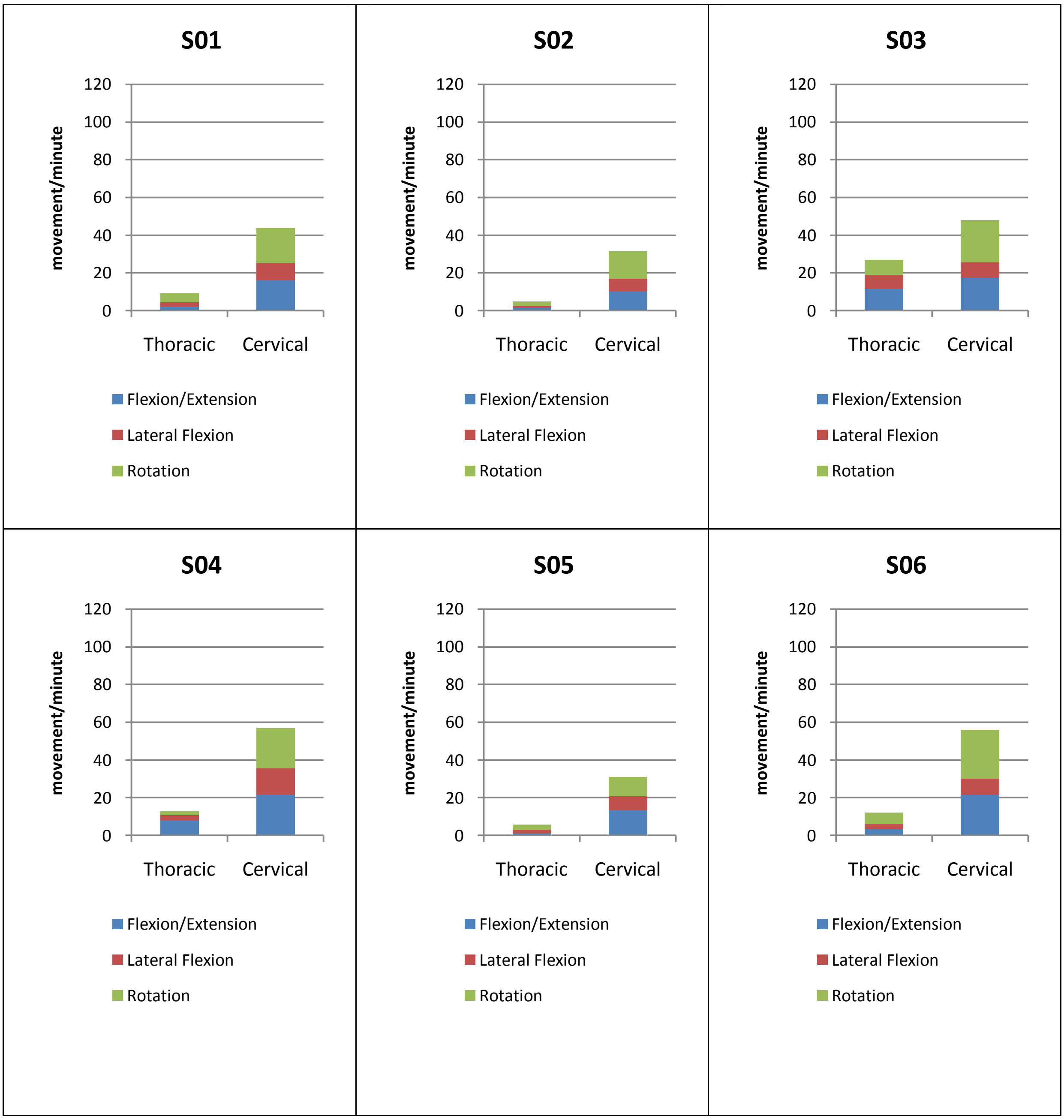
6.5 Task 5: Full sentence typing

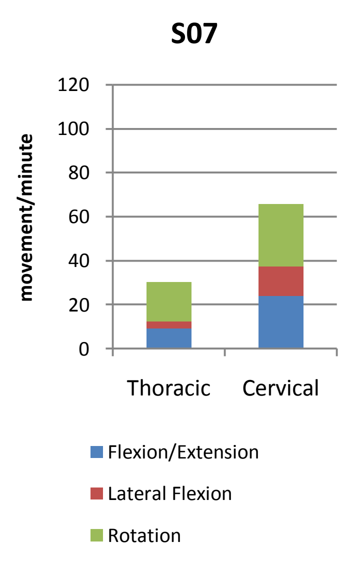
In this task, participants were required to answer questions by typing full sentences.

