A COMPUTER-BASED METHOD TO RECORD THREE-DIMENSIONAL BODY POSTURES

by

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(Abstract)

This thesis reports on the development and validation of a computer tool created to facilitate the input of three-dimensional human postural information. The computer program under development attempts to provide a high resolution technique that is easy to use and not overly time-consuming. The method incorporates two- and three-dimensional graphics and allows the representations to be manipulated to the same perspective as the subject being recorded. A mouse input system is used to allow users to select and manipulate limb postures from one of six different views (left, right, front, back, top, and three-dimensional). The separate views are coordinated to force a consistent representation for later analysis or storage. Human factors concepts have been incorporated into the program to increase the spatial compatibility of the task and to streamline the data input in an attempt to increase both recording accuracy and speed.

A validation experiment was performed using 30 subjects, 15 male and 15 female, who were pre-tested for spatial ability. Subjects were asked to input postural information for five postures that were presented on videotape. The postures represented five different positions ('sitting,' 'pushing,' 'lifting,' 'reaching,' and 'crouching') that spanned the range of positions a worker is likely to adopt in the workplace. Subjects viewed each posture from one of three different viewing angles (the 'right' side in the sagittal plane, the 'front' side in the frontal plane, and an 'oblique' angle between the other two). Kappa coefficients were calculated to compare subjects' responses, and it was demonstrated that

the method was reliable between subjects ($p < .001$). An analysis-of-covariance (ANCOVA) was performed on the speed of response data, with the spatial ability scores representing the covariate variable. Those subjects viewing the posture from the 'right' viewing angle had significantly lower times than those subjects viewing the postures from the 'front' or 'oblique' perspectives. Also, subjects were significantly slower when recording the pushing posture than when recording any of the other four postures. The average time required to record a posture ranged from 2.55 to 5.98 minutes, with an overall average of 4.04 minutes. It was also demonstrated that spatial ability had no effect on the speed of the subjects' responses.

PI coefficients and Gamma Statistics were calculated to determine the accuracy of the method by comparing the subjects' responses to accurate measurements of each posture. It was shown that the recordings were similar to the expert measurements ($p < .05$) in all cases, except for the condition where the subjects were recording the frontal plane of the 'crouching' posture. The accuracy of the method was also evaluated using a analysis-of-covaraince (ANCOVA) to analyze the angular deviations of the subjects responses from the expert measurements. Twelve link segments on the stick figure were used as the dependent measures, and the spatial ability scores were used as the covariate variable. The results of the ANCOVA indicated that subjects viewing the postures from the 'right' viewing angle were significantly more accurate than those subjects viewing the postures from either the 'front' or 'oblique' perspectives. Also subjects were significantly less accurate when recording the 'pushing' posture than when recording any of the other four postures. Finally, it was demonstrated that spatial ability had no effect on the accuracy of the subjects' responses.

ACKNOWLEDGMENTS

I would like to thank Dr. Jeff Woldstad for his direction and advice, as well as his patience. I would also like to thank Marc Dysart for helping me develop the program I used to perform my research. Finally, I would like to thank everyone who helped me finish up while I was working in the 'real world', especially Rally Pagulayan and Mandy Long.

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1. INTRODUCTION

1.1 Rationale

Posture measurement and recording is essential to most ergonomic assessment techniques. A precise description of the posture a person adopts while performing an activity provides essential information for determining the effects that activity has on the person's musculo-skeletal system. Posture recording methods were originally developed to allow the user to directly observe and record working postures as the work was being performed. Today, videotape is commonly used to record work activity and postures are recorded and digitized from the tape. Methods of recording posture range from simple paper and pencil methods to very complex computer-aided video digitization techniques.

Paper and pencil techniques, although inexpensive and readily available, often force a trade-off between speed and accuracy. Methods that are fast and easy to use often provide an inadequate description of posture (Karhu, Kansi, and Kuorinka, 1977; Silva, 1986), while those methods designed to be highly accurate are usually difficult to use and time-consuming (Corlett, Madeley, and Manenica, 1979; Priel, 1974). Some computer-aided methods offer increased speed of data input and encoding of postural information, but like the simple paper and pencil techniques, often lack the complexity necessary to adequately record posture (Keyserling, 1986a, Kilbom, Persson, and Jonsson, 1986).

