

Testing and Evaluation of an Ergokinetic™ Split-Seat Office Chair

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1 Introduction

1.1 Aims and Objectives

Aims

Evaluate the differences of human motion for subjects seated in an Ergokinetic™ Split Seat chair and seated in a standard office chair.

Objectives

Use a motion capture system for motion recognition. Set up a motion scene. Define a set of workstation motion tasks. Complete motion capture studies.

Post process all motion track data files ready for data analysis . Analyse data and produce report.

1.2 Motion Capture and System

Motion capture often abbreviated as ‘mocap’ is defined as “The creation of a 3D representation of a live performance.” Current motion capture systems can be separated into two main groups, optical systems and non-optical systems. The most common of the above, passive optical systems require the subject to wear a body suit with markers attached, coated with a retro-reflective material. Light is then reflected back to the

camera's lens, and when two or more cameras see this marker, a 3D position can be obtained. Multiple cameras are used to update a computer of the marker's exact position at up to 500fps. System setups can have anywhere from 6 - 300 cameras at any one time. The more cameras present, the less likely marker swapping/missing will occur as more cameras will be able to see a single marker at any given time. Having additional cameras also helps with the ability to capture a group of people or more than one subject in a larger capture volume.

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The hardware used to capture the body motion of participants was the MotionAnalysis Eagle Digital System. This is an optical motion capture system, consisting of Digital Cameras, the Eagle Hub, to which all cameras are connected and uplinks to a computer terminal. All the hardware components are controlled by EVaRT 5.04 Real Time software. It is within this software where all data is recorded, processed and displayed, and where post processing takes place.

The system is capable of capturing the most complex of motions with extreme accuracy, to the nearest 2mm and up to 200 frames per second. For our purposes a capture rate of 120 frames per second was adequate. As the Eagle system has real-time capabilities it is possible for the user to see capture results at the same time as the subject is performing the specific workstation motion tasks.

The different stages of a complete motion capture session can be typically summarised as follows:

Studio set-up for multi-camera capture Calibration of motion capture system Capture of motion Clean-up and post-processing of point cloud data.

A brief description of the general tasks required for a capture session will be described in the following section.

1.2.1 Planning a session

Before a capture session can begin a suitable space must be found. A room with no external light is ideal but very hard to find, a suitable alternative was a room with specific black curtains that blocked out 100% of natural light. An open space with flat flooring and a matt finish surface with no furniture nearby, in the cameras field of view is essential. In the case of capturing samples of full body human motion, the space must be at least large enough for a subject to walk freely around. Fortunately for us, our subjects will be stationary and in the seated position, therefore a capture volume of approximately only 3m by 2m squared is required. This in turn, will allow for the closer placement of

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the cameras to the subject's body, in the hope of capturing clean data. See Fig.1 for an image of the typical motion study scene.

Fig.1 -Participant wearing the motion capture suit and seated in the Ergokinetic chair during a capture session.



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2 Methodology

Motion Study– Eleven camera setup For the motion study, an 11 camera setup was planned using 7 cameras from the Motion Analysis Eagle system and 4 cameras from the Motion Analysis Hawk system. A custom marker set was used, this marker set will be discussed further in section 2.2. Each participant was asked to provide personal information which remained confidential. (Name, Age, Sex, Occupation, Contact Details –Email/Tel.). Each participant was assigned a unique anonymous ID number. For anthropometric data, each participant's weight and height was measured and recorded. Reference markers were placed on the underside of the seat and side of the office desk to record accurate heights of both in 3D space. A preliminary measurement of seat height was measured manually whilst the participants were in seated and standing positions on both chairs. For the motion study, 8 workstation tasks were planned, and each participant was asked to repeat the tasks 4 times. Once whilst seated in the standard (ordinary) office chair with their back against lumber support (SOB). Once seated at the front of the standard office chair (SOF). Once whilst seated in the Ergokinetic split-seat chair with their back against lumber support (EGB). Once seated at the front of the Ergokinetic split-seat chair (EGF). See section 2.3 for full list of workstation motion tasks. At the end of each participant session a questionnaire was also completed with questions about the participant's opinion on the study and the chair, and also to get a better understanding of their use with office chairs in everyday life. See appendix A for a copy of questionnaire.

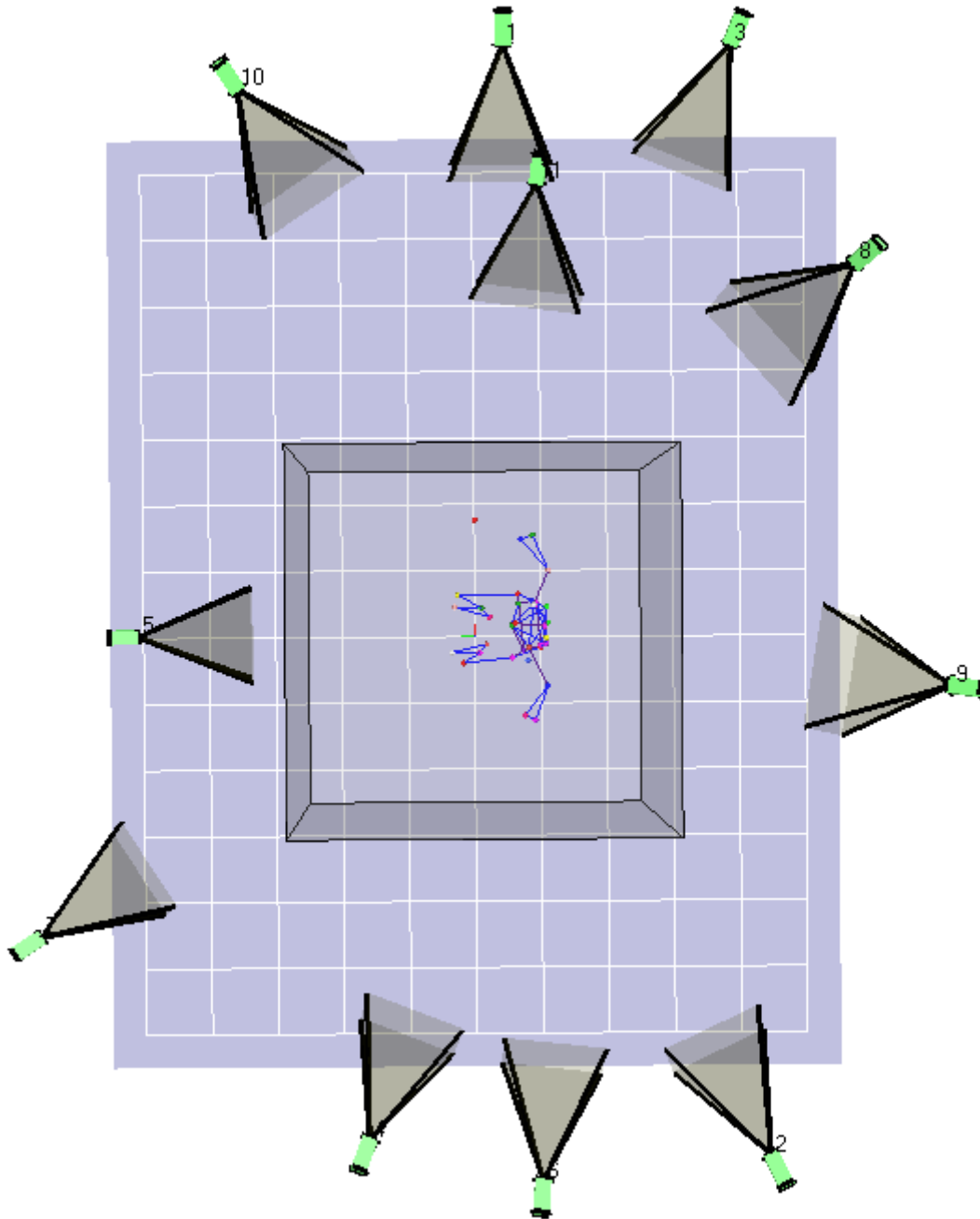
2.1 Scene Setup

Capturing took place in the indoor laboratory described before. With a greater number of markers placed on the back of the subject with the custom marker set, and the constant occlusion from the back rest of the chair, it was vital to have a minimum of 3 cameras placed directly to the left and right of the participant. All cameras located behind the subject were set to the tallest height and arched downward to capture as many of the

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high/mid back markers as possible. Cameras 1 and 5 as displayed in Fig.2, were placed at their lowest height to capture as much data below the office desk. The remaining cameras were evenly spaced. The final layout of the 11 cameras can be seen in Fig.2.