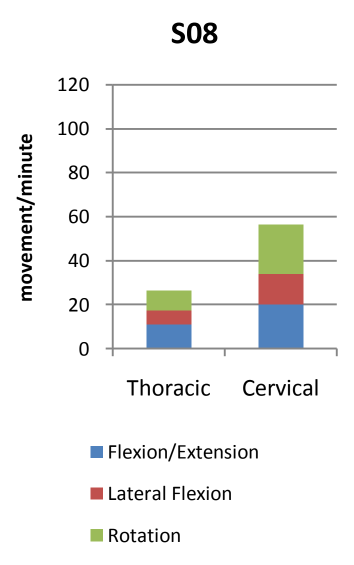
6.5.1 Frequency of motion

This task was associated with a moderate degree of frequency of motion of both cervical and thoracic spines when compared to the other tasks. Table 6.8 presents motion frequencies of the cervical and thoracic spinal segments of all participants.

Table 6.8: Task 5 - Frequency of motion







6.5.2 Ranges of motion

Ranges of motion in the thoracic spine tended to be relatively large in comparison to the other tasks. A tabulated summary of motion ranges and further results from this task are discussed in detail in the article manuscript (see Chapter 5: 5.3.1, 5.3.2 and 5.4).

6.6 Task 6: Cooling down

As with the first task, this 20-second task was not an imitation of a real-life computer task, but served only to end off the sequence of tasks. Both movement frequency and movement range during this short period were very small. Table 6.9 summarises the frequency of motion, and Table 6.10 gives a summary of the ranges of motion of Task 6.

Table 6.9: Task 6 - Frequency of motion (movements/minute)

	S01	S02	S03	S04	S05	S06	S07	S08
Thoracic Flexion/Extension	2.885	2.894	0.000	0.000	0.000	2.862	2.826	2.917
Thoracic Lateral flexion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Thoracic rotation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cervical Flexion/Extension	0.000	5.788	2.844	2.871	0.000	2.862	5.651	8.752
Cervical Lateral flexion	5.769	8.682	5.687	5.742	0.000	2.862	0.000	5.835
Cervical rotation	5.769	8.682	5.687	5.742	2.857	0.000	2.826	8.752

Table 6.10: Task 6 - Range of motion

	Thoracic Spine						Cervical Spine					
	Flexion/Extension		Lateral flexion		Rotation		Flexion/Extension		Lateral flexion		Rotation	
	TRUE ROM[a]	% ROM[b]	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM	TRUE ROM	% ROM
S01	1.854	3.621	0.543	0.823	1.306	1.766	2.498	1.735	2.995	3.460	4.404	2.479
S02	4.291	9.915	0.683	0.944	0.165	0.201	4.045	3.194	3.574	5.665	2.497	1.664
S03	0.863	1.998	2.101	2.772	0.471	0.620	5.849	4.986	2.295	2.788	4.288	3.458
S04	5.312	9.101	0.846	1.502	0.766	1.345	13.545	11.336	1.468	1.838	5.711	4.307
S05	1.130	1.799	1.012	1.714	1.146	2.286	4.145	4.027	1.186	1.455	1.714	1.100
S06	1.115	1.715	0.594	1.018	2.448	3.397	2.699	2.017	2.320	2.697	0.840	0.571
S07	0.658	1.124	0.772	1.248	0.185	0.387	3.838	2.462	1.311	1.617	4.245	3.103
S08	4.674	9.809	0.539	1.014	0.403	0.490	4.538	3.020	5.679	7.115	6.430	4.164
Average		4.885		1.379		1.312		4.097		3.329		2.606

[a] Range of motion (ROM) values between the 10th and 90th percentiles

[b] True ROM as a percentage of full available ROM

6.7 Total motion frequencies

Segmental motion frequency (i.e. total movements/minute of all three planes of motion) per task was calculated for both spinal segments across the entire sample. Figure 6.2 illustrates the relationship between the different tasks in terms of motion frequency for all trial captures.