In response to the lack of accuracy and/or excessive time required to record posture using the paper and pencil techniques, Malone (1991) developed a paper and pencil technique designed to be comprehensive, but still quick and easy to use. The recording technique called *Posture Taxonomy* specifically considers the cognitive and perceptual capabilities of the user, and the anthropometric characteristics of the postural representations. By addressing issues such as spatial compatibility and the sensitivity of the measure, Malone attempted to match the method to the user's mental abilities so that the system would be easier to understand and use. Some problems were encountered with the technique, including lengthy recording times, and inconsistent recordings between views.

This Thesis presents a computer-based method for recording three-dimensional posture that is intended to be accurate, fast, easy to use, and allows postures to be easily encoded into computerized format. The program currently runs on a PC compatible computer system and has been designed to assist the analyst in recording postural information from a videotape or still picture record of the work posture. The method uses relatively simple two-dimensional and simulated three-dimensional graphics to represent the position of the subject. Spatial compatibility is increased by providing views in all three planes, and presenting a three-dimensional figure that can be directly compared to the recorded image. The method also facilitates encoding postural information into computerized format for easy storage and retrieval. The program attempts to provide a relatively simple user interface by incorporating known limitations in human perception and information processing.

1.2 Objectives

A number of characteristics representative of good posture recording methods have been identified in the literature, and this study will attempt to determine if the proposed method meets these requirements. These characteristics include providing a method that:

1) is usable by people with little or no training in anatomy or ergonomics;
2) is relatively fast and easy to use;
3) provides an accurate representation of the posture observed which can be reliably recreated;
4) can be coded easily into computerized format.

A posture method that is easy to use should also produce relatively quick posture recordings (45-60 seconds), but the method should be comprehensive enough to allow for the recording of any posture that is achievable given the range of motion of the human body, and the cognitive and perceptual limitations of the human recorder (Fisher and Tarbutt, 1988). In addition, the recording method should be reliable enough so that the posture can be accurately recreated from the recorded information (Corlett et al., 1979). Finally, it is desirable that the method easily interface with a computer for data reduction, storage, and analysis (Keyserling, 1986a).

2. LITERATURE REVIEW

The following literature review summarizes the information available on several existing posture recording techniques. Paper and pencil methods are discussed along with a description of some computer-assisted techniques. The strengths and weaknesses of the various methods are highlighted to provide justification for the proposed method. In addition, the method developed by Malone (1991), which provides the basis for the proposed method, is evaluated in detail. The description of Malone's method includes a discussion of the cognitive and perceptual abilities of humans, and the importance of these capabilities and limitations in posture recording. Finally, human spatial ability is explored, and its possible effects on posture recording are evaluated.

2.1 Categorical Methods

In some instances, precise link positions are not needed, and only a general description of posture is required. When it is important to identify postures by placing them in general categories, the methods of choice are those that have low resolution and a limited number of posture combinations. These methods are ideal for in-the-field situations where static postures must be recorded quickly. In addition, methods such as these can be easily learned, and can be used by non-experienced recorders.

2.1.1 OWAS: Ovako Working Posture Analyzing System

One of the first methods of posture recording was developed by Karhu, Kansi, and Kuorinka (1977) to identify and evaluate poor postures in the work place. The Ovako Working Posture Analyzing System (OWAS) focused on practicality by providing a small number of postural categories for the user to choose from (see Figure 2.1). Body posture is recorded by indicating one of four back positions, one of three upper limb