Fig.2. - 11 camera setup



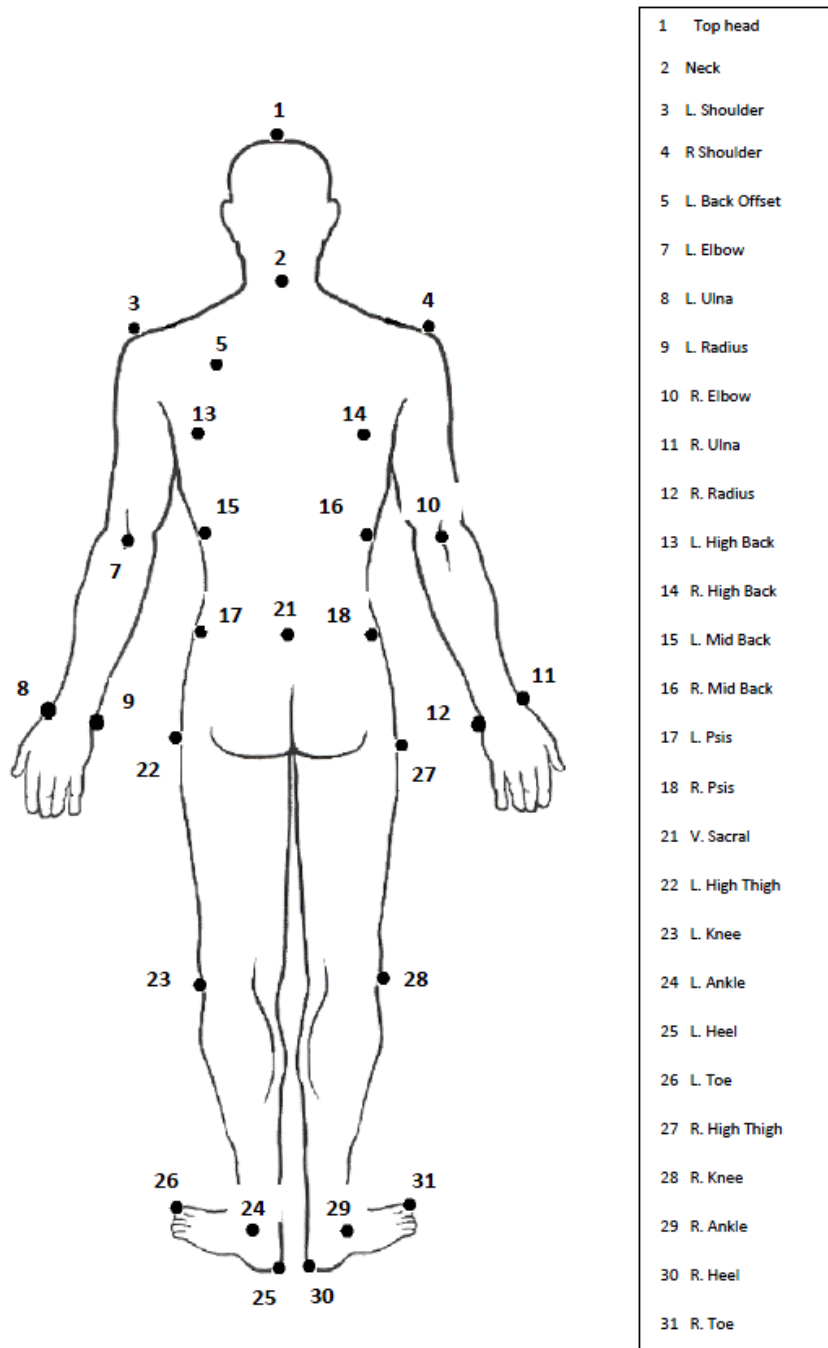
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2.2 Custom Marker Placement

A custom marker set was used to analyse in greater detail the back motion of each participant. The custom marker set is composed of 31 markers instead of the 41 markers used for the jack marker set. A total of 8 markers were placed on the back as opposed to only 5 used in the Jack marker set. The Custom marker set used is displayed in the figures

below.