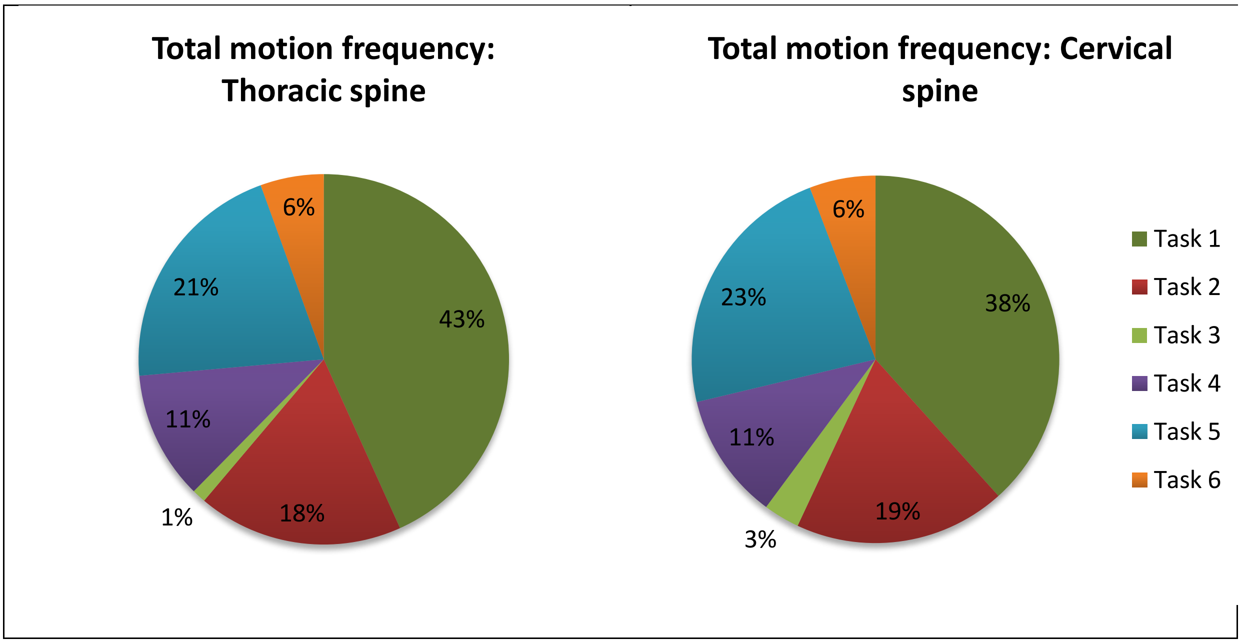


Figure 6.2: Movement frequency of different tasks

6.8 Conclusion

This chapter reports on the additional sitting posture results that were obtained, apart from those discussed in the article manuscript. Interpretation of these results will follow in the concluding chapter.

CHAPTER 7 : DISCUSSION AND CONCLUSION

The primary aim of this study was to provide pilot data for the description of postural dynamism. Postural dynamism specific to different computer tasks was described in terms of spinal kinematics, focusing on the ranges and frequencies of spinal movement. The measurement of 3D postural dynamism was effectively improved in terms of prior technical difficulties and description of outcome parameters.

The secondary aim of this study was to improve the 3D measurement of postural dynamism in sitting. The objectives were to reduce data processing time by improving marker visibility. In this study, data processing time was significantly decreased by means of technical adaptations to the data capturing process.