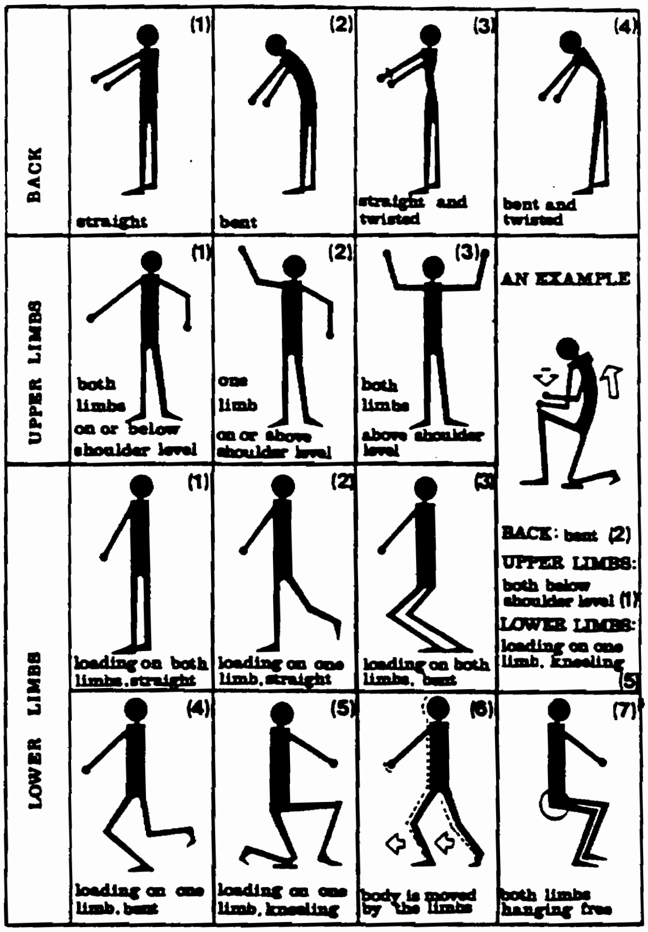


Figure 2.1 The Ovako Working Posture Analyzing System (OWAS) (Karhu et al., 1977).

positions, and one of seven lower limb positions. Pictorial representations are used to demonstrate the various posture categories, and the user selects three pictures to describe a particular posture. This results in a three-digit code that can be categorized into one of four operative classes used to describe successive levels of discomfort. The categories range from normal postures which do not need any special attention to postures needing special attention. The two classes in between represented postures with intermediate ratings. The discomfort levels were subjectively determined by 32 experienced steel workers and a small group of international ergonomists (Karhu et al., 1977).

The four operative classes can be used to evaluate a working environment by identifying the frequency and severity of the postures adopted by the workers. The method was put to use at the Ovako steel company and did contribute to improved working conditions by identifying tasks where workers were adopting "risky" postures that could lead to injuries (Karhu, Härkönen, Sorvali, and Vepsäläinen, 1981). It was determined that in situations where the analyses must be performed on the job, and only a general ergonomic evaluation of the working conditions is required, the OWAS method is ideal.

An experiment was performed by Karhu et al. (1977), to determine the reliability of the method, and they found a fairly good agreement between the two work-study engineers who were participating in the study. Fifty-two tasks were analyzed for a total of 36,240 observations, and the work-study engineers produced a median percentage of agreement of 93%, with a range of 74%-99%.

According to Karhu et al. (1981), the simplicity of the method makes it easy to learn (although the initial training period lasted one week) and use, and postures can be recorded quickly (in a few seconds). The pictograms provide straightforward information that can be interpreted quickly and easily. Furthermore, by encoding the postural information into digital format, the data can be easily entered into a computer and stored for future analysis.

The main disadvantage of the method is that the simple description of posture provides inadequate information for complex ergonomic analysis. Each postural category represents a wide range of link positions, which reduces the sensitivity of the measurement and does not allow for precise description of each individual link. A possible disadvantage, according to Karhu et al. (1977), is that the training period lasts approximately one week, but this includes learning the discomfort categories, and learning to analyze the data collected. It is likely that the time required to learn the recording technique is minimal. Finally, although the postural information is digitized, the collected data still has to be manually entered into a computer for storage and analysis, increasing the overall time of evaluation.

2.1.2 CPM: Categorized Posture Method

Silva (1986) developed a method to assist in categorizing the various postures adopted by older adults performing daily activities. The Categorized Posture Method (CPM) was developed in response to the time-consuming and complex nature of the previously developed systems: Benesh Notation (Benesh and Benesh, 1956), *Labanotation* (Laban, 1971), and ***Posturegram*** (Priel, 1974). Benesh Notation and *Labanotation* were designed as choreographic tools to analyze the changing flow of movements, and to describe the specific position of each link. The ***Posturegram*** was designed to provide an accurate and comprehensive, numerical description of posture, and is described in a later section of this literature review. Silva concluded, based on the extensive amount of reading needed to explain any of these methods, that the training time would be quite lengthy.