Fig. 3 – Back view of custom marker placement



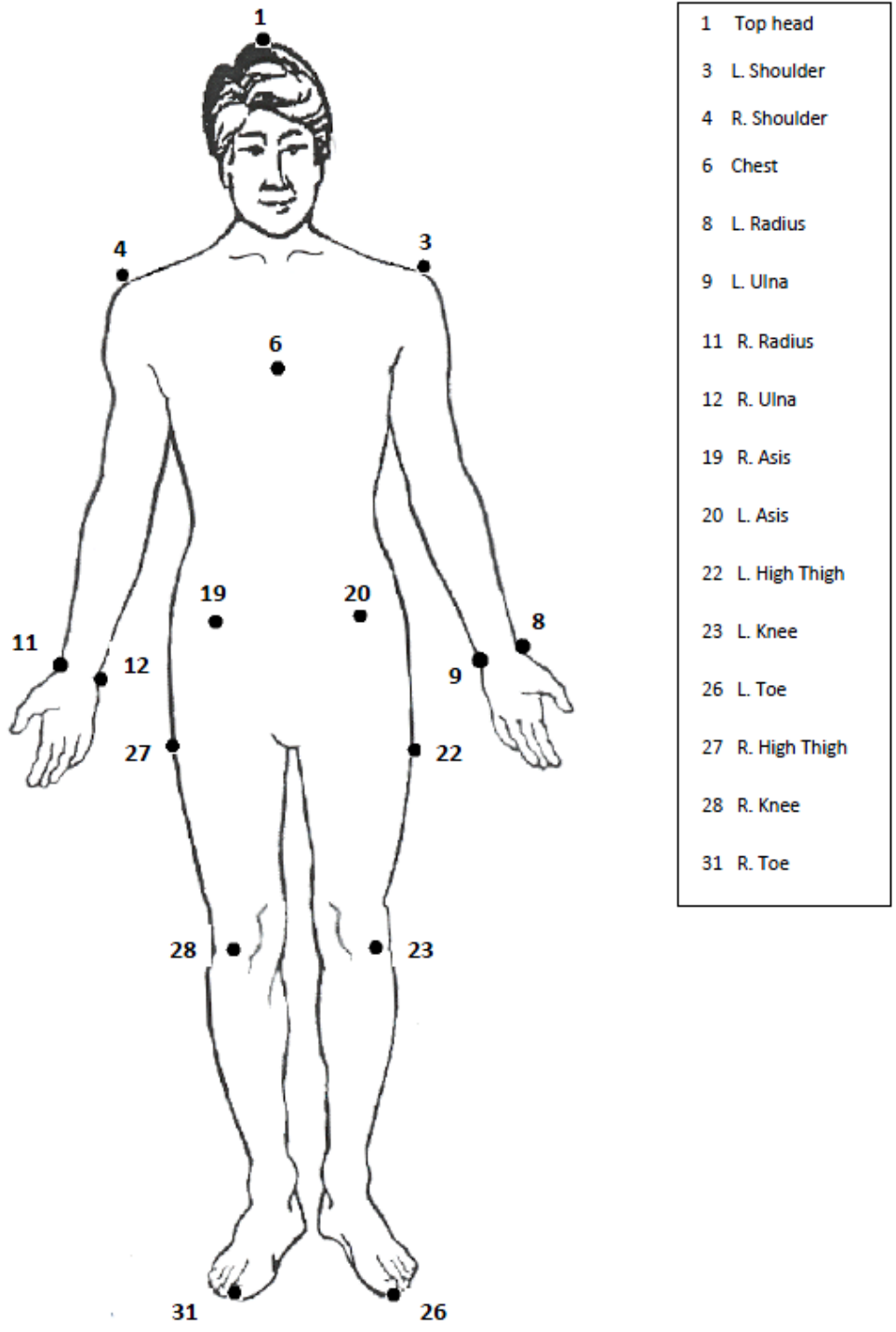


Fig. 4 – Front view of custom marker placement

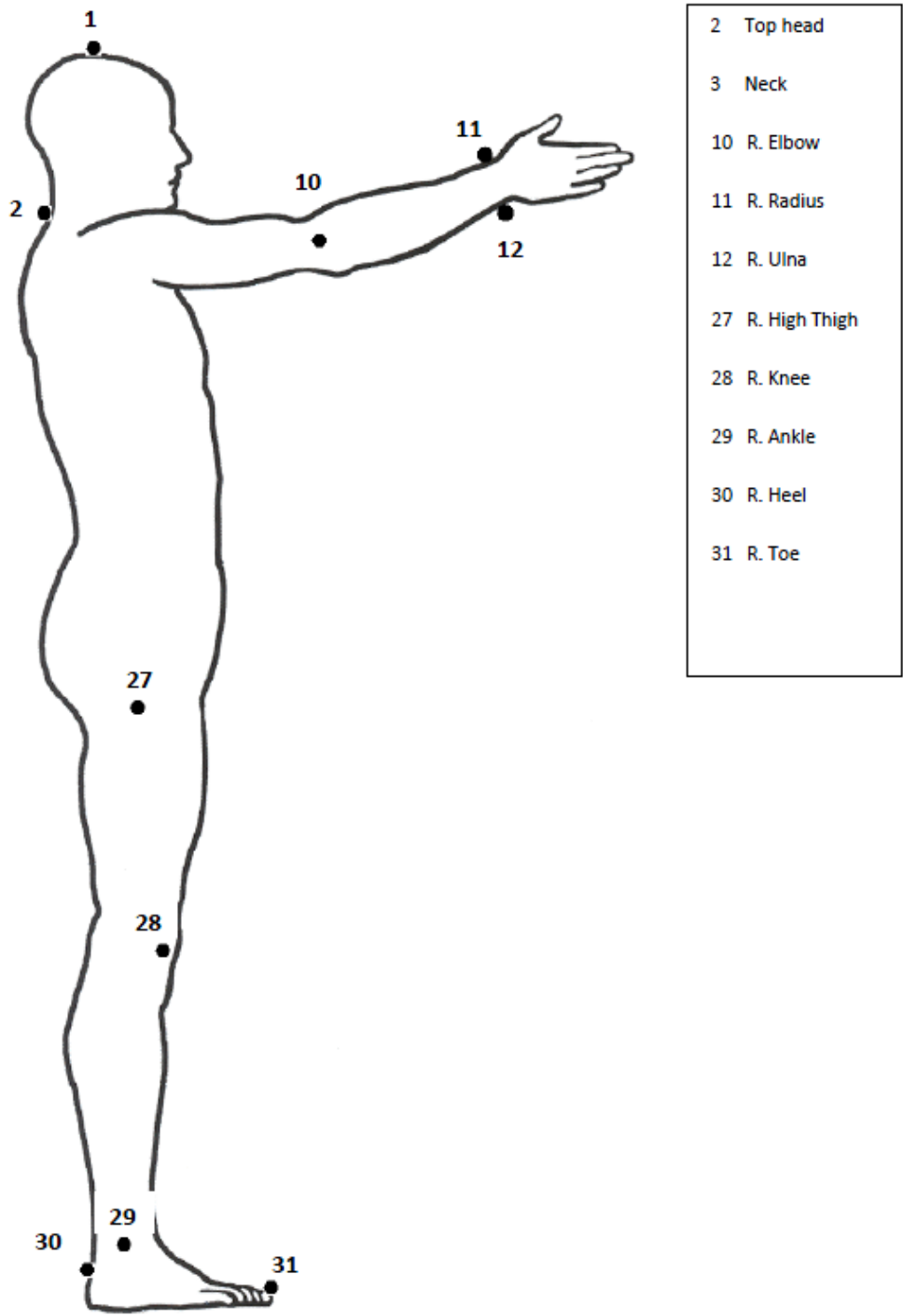


Fig. 5– Side view of custom marker placement

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2.3 Workstation motion tasks

8 motion tasks were selected:

1. Sit, stand up and sit down in one cyclic motion.
2. Lean as far to the left and then to the right without support.
3. Reach to a file cabinet located behind right to the participant (due to the nature and size of a filing cabinet, camera line of site will be affected, thus a suitable prop will be substituted maintaining the same height and reaching properties).
4. Reach to paper on the floor (front left).
5. Reach for a glass of water on desk (front/left to the participant), move it to the participant's mouth, then place it back to the original position on desk.
6. Reach for a telephone on desk (front right to the participant), move it towards the participant's ear, hold for 5 seconds, then return it to the original position on desk.
7. Move a mouse in a square motion around the perimeter of a piece of white A4 paper, taped to the desk top. Two pieces of A4 paper will be placed to accommodate for right and left handed participants.
8. Type at a keyboard. Participants will be asked to type 1 paragraph of text displayed in front of them.

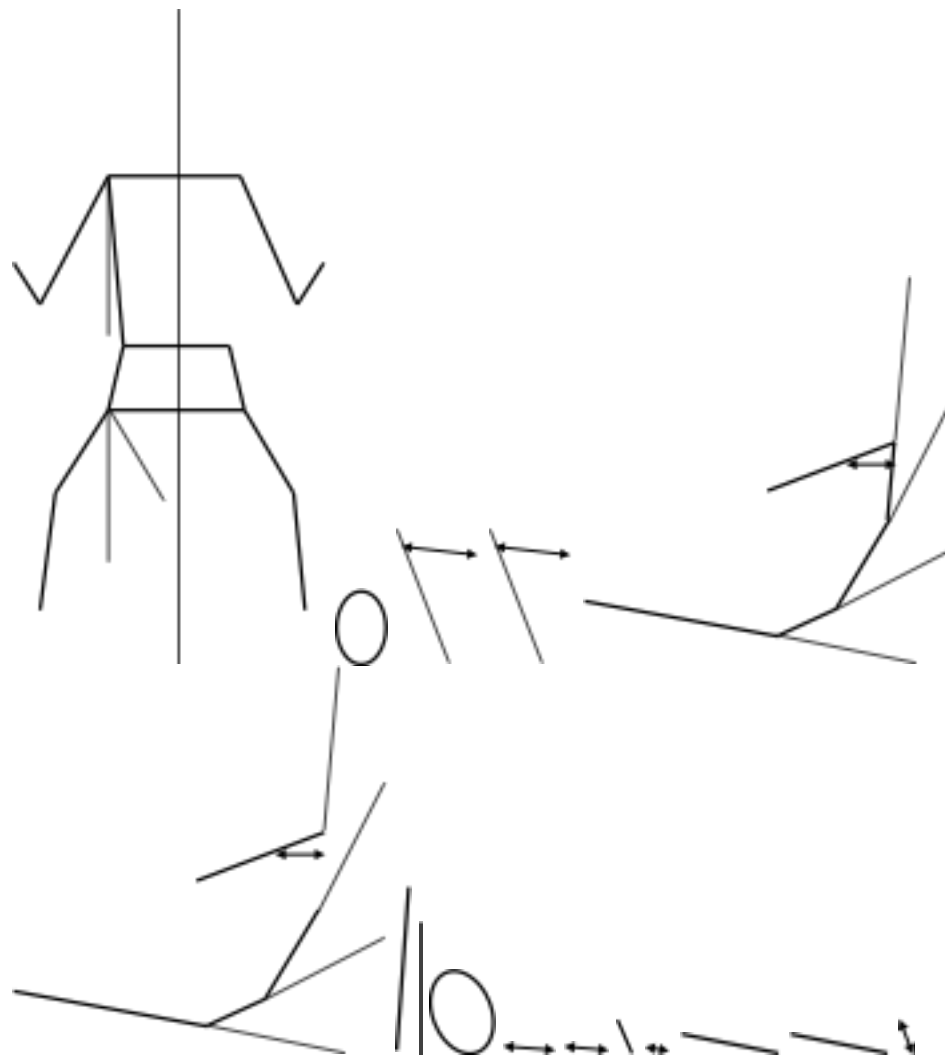
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3 Data Analysis

3.1 Definition of Joint Angles

Analysis of data was completed using a self-developed program in MATLAB. A total of 20 joint angles were evaluated in relation to each of the 8 workstation motion tasks. Joint flexion and abduction/adduction was used to describe the joint movement of the subjects during the motion. The definition of joint angles was made with reference to *G. Androniet al* in *Applied Ergonomics* Vol. 33 pp. 522-522 (2002), and with reference to others' work as well as joint angle definition conventions.

The Figures below show the angles and their definitions on the biomechanical model in the sagittal (Fig 6 (a) and (c)) and in the frontal (Fig 6 (b)) planes.



NF

HBF

SF MBF

HF

SAr

HAr

SAI

HAI



HADr HADI

(b)



(a)

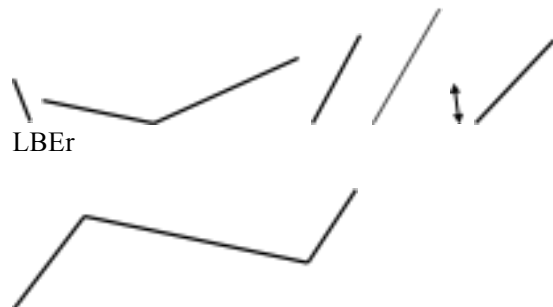


Fig. 6

(c) Defination of Joint Angles

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The definitions of the 20 join tangles and their abbreviations are listed below:

Neck Flexion (NF): the angle between the line of markers Top Head and Neck and the extension line of markers Neck and V.Sacral.

Left Mid Back Flexion (MBFl): the angle between line of markers L.MidBack and L.High Back and the extension line of marker L.Mid Back and a virtual marker constructed by L.Asis and L.Psis.

Right Mid Back Flexion (MBFr): the angle between line of markers R.Mid Back and R.High Back and the extension line of marker R.Mid Back and a virtual marker constructed by R.Asis and R.Psis. In Fig 6 (a), MBF means Mid Back Flexion, including MBFl and MBFr.