7.1 Technical aspects

7.1.1 Data processing time

The main focus for the reduction of data processing time was enhancing the visibility of the anatomical markers. Marker visibility was enhanced by means of optimised camera positioning, strategic workstation setup and marker placement (refer to Chapter 3, sections 3.1.1 and 3.1.2; Chapter 5, sections 5.2.3 and 5.2.4). Data processing time was also controlled by means of improved system preparation (including calibration and masking of potential ghost markers) and trial capture frequency (refer to Chapter 3, sections 3.2).

The eight available camera units were mounted on tripods. Optimal positioning was established by trial and error in a series of pilot studies and the final camera positionings in relation to the workstation were photographed and well documented (refer to Chapter 3, sections 3.1.1, 3.1.2 and 3.2.1). Gold et al. (2012) reported camera position in their study to be ‘an average of 2.53 metres away from the subject’, also implying that there is no gold standard for camera positioning. In other 3D sitting posture studies, camera placement was more symmetrical and patterned (Edmondston et al., 2007; Hansson and Oberg, 1996; Lissoni et al., 2001; O’Sullivan et al., 2012b).

The workstation layout was designed for minimal marker obstruction. The U-shaped foot-piece of the desk, which was specifically designed for this study, optimised lower leg and foot markers visibility. The backrest of the chair was removed to allow for good visibility of the posterior spinal markers (Refer to Chapter 3, section 3.1.2 and Chapter 5, section 5.2.3); this was similarly done by Lissoni et al. (2001). In other deskbound posture studies the workstation layout was determined more by the context and outcome measures of the study than by marker visibility. Szeto et al. (2005) and Straker et al. (2009) used standard desks and adjustable chairs. Straker et al. (2008) compared a horse-shoe shaped desk with a standard desk, with different heights of the visual display monitor. Other context-related workstation setups were performed by Hansson and Oberg (1996), who used a simulated tractor cockpit as the experimental setup. Gold et al. (2012) positioned the subjects in typical positions for laptop use other than being deskbound.

Marker placement was performed according to the full-body Plug-in-Gait model, as per protocol of the Stellenbosch University FNB 3D Motion Analysis Laboratory. Concerning the role of marker placement on visiblity, skin folds were identified as potential marker obstructions (specifically ASIS and substernal markers) (Refer to Chapter 3, section 3.2.3). A possible solution to this would be to place markers on extension sticks; however, similar attempts in previous studies led to poor detectibility of the sticks for these markers (Van Niekerk et al., 2008). Positioning of surface markers, or maybe clusters of markers, to avoid obstruction by skin folds should be investigated in terms of validity and reliability in future studies.

Trial capture was performed at a frequency of 25 Hz (per implication, 25 frames were captured per second). The capture frequency was lower than in other 3D sitting posture studies (Edmondston et al., 2007; Gold et al., 2012; Hansson and Oberg, 1996; Lissoni et al., 2001; O'Sullivan et al., 2012b; Preuss and Popovic, 2010; Straker et al., 2009, 2008; Szeto et al., 2005), It should be noted that all of these studies captured notably shorter durations of about two to three minutes. Based on the review in Chapter 2, none of the published studies reported on data of a 15-minute data capture time. Based on the volume of data, it would be impossible to collect posture data at a frequency higher than 25 Hz. Our rationale was that posture changes in sitting occur at a relatively slow rate and therefore 25 Hz would be sufficient to capture all postural changes (refer to Chapter 3 section 3.1.1; and Chapter 5 section 5.2.5). Future sitting posture studies could explore further possibilities regarding capture frequency.

7.1.2 Regulation of activity while performing the computer task

The control of activity performed by the subject during trial capture improves the repeatibility and thus reliability of 3D posture analysis. For this study, a computer program based on specific time frames was designed to provide a range of computer activities to be performed by the participant (refer to Chapter 3, section 3.1.3 and Chapter 5, section 5.2.5).