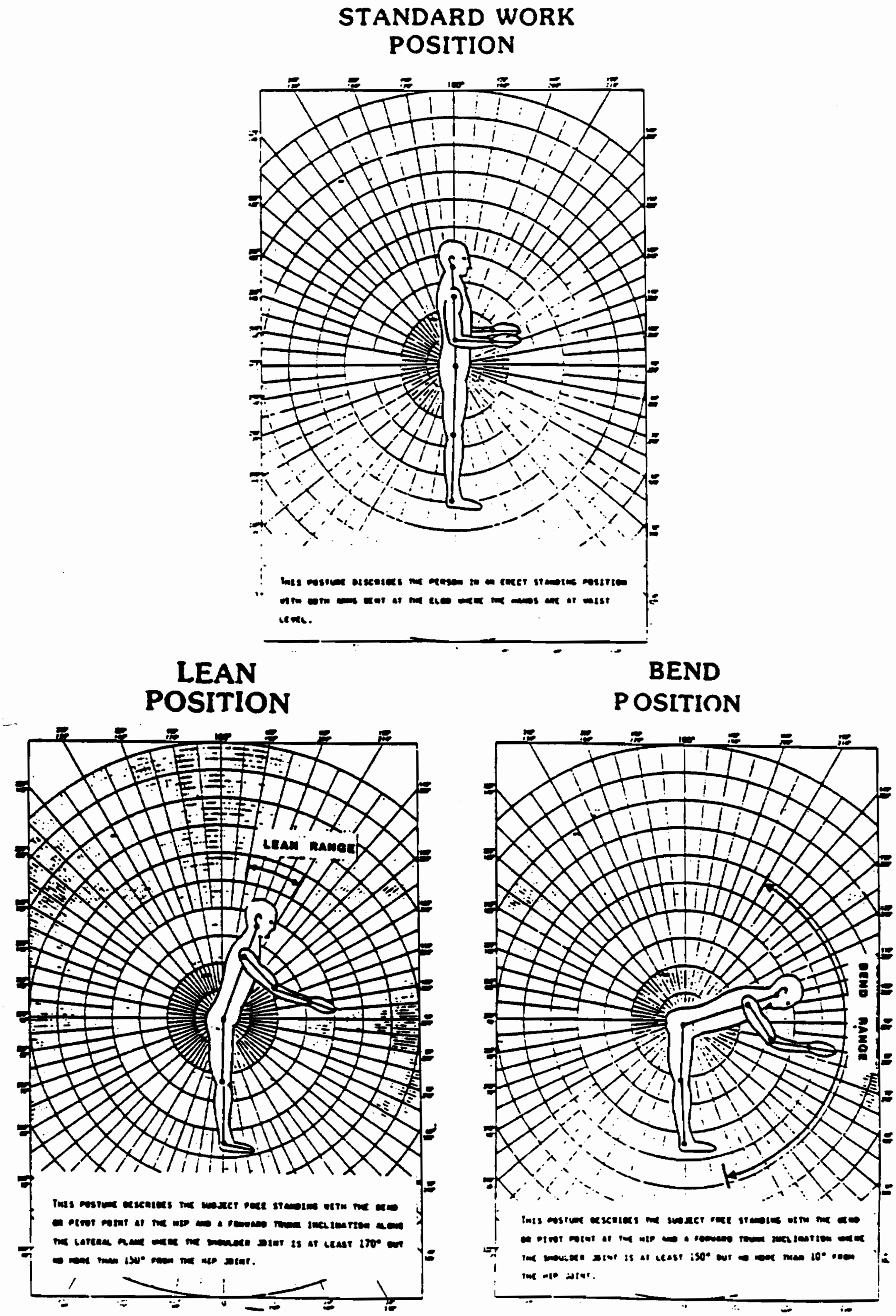
The CPM was designed so that users could simply and easily identify a posture, and place it into an appropriate category, with minimal training time. The method uses four basic posture categories, lean, bend, stoop, and squat, that are defined by mild to extreme deviations from a pre-defined, standard work position (see Figures 2.2 and 2.3). The basic posture categories differ from OWAS because they are defined by a range of angular deviations, instead of specific static postures. In addition, if reaching movements occur, they are included as additions to one of the basic categories (see Figure 2.3).

Silva's implementation of the method involved videotaping elderly subjects performing regular activities, such as meal preparation, and then analyzing the videotape so that the basic postures could be recorded and encoded for computer analysis. Although specific data was not presented, Silva found the method to be easy to learn, given a short training session of five to ten minutes, and also found the method to be highly reliable. Also, presumably because of it's simple nature, Silva found the method to be easy to use, and recording time to be short. Another advantage of the CPM is that the format of the CPM allows it to be easily encoded for computer analysis.