Left High Back Flexion (HBFl): the angle between line of markers L.High Back and L.Shoulder and the extension line of markers L.Mid Back and L.High Back.

Right High Back Flexion (HBFr): the angle between line of markers R.High Back and R.Shoulder and the extension line of markers R.Mid Back and R. High Back. In Fig 6 (a), HBF means High Back Flexion, including HBFl and HBFr.

Left Shoulder Flexion (SFl): the angle between the line of markers L.Shoulder and L.Elbow and the line of markers L.Shoulder and L.Asis.

Right Shoulder Flexion (SFr): the angle between the line of markers R.Shoulder and R.Elbow and the line of markers R.Shoulder and R.Asis. In Fig 6 (a), SF means Shoulder Flexion, including SFl and SFr.

Left Shoulder Abduction (SAI): the angle between the line of markers L.Shoulder and L.Elbow projected to frontal plane and a virtual line which parallel to central body line in frontal plane.

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Right Shoulder Abduction (SAr): the angle between the line of markers R.Shoulder and R.Elbow projected to frontal plane and a virtual line which parallel to central body line in frontal plane. SA means

Shoulder Abduction, including SA_l and SA_r which are illustrated in Fig 6 (b).

Left Elbow Flexion (EF_l): the angle between the line of marker L.Elbow and a virtual marker constructed by L.Radius and L.Ulna and the extension line of markers L.Shoulder and L.Elbow.

Right Elbow Flexion (EF_r): the angle between the line of marker R.Elbow and a virtual marker constructed by R.Radius and R.Ulna and the extension line of marker R.Shoulder and R.Elbow. In Fig 6 (a), EF means Elbow Flexion, including EF_l and EF_r.

Left Hip Flexion (HF_l): the angle between the line of marker L.Mid Back and a virtual marker constructed by L.Asis and L.Psis and the extension line of marker L.Knee and the virtual marker constructed by L.Asis and L.Psis.

Right Hip Flexion (HF_r): the angle between the line of marker R.Mid Back and a virtual marker constructed by R.Asis and R.Psis and the extension line of marker R.Knee and the virtual marker constructed by R.Asis and R.Psis. In Fig 6 (a), HF means Hip Flexion, including HF_l and HF_r.

Left Hip Abduction (HA_l): the angle between the line of marker L.Knee and a virtual marker constructed by L.Psis and L.Asis projected to frontal plane and a virtual line which parallel to central body line, when left leg moved outside of body.

Right Hip Abduction (HA_r): the angle between the line of marker R.Knee and a virtual marker constructed by R.Psis and R.Asis projected to frontal plane and a virtual line which parallel to central body line, when right leg moved outside of body. HA means Hip Abduction, including HA_l and HA_r which are illustrated in Fig 6 (b).

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Left Hip Adduction (HA_lD): the angle between the line of marker

L.Knee and a virtual marker constructed by L.Psis and L.Asis projected to frontal plane and a virtual line which parallel to central body line, when left leg moved inside of body.

Right Hip Adduction (HADr): the angle between the line of marker R.Knee and a virtual marker constructed by R.Psis and R.Asis projected to frontal plane and a virtual line which parallel to central body line, when right leg moved inside of body. HAD means Hip Adduction, including HADl and HADr which are illustrated in Fig 6 (b).

Left Knee Flexion (KFl): the angle between the line of markers L.Knee and L.Heel and the extension line of markers L.Knee and L.High Thigh.

Right Knee Flexion (KFr): the angle between the line of markers R.Knee and R.Heel and the extension line of markers R.Knee and R.High Thigh. In Fig 6 (a), KF means Knee Flexion, including HFl and HFr.

Right Mid Back Hyperextension (MBEr): (*Applicable for motion task 3 only*) the angle between line of marker R.Midback and R.Highback and the extension line of marker R.Midback and a virtual marker constructed by R.Asis and R.Psis, when R.Highback move behind R.Midback.

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3.2 Calculations and Denotations

For each workstation tasks and for each chair types seated in the front and the back, computations of the above 19 angles (for motion task 3, 20 angles) were carried out using the following steps:

Computation of the mean value, related standard deviations (SD), maximum value, and minimum value of a single subject;

Computation of the mean angles, SD of mean angles by averaging

all the 17 subjects.

Computation of the average maximum angles, and average minimum angles of all the 17 subjects. Finally for the 8 motion tasks, the obtained mean angles (average of average), SD of mean angle, average of maximum angles, and average of minimum angles for subjects seated on Ergokinetic™ chair front (EGF), seated on standard office chair front (SOF), seated on Ergokinetic™ chair back (EGB), seated on standard office chair front (SOB), are listed in Table 1 – Table 8 in Appendix B. They are the basis for comparing the Ergokinetic™ chair with standard office chair. For this purpose, denotations ‘<’ or ‘>’ means 2-4 degree in difference, ‘<<’ or ‘>>’ means 4-8 degree difference, and ‘<<<’ or ‘>>>’ means the difference above 8 degree. Joint angles in a specific chair at a specific position are denoted with subscript, EGF, SOF, EGB and SOB. For example, NF_{EGB} means Neck Flexion while seated on Ergokinetic™ chair back, MBF_{SOF} means left Mid Back Flexion while seated on standard office chair front. **The main focus of the analysis is on the mean value (average of average in the tables), because this mean value is the average of 17 subjects’ average values during this entire motion task (about 500 frames). This mean value has much more weight in analysis. The above described joint angle notation, if no prefix, it means the mean value.** The notations for other statistics values of joint angles are appearing as prefix, for example, max- MBF_{SOF} means the average maximum left Mid Back Flexion while seated on standard office chair front, min- NF_{EGB} means the average minimum Neck Flexion while seated on Ergokinetic™ chair back.

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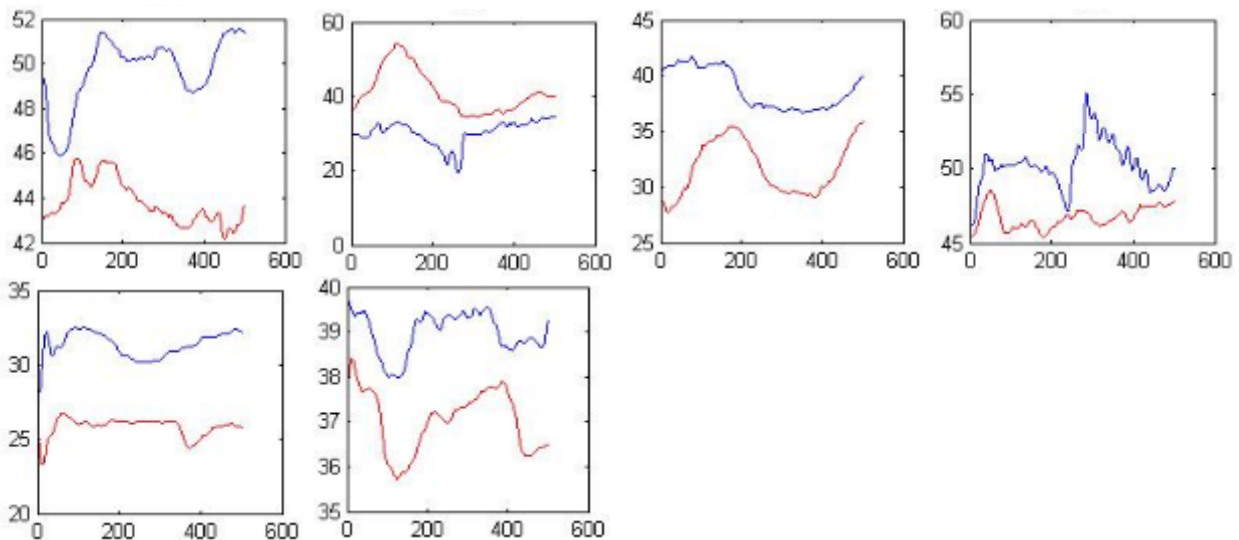
4 Results

Out of the 20 participants captured during the motion study, 3 data sets

were unable to be cleaned during post processing. This could have been due to a poor system calibration on that day or too many people near or around the capture volume causing noise. With the remaining 17 subjects all data was cleaned with a minimal amount virtual correction. Fig 7 shows some typical examples of joint angle variations during the workstation tasks seated on the ergo chair compared with seated on standard office chair by individual subjects. In all the graphs in Fig 7, blue curve represents seated on Ergokinetic chair and red curve represents seated on standard office chair, The Y axis of the graph is the joint angle degree, and X axis of the graph is the mocap frame number.

- (a) Hip Flexion (left) (b) Hip Flexion (right) (c) Midback Flexion (left)
- (d) Midback Flexion (right) (e) Shoulder Flexion (left) (f) Shoulder Flexion (Right)

For more graphs on comparisons about joint angles from 17 individual subjects seated in the front and back of the Ergokinetic chair and standard office chair, please see companion CD.