Instructions for every task were clear and concise and the subjects were allowed minimal opportunities to perform prominent uncontrolled movements. Previous studies involving computer activities also had a set framework for a sequence of closely controlled activities (O'Sullivan et al., 2012b). In other studies (Gold et al., 2012; Straker et al., 2009, 2008), subjects were also required to perform specific activities over time, but were given longer time periods for a monotomous activity (for example, ten minutes of reading from an encyclopedia or filling out a form), thereby increasing the probability of uncontrolled movements such as touching the hair or looking around. The occurrence of uncontrolled movements is not as such an undesirable factor – the aim of motion analysis might well be to study both controlled and uncontrolled movements relevant to a specific task or subject (Gold et al., 2012; Nicholson et al., 2001). However, for the purpose of the current study, the control of activity provided relatively analogous data among subjects, allowing for the observation of tendencies and movement patterns related to specific activities.

In order to study sustained sitting in real-life contexts in future research, postural dynamism can be further explored by means of field studies incorporating larger samples such as scholars, office workers or workers in the production industry. In order to replicate everyday activities that are specific to the individual, activities performed in such studies should be context-specific.

7.2 Postural Dynamism

In this study, postural dynamism was described in terms of kinematics of the thoracic and cervical spines. Movement in the cervical and thoracic segments was measured in terms of motion range and motion frequency (refer to Chapter 5, section 5.2.7). Six different computer tasks were performed and a computer mouse and keyboard were used as input devices.

Very different inter-subject trends of spinal kinematics specific to the different tasks were observed, although generic patterns were notable. The goal of this study was not to ascertain intra-subject reliability; this could be done in future studies. A general observation was the increased frequency of motion of the cervical spine when compared with the thoracic spine; not surprisingly so, since the cervical spine is known for its considerable mobility (Salem et al., 2013). In a systematic review, the importance of cervical spinal mobility for the functional movement and orientation of the sensory organs was highlighted (Bogduk and Mercer, 2000). In this study, the mean value for normal axial rotation of the cervical spine was reported to be 68.9 degrees. In contrast, Kouwenhoven et al. (2006) found axial rotation of the entire thoracic spine to be only 15.21 degrees. Regarding sagittal plane motion, mean cervical flexion/extension for healthy adults has been measured to be 107.6 degrees (Ordway et al., 1997). In comparison, mean thoracic flexion/extension in adolescents has been found to be 71.8 degrees (Widhe, 2001). According to this latter literature source, thoracic motion range decreases significantly with age, implying further decrease in mobility towards adulthood. Interestingly in the current study, even though the cervical spine had a much bigger actual motion range than the thoracic spine, thoracic movement ranges relative to full available ranges were not by trend smaller than cervical movement ranges. Spinal kinematics specific to the different tasks are discussed in the following section to explore these trends.

7.2.1 Warm-up task

In Task 1, the subject was required to strike different keys with alternating hands. The trends that were noted indicated generally larger ranges of motion in thoracic rotation than in thoracic flexion/extension or lateral flexion. The performance of this task is associated with the highest collective frequency of motion for both the thoracic and cervical spines when compared to the other tasks (refer to Chapter 6, section 6.1.1 and 6.7). All these observations are consistent with the activity performed – thoracic rotation is likely to occur coupled with subtle shoulder flexion when striking keys with alternating hands. A similar movement pattern was found in previous research, which has shown full range shoulder flexion in both the sagittal and scapular planes to be coupled with thoracic rotation (Theodoridis and Ruston, 2002). In this study, Theodoridis and Rustin also found thoracic lateral flexion to be coupled with shoulder flexion, which was not the case in the current study. This difference may be due to the fact that, in the warm-up task, shoulder flexion/extension was performed through a small range of motion, which may not have allowed for significant thoracic lateral flexion. The high frequency of motion in comparison to the other tasks in this study may be attributed to it being the first task and that the participants may not have settled into a more stationary position yet. Settling time into the sitting position has not yet been verified. In a study of the sitting posture whilst driving, Kyung et al (2008) considered 15 minutes as settling time, based on previous literature. However, these authors also reported that literature contradicts the actual time needed to completely settle into the sitting position. It is also questionable whether such a timeline can realistically be established. Future technological advances may allow longer capture durations to address some of these isssues.