The method is very useful for easily recording basic positions, but it does have some disadvantages. Like OWAS, the method allows for a wide range of possible postures within each category, making it an inadequate method for obtaining detailed recordings. Also, CPM only provides postural representations in the sagittal plane, so the accuracy of the recordings is reduced because information concerning postures in the transverse and frontal planes is lost. Finally, like the OWAS method, the postural information has to be manually encoded and entered into a computer for storage and analysis.

2.2 Computerized Categorical Methods

The development of computer-assisted methods was inspired by the characteristic lack of detail in the categorical techniques (Karhu et al., 1977; Silva, 1986) and the complex and time-consuming nature of the more detailed methods



STANDARD WORK POSITION

THIS POSTURE DESCRIBES THE PERSON IN AN ERECT STANDING POSITION WITH BOTH ARMS BENT AT THE ELBOW WHERE THE HANDS ARE AT WAIST LEVEL.

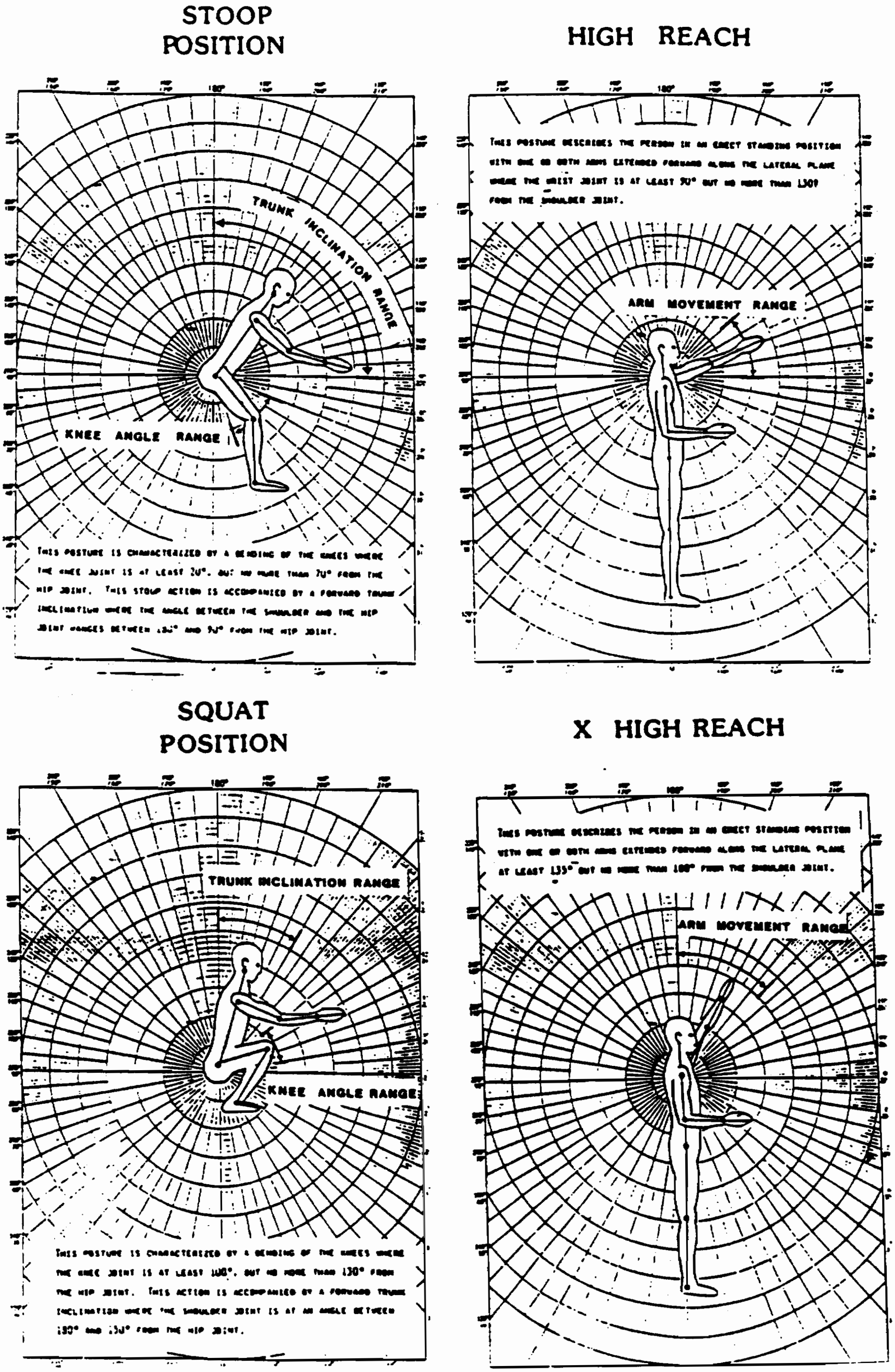
LEAN POSITION

THIS POSTURE DESCRIBES THE SUBJECT FREE STANDING WITH THE BEND OR PIVOT POINT AT THE HIP AND A FORWARD TRUNK INCLINATION ALONG THE LATERAL PLANE WHERE THE SHOULDER JOINT IS AT LEAST 170° BUT NO MORE THAN 150° FROM THE HIP JOINT.

BEND POSITION

THIS POSTURE DESCRIBES THE SUBJECT FREE STANDING WITH THE BEND OR PIVOT POINT AT THE HIP AND A FORWARD TRUNK INCLINATION WHERE THE SHOULDER JOINT IS AT LEAST 150° BUT NO MORE THAN 10° FROM THE HIP JOINT.

Figure 2.2 Categorized Posture Method (CPM) - Basic Positions (Silva, 1986).



THIS POSTURE IS CHARACTERIZED BY A BENDING OF THE KNEES WHERE THE KNEE JOINT IS AT LEAST [illegible], BUT NO MORE THAN [illegible] FROM THE HIP JOINT. THIS STOOP ACTION IS ACCOMPANIED BY A FORWARD TRUNK INCLINATION WHERE THE ANGLE BETWEEN THE SHOULDER AND THE HIP JOINT RANGES BETWEEN [illegible] AND [illegible] FROM THE HIP JOINT.

THIS POSTURE DESCRIBES THE PERSON IN AN ERECT STANDING POSITION WITH ONE OR BOTH ARMS EXTENDED FORWARD ALONG THE LATERAL PLANE WHERE THE WRIST JOINT IS AT LEAST 90° BUT NO MORE THAN 130° FROM THE SHOULDER JOINT.