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4.1 Workstation motion task 1 (*From sitting to standing up and sitting down*) Please see Table 1 in Appendix B for full comparison of workstation motion task 1. When seated in, stood up and sit down again

at the front of chairs, $NF_{EGF} > NF_{SOF}$, $MBFl_{EGF} > MBFl_{SOF}$,
 $HBFl_{EGF} < HBFl_{SOF}$, $SF_{EGF} > SF_{SOF}$, $SA_{EGF} > SA_{SOF}$,

$KF_{EGF} < KF_{SOF}$. Whilst seated in, stood up and sit down again at the back of chairs,

$SFl_{EGB} > SFl_{SOB}$, $SA_{EGB} > SA_{SOB}$, $KF_{EGB} < KF_{SOB}$. The result indicates Ergokinetic chair provided slightly more shoulder movement and slightly less knee bending in motion task 1. The difference is more obvious while seated in the front of chairs.

4.2 Workstation motion task 2 (*Leaning to the left and then to the right*) Please see Table 2 in Appendix B for full comparison of workstation motion task 2. When seated in, lean to the left and then to the right at the front of chairs, $MBFl_{EGF} >> MBFl_{SOF}$, $SF_{EGF} >> SF_{SOF}$, $EFl_{EGF} > EFl_{SOF}$, $HAL_{EGF} > HAL_{SOF}$, $HADr_{EGF} >> HADr_{SOF}$ When seated in, lean to the left and then to the right at the back of chairs, $EFl_{EGB} > EFl_{SOB}$, $HAr_{EGB} < HAr_{SOB}$, $HADl_{EGB} < HADl_{SOB}$, $HADr_{EGB} << HADr_{SOB}$ The result indicates Ergokinetic chair provided more shoulder movement while seated in the front of chair, and less hip rotation while seated in the back of chair.

4.3 Workstation motion task 3 (*Reaching to the file cabinet at behind right*) Please see Table 3 in Appendix B for full comparison of workstation motion task 3. When seated in the front of chairs, reaching to the file cabinet at behind right $NF_{EGF} > NF_{SOF}$, $MBFl_{EGF} >> MBFl_{SOF}$, $MBFr_{EGF} > MBFr_{SOF}$, $HBFr_{EGF} > HBFr_{SOF}$, $SFl_{EGF} >> SFl_{SOF}$, $SAl_{EGF} > SAl_{SOF}$, $HF_{EGF} < HF_{SOF}$, $HAL_{EGF} >> HAL_{SOF}$, $HAr_{EGF} << HAr_{SOF}$, $HADr_{EGF} < HADr_{SOF}$, $KFr_{EGF} > KFr_{SOF}$, $MBEr_{EGF} >> MBEr_{SOF}$ When seated in the back of chairs, reaching to the file cabinet at behind right $MBFl_{EGB} > MBFl_{SOB}$, $SAl_{EGB} < SAl_{SOB}$, $EFl_{EGB} >> EFl_{SOB}$, $EFr_{EGB} > EFr_{SOB}$,

$$HF_{r_{EGB}} < HF_{r_{SOB}}, HA_{l_{EGB}} > HA_{l_{SOB}}, HA_{d_{l_{EGB}} > HA_{d_{l_{SOB}}},$$

$$HA_{d_{r_{EGB}} > > HA_{d_{r_{SOB}}}, MB_{e_{r_{EGB}} > > MB_{e_{r_{SOB}}}$$

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The results indicate that Ergokinetic chair provided more mid back, shoulder mobility, less hip flexion, and more hip rotation on left side and less hip rotation on right side than standard office chair while seated in the front. Whilst seated in the back, Ergokinetic chair provided more hip rotation and mid back mobility.

In this motion task, subject has to twist the body from left to right in order to reach the file cabinet in the behind right. There is a clear difference in posture of the mid back and hips between the Ergokinetic chair and standard chair. These differences however are less when sitting at the back of the chair than in the front of chair. Also, there is a noticeable difference between the left side and right side of the body. Specifically, we computed hyperextension for the right mid back.

∴ These results suggest that subjects had much more mid back mobility and much more hip

rotation while seated in the Ergokinetic chair.

4.4 Workstation motion task 4 (*Reaching to paper on the floor at front left*) See table 4 in appendix B for full comparison of workstation motion task 4 in table form. For this motion, the hip flexion was relatively close in comparison however the hip abduction/adduction showed obvious differences between the two chairs.

∴ ∴ ∴ ∴ ∴ ∴

; Hip adduction occurred when the knee moved towards the centre of the body. There were no static rules in hip abduction and adduction. The only thing that can be stated is that the hips have a wider varying scale in the Ergokinetic chair than in the standard chair.

∴ ∴

The above shows that in general the subjects' mid back bends more in EGF than in SOF, however subjects' mid back were almost the same in EGB and in SOB.

; $SF_{EGF} > SF_{SOF}$, $SAl_{EGF} > SAl_{SOF}$ There are slight difference in highback and shoulder movement. Right shoulder flexion in EGF motions, was 3 degrees higher than in SOF motions.

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The results indicate that Ergokinetic chair provided more hip rotations and midback and shoulder mobility.

4.5 Workstation motion task 5 (*Reaching for a glass of water on the front left of desk*) Please see Table 5 in Appendix B for full comparison of workstation motion task 5. When seated in the front of chairs, reaching for a glass of water on the front left of desk, $MBF_{EGF} > MBF_{SOF}$, $HBF_{EGF} > HBF_{SOF}$, $SFr_{EGF} > SFr_{SOF}$, $HFr_{EGF} < HFr_{SOF}$
 $HA_{EGF} > HA_{SOF}$

Whilst seated in the back of chairs,

$EFl_{EGB} > EFl_{SOB}$, $EFr_{EGB} > EFr_{SOB}$, $HF_{EGB} < HF_{SOB}$, $HAr_{EGB} < HAr_{SOB}$

The results indicate that while seated in the front, Ergokinetic chair provided slightly more mid back and high back bending, and more right shoulder flexion, and slightly less hip bending on right side. Whilst seated in the back, Ergokinetic chair provided more elbow flexion and less hip flexion.

In this motion and motion 6, hip adduction was not accounted for, since there were very few subjects that had this angle.

4.6 Workstation motion task 6 (*Reaching for a telephone on the*

front right of desk) Please see Table 6 in Appendix B for full comparison of workstation motion task 6. When seated in the front of chairs, reaching for a telephone on the front right of desk, $MBFl_{EGF} > MBFl_{SOF}$, $HBFr_{EGF} > HBFr_{SOF}$, $SFl_{EGF} > SFl_{SOF}$, $EFl_{EGF} < EFl_{SOF}$, $HAl_{EGF} > HAl_{SOF}$, $HAr_{EGF} > HAr_{SOF}$

Whilst seated in the back of chairs,

$SFr_{EGB} < SFr_{SOB}$, $HFr_{EGB} < HFr_{SOB}$, $HAl_{EGB} > HAl_{SOB}$,

The results indicate that while seated in the front, Ergokinetic chair provided slightly more mid back and high back bending, and more left shoulder flexion. This is in contrast with motion task 5 which provided more right shoulder flexion. In both cases, more shoulder flexion occurred on the side opposite to picking motion side. More hip rotation occurred while seated in the front of Ego chair. Whilst seated in the back, Ergokinetic chair provided slightly less hip flexion, and slightly less shoulder flexion on the right side which is the picking motion side, and slightly more hip rotation on the left side.

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Results show that subject's knees moved more away from centre of the body in the Ergokinetic chair than in the standard chair. Also, It is an interesting and consistent rule that subjects had higher right shoulder flexion when they were getting something at left in the Ergokinetic chair than in standard chair, and had higher left shoulder flexion when they were getting something towards the right in the Ergokinetic chair than in the standard chair, excluding when they were picking something up from on the floor.

4.7 Workstation motion task 7 (*Moving a mouse in a square motion on desk*) See table 7 in appendix B for full comparison of workstation motion task 7 in table

form.. ; ; While moving the computer mouse on the desk with right hand, the left mid back flexion was higher when seated in the Ergokinetic chair than in the standard chair, and also more high back flexion on the right side when seated in the front.

;;; While seated in the front, shoulder flexion was increased in both sides in the Ergokinetic chair than in the standard chair while using the right hand to move the mouse. While seated in the back, the right shoulder flexion had lower value in EGB than in SOB.

$EFl_{EGB} > EFl_{SOB}$ This means that the left elbow bent more in the Ergokinetic chair than in the standard chair whilst seated in the back of the chair.

; ; Results showed that the hip bent less in the Ergokinetic chair than in the standard chair whilst seated in the back of the chair.

;;; Overall subject's knees moved more away from the centre of the body in the Ergokinetic chair. Results showed that there was more freedom about hip abduction in the Ergokinetic chair than in the standard chair.