7.2.2 Typing tasks

The second task involved answering multiple-choice questions by striking four consecutive keys per set of questions. In the fifth task, the participants were required to answer questions by typing long sentences. The anticipated motion patterns for both of these tasks were a continuous alternation of gaze between the screen and the keyboard, resulting in general spinal flexion/extension movements. Accordingly, in both the typing tasks, frequency of sagittal plane movement and horizontal plane movement was more than frontal plane movement. This tendency is more prominent in the cervical spine than in the thoracic spine (Chapter 6, refer to 6.2 and 6.5). Interestingly, rotatory motion in the cervical spine occured more frequently in the majority of the subjects (refer to Chapter 6, sections 6.2 and 6.5, Table 6.3 and Table 6.8), although sagittal plane movements were generally bigger in range than horizontal and frontal plane movements (refer to Chapter 5, section 5.3.1 (Table 5.3b) and Chapter 6 (Table 6.4)). When considering healthy spinal movement, motion either occurs purely in the primary planes of motion (i.e. sagittal, frontal or horizontal), or as a combination, implying a primary motion coupled with motion in other planes. According to Salem et al. (2013), cervical flexion/extension and rotation are the most frequently executed movements of the cervical spine. The abovenamed authors also described cervical rotation to be coupled with both cervical flexion/extension and lateral rotation, depending on the spinal segment studied. According to Malmström et al. (2006), cervical flexion is coupled with a great deal of rotation. In the current results, frequent motion in the horizontal and sagittal planes, together with the largest range of motion in the sagittal plane, may be suggestive of primary flexion/extension with a great deal of coupled rotatory movements in the cervical spine.

Edmondston et al. (2007) studied thoracic rotation and coupled lateral flexion, from initial positions in different degrees of flexion/extension. According to Edmondston et al., rotation is the dominant direction of movement of the thoracic spine. Lateral flexion coupled with thoracic rotation is related to the starting position – if rotation initiates from end-range thoracic flexion, the frequency of coupled lateral flexion is higher than when the movement is initiated from a more neutral spine. When observing thoracic motion frequencies, less frequent lateral flexion coupled with rotation may be indicative of a more neutral posture; conversely, more frequent lateral flexion motion may indicate a more flexed thoracic spine.

In the results of the current study, no relation between higher ranges in the sagittal plane and higher frequencies of frontal plane movement in the typing tasks could be observed. The frequency of motion of thoracic rotation was generally slightly higher than the frequency of flexion/extension in the sample. However, the ranges of motion of flexion/extension in the majority of subjects exceeded those of rotation (Chapter 6, sections 6.2 and 6.5). This may be indicative that flexion/extension was the primary motion performed in the typing tasks. In the study by Edmonston et al. (2007), rotation served as the primary motion; therefore, the resultant coupled movements observed may differ from the coupled movements performed in the current study. Future studies may verify primary and coupled movement patterns typical to keyboard activities in order to identify aspects of motion that may be a risk for musculoskeletal pain.

7.2.3 Mouse clicking task

In the third task, the participants were required to click on the different locations indicated on the screen. Both range and frequency of motion that were measured in this task indicated a stationary spinal position for the whole duration of the activity. The duration of this task was relatively short in comparison to the other tasks, which may sustain the argument that movement might have increased with time if the duration was longer. However, in a study by Bruno-Garza et al. (2012) mouse use contributed to 42 % of computer activity over approximately two hours, and was also associated with a more fixated posture of the cervical spine and the upper limb. In the current study, no thoracic motion was recorded for 50 % of the participants.

Decreased motion over a prolonged period of time may lead to sustained load on intervertebral discs as well as damage to the cartiligious endplates of vertebral bodies. Both of these factors increase the risk for longterm premature intervertebral disc damage with subsequent pain in the vertebrae and surrounding soft tissue. When considering the relationship, as reported, between thoracic and upper limb motion (Theodoridis and Ruston, 2002), the abscence of thoracic motion implicates minimal shoulder movement. This occurrence is substituted by the findings of Dennerlein et al. (2006), who also found a decreased posture variation as well as non-neutral angles (specifically external rotation) of the shoulder associated with mouse use. Sustained movement of the shoulder in an extreme position may also lead to scapular muscle imbalances and sustained tension on soft tissue structures, in turn resulting in musculoskeletal pain in the shoulder complex.