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4.8 Workstation motion task 8 (*Typing at a keyboard on desk*) See table 8 in appendix B for full comparison of workstation motion task 8 in table form. This action is very similar with just sitting in still motion.

;;; Results showed that the hip bent less whilst seated in the Ergokinetic chair than in standard chair when sitting at the back of chair, but almost the same whilst seated in the front of chair. The right high back flexion was slightly higher when sitting in the front of chair.

;;; Left shoulder flexion had lower value in EGB than in SOB. Right shoulder flexion had higher value in EGF than in SOF, but had lower

value in EGB than in SOB.

;;; One thing we can state is that hip rotation angles (HA) varying scale was wider in the Ergokinetic chair than in standard chair since most of max-HA were higher in Ergokinetic chair than in standard chair.

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5 Conclusion

Eight common workstation motion tasks were designed in order to test the main function and design of the Ergokinetic split seat chair in comparison with a standard office chair. After analysing all the results of motion study, a clear difference between the two types of chair became apparent. After examination of all joint angles across the eight workstation motion tasks, we summarised some common ground for the Ergokinetic chair.

The main distinct difference between the Ergokinetic chair and the standard chair was evident mainly at the hips, mid back and highback. Each of these was affected by the different designs presented in both chairs. Overall the subject's hips bent less whilst completing the motion tasks seated in the Ergokinetic chair than in standard chair. Subjects were inclined to bend their mid backs and higher backs instead of their hips. This difference was very obvious in some actions which leads subjects to change their centre of gravity whilst reaching for the items on the desk (left/front or right/front), as well as something behind. The difference was more apparent when subjects were sitting at the front of chair rather than sitting at the back of chair.

In some other motions, subjects showed wider varied scale about hip angles including hip abduction and hip adduction. In addition, subjects had almost the same hip flexion but very different hip abduction and adduction results when asked to pick an item up from the floor. Subjects had much more freedom about how they positioned their hips and legs in the Ergokinetic chair when completing these actions.

Subjects have a higher shoulder flexion value in most actions. When twisting their body, left/right shoulder flexion were both higher. When reaching for a glass of water in the left front on desk, right shoulder flexion was higher in the Ergokinetic chair than in standard chair. For the opposite type of motion, reaching to answer the telephone at the front right on the desk, the left shoulder flexion was higher in ergo chair than in standard chair. Elbow and knee angles didn't have much difference between the chairs.

According to the above analysis, the advantages of the Ergokinetic chair are clear. The Ergokinetic chair offers greater support and motion advantages surrounding the hip area of the human body. People seated in the Ergokinetic chair are not required to bend their hips as much, in order to carry out the same motion as when seated in the standard

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office chair. When a change in centre of the gravity occurs, the Ergokinetic chair offers more support which protects the hips. Thus, the mid back bends instead of hips. The Ergokinetic chair also provides more flexibility about hips and legs when completing general actions such as standing, typing etc. Ergokinetic chair increases balance as subject gained a higher level of shoulder flexion on the opposite arm when completed the reaching workstation motion tasks.

Our results showed that the Ergokinetic chair is more effective when the subjects were seated towards the front of the chair, than sitting against the back lumbar support. Little difference was noticed with elbow, knee and lower leg movements between the Ergokinetic chair and standard office chair.

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Appendix A: Ergokinetic Chair Study Questionnaire

Name..... ID.....

1 – How many hours on average do you sit on an office chair per day during working hours? 0-2 Hours 2-4 Hours 4-6 Hours 6+ Hours

2 – When using your current office chair do you have any neck, shoulder, back or arm pains, or fatigue after prolonged use?

Yes No

Any further information:

.....
.....
.....

3 – Do you suffer from any known medical neck, shoulder, back or arm problems?

Yes No

Any further information:

.....
.....

4 – Does your current office chair use any technology designed to help with back strain?

Yes No

Any further information:

.....
.....

5 – When sitting, do you feel the need to stand up and walk to relieve any pain or strain? Yes No

6 - Does your current office chair have a built in special lumbar support (other than a normal back rest) or do you use any 3rd party device (like a cushion)?

Yes..... No

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7 – Is your office chair height adjustable? Yes No

9 – Do you normally use a footstool under your desk when seated? Yes No

10 – Do you feel that during the test the Ergonkinetic chair provided more mobility to your body than the standard office chair?

Yes No Not Sure

11 – Do you feel that during the test the Ergonkinetic chair was more comfortable than the standard office chair?

Yes No Not Sure

12- After completing this study, what are your views of comparison between the Ergonkinetic chair, and the standard office chair?

.....
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Signature..... Date.....

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Appendix B: Table 1 – Workstation Motion Task 1

Indicators	EGF				SOF				EGB		
	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max
Neck Flexion	19.00	7.99	32.49	5.69	16.66	7.16	28.31	5.64	17.69	8.02	31.5
Midback Flexion-Left	33.83	9.59	40.70	25.72	31.93	9.51	39.70	24.52	34.13	9.39	41.8

Midback Flexion-Right	46.99	8.98	57.29	34.32	46.57	9.48	57.75	34.25	47.48	8.01	58.7
Highback Flexion-Left	49.56	11.60	54.95	42.58	52.44	10.93	57.08	45.95	49.08	10.48	56.0
Highback Flexion-Right	55.24	9.28	60.91	47.95	55.29	6.48	60.29	48.07	53.17	6.60	60.6
Shoulder Flexion-Left	26.42	11.93	36.65	18.93	24.48	9.18	34.60	17.67	25.82	4.58	36.6
Shoulder Flexion-Right	29.56	10.49	39.27	22.83	27.70	8.28	35.65	21.69	28.59	4.29	39.2
Shoulder Abduction-Left	21.47	6.89	39.67	11.82	19.19	4.58	35.01	11.29	23.13	7.10	45.4
Shoulder Abduction-Right	22.78	7.07	40.86	13.32	20.21	5.39	36.18	12.01	24.86	6.77	47.4
Elbow Flexion-Left	66.27	13.57	91.40	47.17	65.94	13.44	92.07	47.44	68.81	13.77	97.1
Elbow Flexion-Right	63.52	13.32	89.14	43.68	62.00	12.97	87.45	43.79	65.90	12.14	93.0
Hip Flexion-Left	34.45	4.73	56.65	8.70	34.41	4.38	56.22	8.45	35.93	4.94	61.4
Hip Flexion-Right	34.32	6.02	58.04	7.12	33.82	5.13	56.35	7.33	35.44	6.68	62.1
Hip Abduction-Left	12.17	8.27	26.59	3.32	10.46	7.51	22.25	2.38	10.87	7.22	24.6
Hip Abduction-Right	9.52	7.08	22.36	1.53	8.55	4.61	20.19	1.24	8.91	5.10	21.6
Hip Adduction-Left	1.93	1.86	3.87	0.67	2.16	3.19	4.56	0.01	2.20	2.52	4.89
Hip Adduction-Right	3.58	4.76	6.58	0.71	3.74	4.28	7.10	0.56	3.54	4.62	6.85
Knee Flexion-Left	57.25	5.95	93.68	14.97	60.17	9.97	94.81	14.83	54.27	6.52	87.9
Knee Flexion-Right	67.12	6.52	102.45	25.53	69.37	8.92	102.29	25.74	63.64	7.02	96.3

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Table 2 – Workstation Motion Task 2

Indicators	EGF				SOF				EGB		
	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max
Neck Flexion	20.55	9.29	27.45	13.10	19.69	7.03	26.45	12.19	23.65	10.28	32.4
Midback Flexion-	38.59	9.33	49.84	30.47	34.67	8.94	47.16	25.91	40.45	8.19	52.4