To conclude, the movement patterns observed in this study link mouse work with decreased postural dynamism of the spine, with consequential increased risk for musculoskeletal pain (Prins et al., 2008; Pynt et al., 2008). In future studies, the time period of mouse activity may be increased to observe the effect of mouse use over a longer time period. Different computer activities of similar duration may also provide more comparable data in posture analysis studies specific to computer use. Future studies should ideally have an equal time of activities for better comparison.

7.2.4 Reading task

In the fourth task, the participants had to read a piece of fiction displayed on the monitor. At a given moment the participants were requested to use their right hand to lift up an object positioned on the left-hand side of the keyboard and to place it on a designated position marked on the right-hand side of the keyboard. Bruno Graza et al. (2012) reported idle activity (that is, not engaged with either continuous mouse or keyboard activity) to be associated with the greatest variability in all head, neck and torso postures when compared to mouse and keyboard activities. In the current study, only a moderate motion frequency in both the thoracic and cervical spines was found when compared to the other tasks (refer to Chapter 6, section 6.7); however, data describing range of motion shows thoracic movements for this task to be the largest compared to all other tasks (refer to Chapter 6, section 6.4). It should be noted that the diagonal movement (included in the task to test upper limb marker visibility when moved accross midline) may have obscured realistic range of motion data for this task, since such an activity would not typically occur when reading from a computer monitor. Further research is necessary to study different activities that may occur during an idling period, as well as the effect of these on spinal kinematics over a prolonged time period.

7.3 Limitations and recommendations

The study had a number of limitations. A small convenience sample was used, with exclusion of candidates with above-normal ranges of body-mass index and waist-hip ratio. For future 3D sitting posture studies, a much bigger sample with a larger representation of the population to be studied will be needed for accurate normative data. Normative studies are needed to define normal spinal kinematics and dynamism in order to classify atypical patterns that may predict pain or musculoskeletal dysfunction. The process for marker placement should be standardised and validiated for all body shapes in order to overcome the limitation of marker obstruction by skin folds.

This study focused only on inter-subject and task-specific movement patterns of the cervical and thoracic spines. Future studies with access to innovative technology could focus more on intra-segmental movement tendencies, and should also include the lumbar spine in order to provide comprehensive information on spinal dynamism.

In this study, the only computer input devices studied were the keyboard and the mouse. Emerging new information technology devices such as laptops and touch-screen tablets should not be overseen. The use of more recently developed computer input devices should be included in future workstation-based sitting posture studies.

Randomized controlled trials can be conducted to test the effect of possible workstation alterations on postural dynamism and musculoskeletal symptoms.

7.4 Conclusion

The aim of this study was to improve the 3D measurement of postural dynamism in sitting. Task-specific postural dynamism will provide researchers with a better understanding of the posture-related predictors of pain associated with prolonged computer usage. Computer activities that are associated with a higher risk for musculoskeletal disorders due to decreased postural dynamism can be identified and alternatives can be investigated. The accurate and reliable measurement of spinal postural dynamism enables a comprehensive analysis of human movement whilst sitting at a desktop computer.

The identification and alteration of technical limitations for 3D sitting posture measurement made a significant improvement in data processing time. This enabled the analysis of postural dynamism by measuring frequency and total range of the cervical and thoracic spine while subjects performed typical computer tasks. General trends of postural dynamism were noted between subjects. This included relatively less dynamism during mouse tasks compared to typing on a keyboard.

The improvement of a 3D motion analysis system in terms of data processing simplifies the operation and use of this tool to study sitting posture, thereby improving its efficacy as a measurement tool in empirical studies. The current study marks the need for further research for verification of the findings and further investigation into understanding human sitting posture and how it relates to pain.