Left											
Midback Flexion-Right	52.93	9.26	61.19	45.21	51.73	9.80	61.19	42.60	53.91	8.46	61.71
Highback Flexion-Left	51.97	12.26	58.04	46.56	51.69	10.00	55.91	47.73	51.53	11.20	56.31
Highback Flexion-Right	57.40	8.55	62.35	52.41	55.53	6.59	59.84	51.31	55.98	6.59	62.11
Shoulder Flexion-Left	27.24	12.11	34.12	22.61	21.87	6.15	29.09	17.11	25.49	7.49	34.01
Shoulder Flexion-Right	29.68	11.80	36.20	25.27	25.84	7.09	33.77	20.84	27.62	8.15	34.41
Shoulder Abduction-Left	25.16	5.99	55.09	0.50	25.89	6.08	54.06	0.04	25.97	7.51	55.31
Shoulder Abduction-Right	25.51	6.57	56.62	0.23	24.44	5.01	53.04	0.06	25.50	7.33	56.11
Elbow Flexion-Left	73.97	20.46	87.54	61.37	70.30	17.44	85.25	58.76	75.64	20.86	90.31
Elbow Flexion-Right	70.10	18.99	82.83	57.31	69.78	17.85	84.66	56.04	72.50	20.23	86.41
Hip Flexion-Left	30.36	9.35	40.01	22.65	30.18	7.34	37.30	23.91	29.26	12.54	40.11
Hip Flexion-Right	30.74	8.91	38.47	22.91	29.97	6.69	37.39	23.19	29.05	12.94	36.71
Hip Abduction-Left	28.44	14.97	41.79	13.70	26.07	13.21	34.44	16.38	27.43	15.64	39.21
Hip Abduction-Right	26.26	12.68	38.50	13.88	26.36	11.92	37.96	15.18	24.10	14.40	35.61
Hip Adduction-Left	10.38	7.56	15.99	0.09	11.21	5.70	18.52	0.05	4.36	4.39	6.69
Hip Adduction-Right	15.53	7.14	25.40	0.16	10.04	8.57	18.01	0.06	10.44	7.92	17.01
Knee Flexion-Left	91.80	7.00	97.91	85.14	90.75	7.47	97.08	83.61	86.59	6.17	92.01
Knee Flexion-Right	100.40	5.91	106.90	93.11	98.45	7.44	105.00	91.43	95.12	5.88	100.11

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Table 3 – Workstation Motion Task 3

Indicators	EGF				SOF				EGB		
	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max

Neck Flexion	24.48	7.47	30.43	15.25	21.59	6.93	27.16	13.88	25.08	7.09	31.0
Midback Flexion-Left	40.04	11.23	44.53	32.26	33.99	10.79	38.09	27.78	37.67	11.04	41.9
Midback Flexion-Right	49.89	8.09	55.17	43.69	47.60	8.14	51.60	43.25	48.16	8.45	53.9
Highback Flexion-Left	47.10	12.73	53.22	43.35	47.22	12.10	54.55	43.41	47.92	13.59	54.6
Highback Flexion-Right	54.20	9.21	63.82	46.49	51.87	7.30	62.60	45.12	53.22	7.66	63.2
Shoulder Flexion-Left	30.47	20.61	37.24	22.65	24.62	7.98	30.52	18.51	27.04	8.39	32.7
Shoulder Flexion-Right	62.51	9.70	89.53	26.07	63.00	9.68	90.96	22.93	61.72	9.31	85.8
Shoulder Abduction-Left	28.45	12.80	39.05	12.82	25.74	9.36	35.14	11.33	24.83	9.58	31.9
Shoulder Abduction-Right	39.27	12.81	62.75	13.83	41.12	14.93	66.88	9.36	43.07	11.64	67.3
Elbow Flexion-Left	67.58	16.85	84.00	53.67	65.57	16.58	79.76	55.90	75.25	21.76	87.9
Elbow Flexion-Right	69.48	10.57	106.25	44.39	67.63	12.62	107.44	43.84	75.27	12.54	110.
Hip Flexion-Left	23.93	10.86	32.16	17.58	27.24	8.48	35.41	20.43	24.97	13.25	31.5
Hip Flexion-Right	24.74	9.05	31.00	20.53	28.55	7.11	34.84	22.80	24.94	11.05	29.7
Hip Abduction-Left	30.78	15.73	37.73	21.02	23.93	16.16	32.23	14.69	26.25	15.12	33.4
Hip Abduction-Right	25.04	12.74	33.07	10.61	29.29	12.88	39.31	10.50	29.55	13.88	36.4
Hip Adduction-Left	8.38	7.56	13.01	1.12	7.61	5.75	13.20	0.57	12.42	13.56	19.6
Hip Adduction-Right	6.46	8.21	11.61	2.17	8.80	8.94	15.11	2.33	20.85	11.52	30.6
Knee Flexion-Left	90.26	7.18	94.63	86.86	89.03	7.53	93.12	85.28	88.15	5.54	90.8
Knee Flexion-Right	100.26	7.95	103.06	97.72	96.47	8.84	99.61	94.01	94.75	7.07	98.1
Lowback Hyperextension-	igh4t6.01	6.95	50.18	41.19	41.18	6.72	45.22	36.42	43.35	9.80	46.8

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Table 4 – Workstation Motion Task 4

Indicators	EGF				SOF				EGB		
	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max
Neck Flexion	21.59	7.40	30.80	14.11	19.98	7.72	29.65	11.00	21.12	8.03	31.2
Midback Flexion-Left	54.47	10.97	69.52	35.37	50.51	11.44	67.49	29.72	53.12	11.33	67.8
Midback Flexion-Right	55.96	9.50	60.69	49.36	53.95	10.16	58.61	46.03	56.12	9.33	61.0
Highback Flexion-Left	43.34	10.39	56.09	31.94	42.85	10.15	55.21	30.26	44.11	13.64	56.6
Highback Flexion-Right	57.58	8.29	60.92	54.18	55.90	6.18	59.07	52.69	56.74	6.91	60.8
Shoulder Flexion-Left	42.40	8.77	63.16	23.94	40.09	5.63	63.78	20.16	43.09	9.50	63.2
Shoulder Flexion-Right	33.82	12.06	39.51	28.29	30.04	5.70	35.17	24.73	34.42	12.81	41.2
Shoulder Abduction-Left	15.73	10.31	28.93	7.21	13.14	4.83	24.19	6.29	17.27	12.07	30.8
Shoulder Abduction-Right	50.87	15.65	88.01	16.91	50.83	7.92	93.06	15.52	49.79	13.60	88.1
Elbow Flexion-Left	62.45	11.09	86.12	47.76	63.53	10.22	89.61	45.91	67.17	13.85	92.1
Elbow Flexion-Right	79.35	17.11	88.83	66.76	81.66	17.74	89.63	69.54	81.81	18.65	92.4
Hip Flexion-Left	51.21	9.11	76.73	24.24	51.84	11.53	79.83	26.94	53.31	12.70	82.6
Hip Flexion-Right	43.86	8.24	58.77	25.07	43.37	7.70	58.38	25.27	44.26	9.44	61.6
Hip Abduction-Left	27.20	16.22	33.13	21.62	21.74	14.25	26.57	15.67	21.71	17.14	26.8
Hip Abduction-Right	26.37	11.81	32.62	18.24	27.35	8.58	33.51	18.54	25.08	9.94	30.8
Hip Adduction-Left	8.61	10.37	14.93	2.24	14.84	7.95	24.18	2.85	7.77	7.85	15.0
Hip Adduction-Right	15.63	5.74	24.67	6.51	6.39	5.21	10.33	1.19	16.70	1.72	23.8
Knee Flexion-Left	92.30	8.42	94.50	89.95	91.40	8.60	93.91	88.57	88.10	6.91	90.7
Knee Flexion-Right	96.32	7.38	101.48	91.13	92.80	8.95	97.55	87.40	91.50	6.24	96.4

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Table 5 – Workstation Motion Task 5

Indicators	EGF				SOF				EGB		
	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max
Neck Flexion	20.73	6.02	27.09	15.11	20.72	6.74	27.74	14.56	21.34	7.33	29.1
Midback Flexion-Left	42.58	8.52	49.32	32.85	40.19	8.81	47.75	29.45	42.80	8.93	49.7
Midback Flexion-Right	51.78	5.24	56.76	46.90	48.17	8.02	52.12	42.68	50.44	6.55	55.2
Highback Flexion-Left	40.66	11.43	52.65	34.54	38.69	8.82	52.62	32.19	39.92	9.26	53.7
Highback Flexion-Right	57.65	7.65	60.98	54.25	55.73	7.26	58.36	53.36	57.53	6.80	60.5
Shoulder Flexion-Left	50.13	5.77	61.65	32.01	49.82	5.40	62.56	28.61	49.56	4.79	61.9
Shoulder Flexion-Right	35.96	14.36	42.40	32.13	30.83	5.90	37.04	27.70	33.04	5.65	39.2
Shoulder Abduction-Left	39.06	5.96	53.84	19.48	39.22	6.70	54.08	19.97	39.81	6.01	56.0
Shoulder Abduction-Right	26.60	8.74	34.00	19.38	25.59	6.12	32.79	18.20	25.54	5.75	32.1
Elbow Flexion-Left	97.55	6.73	145.73	57.61	97.66	6.46	149.53	55.39	99.48	6.76	149.1
Elbow Flexion-Right	89.13	20.72	98.66	78.30	90.07	16.31	96.55	80.43	93.69	16.20	100.1
Hip Flexion-Left	34.89	8.11	43.00	26.91	36.50	8.58	44.78	28.30	35.27	9.20	44.4
Hip Flexion-Right	29.68	8.14	36.29	22.66	32.48	8.23	40.19	25.96	30.31	9.42	38.3
Hip Abduction-Left	26.30	15.56	29.03	23.94	23.73	12.32	26.03	20.27	24.94	16.59	27.7
Hip Abduction-Right	24.74	13.55	27.15	22.04	22.90	11.43	25.73	19.30	22.61	12.90	25.2
Hip Adduction-Left	7.34	6.18	10.28	4.50	8.39	6.36	12.50	3.71	3.91	4.53	6.16
Hip Adduction-Right	8.17	6.90	10.99	5.78	2.73	2.53	4.28	0.91	7.87	9.74	10.6
Knee Flexion-Left	94.11	9.32	95.21	93.07	93.32	8.17	94.57	92.35	87.22	7.67	88.3
Knee Flexion-Right	100.03	9.24	101.21	98.74	97.57	6.66	99.39	95.87	94.33	7.40	95.6

Table 6 – Workstation Motion Task 6

Indicators	EGF				SOF				EGB		
	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max
Neck Flexion	19.67	6.29	28.73	12.22	18.52	6.56	25.69	10.32	19.24	6.09	28.11
Midback Flexion-Left	35.75	8.81	38.30	32.37	33.08	8.19	36.10	29.82	35.51	9.25	38.21
Midback Flexion-Right	60.26	8.75	67.81	48.68	58.56	10.06	66.26	46.28	59.71	9.18	66.71
Highback Flexion-Left	51.71	10.62	55.08	47.94	51.04	10.41	54.44	47.17	51.71	10.98	55.31
Highback Flexion-Right	44.23	11.92	60.71	35.84	40.97	6.69	58.08	33.15	41.29	6.67	57.61
Shoulder Flexion-Left	30.77	14.70	37.93	28.19	26.49	5.13	33.71	24.10	27.86	6.17	35.21
Shoulder Flexion-Right	50.03	5.32	63.08	32.09	49.43	4.23	63.09	29.77	48.84	4.10	63.11
Shoulder Abduction-Left	20.90	7.77	27.83	15.17	19.34	6.51	25.62	14.34	20.54	6.88	28.01
Shoulder Abduction-Right	34.31	6.40	47.90	17.96	34.32	7.36	47.90	18.16	35.43	5.27	49.51
Elbow Flexion-Left	89.65	22.73	103.38	79.40	91.85	15.20	102.45	80.94	88.67	19.50	97.91
Elbow Flexion-Right	96.85	5.83	146.86	54.03	98.25	8.00	150.73	51.35	95.51	5.43	149.11
Hip Flexion-Left	34.18	8.12	40.12	27.18	35.29	7.91	41.25	28.83	35.93	8.33	43.21
Hip Flexion-Right	35.86	8.00	45.12	25.10	36.78	8.36	45.63	27.42	36.61	9.23	46.31
Hip Abduction-Left	26.38	15.35	29.39	23.18	20.59	13.55	23.31	17.24	22.43	14.81	26.81
Hip Abduction-Right	25.79	14.51	27.94	23.36	22.20	12.34	25.27	19.00	23.57	11.79	26.61
Hip Adduction-Left	4.48	3.15	7.77	0.57	6.91	4.71	9.43	2.35	4.90	4.09	7.76
Hip Adduction-Right	8.47	6.21	10.86	5.78	7.21	1.22	11.66	1.39	8.56	8.59	11.81
Knee Flexion-Left	93.46	9.69	94.71	92.29	92.94	8.80	94.30	91.74	87.07	7.50	88.81
Knee Flexion-Right	100.56	9.00	101.41	99.63	98.75	7.47	99.81	97.58	94.66	7.52	95.71

Table 7 – Workstation Motion Task 7

Indicators	EGF				SOF				EGB		
	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max
Neck Flexion	28.22	7.36	32.17	22.09	27.04	6.48	30.89	20.58	28.23	6.03	32.6
Midback Flexion-Left	36.67	9.76	38.66	33.81	33.36	9.79	35.27	30.42	36.01	9.94	38.2
Midback Flexion-Right	54.40	8.18	59.03	48.48	53.56	8.46	58.50	46.47	55.43	10.40	60.6
Highback Flexion-Left	51.85	11.66	54.04	49.81	51.01	11.30	53.08	49.34	52.55	12.11	54.8
Highback Flexion-Right	51.25	9.46	59.51	45.69	48.86	5.97	58.04	42.98	49.24	6.13	58.0
Shoulder Flexion-Left	30.02	13.66	37.19	27.81	27.02	7.11	33.57	25.49	27.39	7.52	32.7
Shoulder Flexion-Right	39.59	7.17	48.98	29.38	36.48	3.64	47.24	24.78	36.57	3.94	46.2
Shoulder Abduction-Left	21.17	7.43	27.17	16.62	21.33	6.92	26.21	17.43	20.90	7.72	25.6
Shoulder Abduction-Right	33.87	5.29	41.40	20.65	32.49	5.28	41.74	20.93	33.04	5.08	41.6
Elbow Flexion-Left	88.50	23.06	96.58	82.94	93.29	16.46	98.52	87.19	89.62	19.10	94.1
Elbow Flexion-Right	85.07	7.49	115.32	60.26	83.61	5.61	113.45	58.73	82.37	8.41	110.0
Hip Flexion-Left	30.70	9.45	33.12	27.24	31.27	8.13	33.57	28.50	30.06	9.40	33.1
Hip Flexion-Right	29.97	9.03	33.06	25.23	31.06	8.17	33.73	27.71	29.55	10.58	33.0
Hip Abduction-Left	28.68	14.61	30.12	26.69	23.89	13.86	25.29	22.14	27.17	17.22	28.8
Hip Abduction-Right	25.53	14.48	26.97	23.75	23.54	10.30	24.91	21.70	25.86	10.70	27.4
Hip Adduction-Left	16.04	17.31	19.29	13.27	5.48	2.29	7.83	3.81	3.44	1.39	6.52
Hip Adduction-Right	7.70	7.16	9.34	6.12	5.11	2.83	7.41	3.36	11.50	8.30	12.8
Knee Flexion-Left	93.73	9.47	94.66	92.81	93.38	9.13	93.95	92.82	87.20	7.45	88.4
Knee Flexion-Right	101.20	9.01	101.71	100.64	99.35	7.62	99.83	98.85	94.97	7.51	95.4

Table 8 – Workstation Motion Task 8

Indicators	EGF				SOF				EGB		
	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max	average of min	average of average	SD of average	average of max
Neck Flexion	32.43	9.04	35.33	28.54	35.57	7.16	39.84	31.62	32.09	8.74	34.5
Midback Flexion-Left	38.48	9.42	39.88	36.59	36.73	8.54	38.16	34.69	38.64	10.40	40.2
Midback Flexion-Right	54.68	9.60	56.46	52.36	53.62	10.10	55.46	51.07	55.80	11.33	57.8
Highback Flexion-Left	44.63	11.61	46.31	43.30	44.22	10.48	45.80	42.99	44.70	11.15	46.9
Highback Flexion-Right	49.14	9.75	51.21	47.30	47.05	6.02	49.66	44.82	46.82	6.40	49.3
Shoulder Flexion-Left	32.82	9.92	34.95	31.07	30.70	6.29	32.85	28.45	30.30	6.24	32.3
Shoulder Flexion-Right	26.43	11.19	29.91	24.27	24.21	5.83	28.46	21.06	23.82	4.46	27.9
Shoulder Abduction-Left	22.08	7.72	24.52	20.21	21.14	6.95	23.54	19.13	20.72	6.61	22.9
Shoulder Abduction-Right	20.82	7.02	25.05	18.27	21.29	7.20	25.65	17.88	19.17	6.48	23.6
Elbow Flexion-Left	99.69	8.55	104.02	96.50	100.42	7.93	104.07	96.74	97.03	8.12	101.0
Elbow Flexion-Right	95.93	9.25	100.54	91.76	96.25	8.35	100.37	91.93	93.62	8.90	98.5
Hip Flexion-Left	33.98	9.17	35.11	32.40	35.05	9.37	36.21	33.43	34.94	9.98	36.0
Hip Flexion-Right	30.23	7.80	31.59	28.76	31.35	8.69	32.41	29.78	30.21	9.61	31.5
Hip Abduction-Left	26.34	14.15	27.08	25.30	23.24	13.35	24.07	22.45	25.26	17.31	26.2
Hip Abduction-Right	27.04	12.73	27.90	26.19	23.17	11.25	24.16	22.19	25.39	10.25	26.1
Hip Adduction-Left	15.75	16.34	16.77	14.48	8.05	2.79	8.95	7.49	5.92	3.45	7.35
Hip Adduction-Right	8.72	8.26	9.71	8.23	5.00	6.19	5.75	4.53	12.24	9.20	13.6
Knee Flexion-Left	94.44	9.33	94.78	94.24	94.90	11.06	95.16	94.61	87.75	7.44	88.1
Knee Flexion-Right	99.12	8.76	99.40	98.86	98.85	9.60	99.17	98.49	93.68	7.49	94.0