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APPENDICES

A. Vicon calibration protocol

System calibration was performed according to standard laboratory protocol. The laboratory technician performs a ‘wand wave’ by moving a standard Vicon Calibration T-wand throughout the capture volume. The system detects the wand moving within the volume and calibrates accordingly. This allows a large capture volume to be calibrated by a small calibration object. The T-wand is then placed at the lower right, front corner of the desk to specify the system measurement origin.

Further, the subject calibration is split into a static and dynamic portion. The dynamic calibration accurately positions joint centres within the biomechanical model, while static calibration calibrates limb lengths and orientations within the model. Dynamic calibration was done prior to a series of consecutive trials, and static calibration was performed before each individual trial. During the static trial, each participant was required to assume a T-pose (participant erect with both shoulders abducted to 90 degrees). The trial was reconstructed by manually labelling each marker in relation to each other, in order to produce a 3D graphical image of the participant.

B. Marker placement protocol

The marker placement protocol used at the SU FNB motion analysis laboratory is based on the protocol of the full-body Plug-in-Gait (PIG) model. Anatomical landmarks are summarised in the following table.

Table 1: Marker placement protocol based on the full-body PIG model

Segment	**Section**	**Landmarks**[a]
Head	Front of Head	Approximately over temples
	Back of Head	In horizontal line to front markers
Torso	Clavicular	Suprasternal notch
	Sternal	Xiphoid process
	Right Back	Approximate centre of scapula (right side only)
	C7	Spinous process of C7
	T10	Spinous process of T10
Arm	Shoulder	Acromioclavicular joint
	Elbow	Humeral lateral epicondyle
	Wrist medial	Medial
	Wrist lateral	lateral
	Finger	Dorsum of hand, below head of 2nd metacarpal
Pelvis	Anterior	Anterior superior iliac spines
	Posterior	Posterior superior iliac spines
Leg	Knee	Femoral lateral epicondyle
	Thigh	Lower 1/3 surface of thigh lateral, just below swing of hand, in line from greater trochanter to knee marker
	Ankle lateral	Lateral malleolus
	Tibia	Lower 1/3 surface of tibia lateral, in line with knee and ankle markers
	Foot: Toe	Head of 2nd metatarsal
	Foot: Heel	Calcaneus, on the same height from dorsum than toe marker

*All head and peripheral landmarks with exception of Right Back is positioned bilaterally

C. Ethical approval

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Approval Notice
New Application

27-Jul-2012
VAN EEDEN, Saric Marissa

Ethics Reference #: S12/06/158
Title: Reducing data processing time in the three-dimensional measurement of postural dynamism in sitting: A feasibility study

Dear Miss Saric VAN EEDEN,

The **New Application** received on **19-Jun-2012**, was reviewed by members of **Health Research Ethics Committee 1** via Expedited review procedures on **24-Jul-2012** and was approved.
Please note the following information about your approved research protocol:

Protocol Approval Period: **24-Jul-2012 -24-Jul-2013**

Please remember to use your **protocol number** (S12/06/158) on any documents or correspondence with the REC concerning your research protocol.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

After Ethical Review:
Please note a template of the progress report is obtainable on www.sun.ac.za/rds and should be submitted to the Committee before the year has expired.
The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number projects may be selected randomly for an external audit.
Translation of the consent document in the language applicable to the study participants should be submitted.

Federal Wide Assurance Number: 00001372
Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Helene Visser at City Health (Helene.Visser@capetown.gov.za Tel: +27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.
For standard REC forms and documents please visit: www.sun.ac.za/rds

If you have any questions or need further help, please contact the REC office at 0219389657.

Included Documents:
Consent
Protocol
Checklist
CV
Appendices
Declaration
Application
Synopsis

Sincerely,

Franklin Weber
REC Coordinator
Health Research Ethics Committee 1

D. Data collection forms

The following form was used for the collection of anthropometric data of the study participants.

Data Capture Form

Client Code ☐ **Capture Date** ☐

	Left	Right
Weight		
Height		
Leg Length		
Knee width		
Ankle width		
Shoulder Offset		
Elbow Width		
Wrist Width		
Hand Thickness		
Popliteal Height		