THIS POSTURE IS CHARACTERIZED BY A BENDING OF THE KNEES WHERE THE KNEE JOINT IS AT LEAST 100°, BUT NO MORE THAN 130° FROM THE HIP JOINT. THIS ACTION IS ACCOMPANIED BY A FORWARD TRUNK INCLINATION WHERE THE SHOULDER JOINT IS AT AN ANGLE BETWEEN [illegible] AND [illegible] FROM THE HIP JOINT.

THIS POSTURE DESCRIBES THE PERSON IN AN ERECT STANDING POSITION WITH ONE OR BOTH ARMS EXTENDED FORWARD ALONG THE LATERAL PLANE AT LEAST 135° BUT NO MORE THAN 180° FROM THE SHOULDER JOINT.

Figure 2.3 Categorized Posture Method (CPM) - Basic Positions (continued) and Reaching (Silva, 1986).

(Benesh and Benesh, 1956; Laban, 1971; Priel, 1974; Corlett et al., 1979). By using a computer to assist the user in posture recording, methods such as these attempt to resolve the trade-offs between the simple and comprehensive techniques (Kilbom, et al., 1986; Keyserling, 1986a; Keyserling, 1986b). The computer-assisted methods are similar to the simple paper and pencil systems because they use general categories to represent a defined range of postures. They differ, however, because the computer-assisted techniques often use more categories, allowing for a more accurate description of posture. The categories are labeled with simple codes, a numeral or letter, so a single keystroke can be used to enter the postural information. This data input technique can make the methods even faster than the simple paper and pencil techniques, and the use of more postures can increase the accuracy. Also, because the data is automatically digitized as it is entered, there is no encoding time from paper to computer format.

2.2.1 VIRA

In 1983, Persson and Kilbom developed a method called VIRA to evaluate the effect of working postures on neck and shoulder disorders. A worker's posture is videotaped and then viewed in real time to record the postures adopted, and to determine the amount of time each posture is held. Ten standard posture categories are used to classify the observed position of the neck and shoulders, making the technique more detailed than the OWAS method (see Figure 2.4). Each category is associated with a key on the keyboard, and a specific posture can be described by a certain combination of keys. For example, a user would press one of two keys for neck posture in the sagittal plane, then one of four keys for shoulder flexion-extension, and finally one of four keys for shoulder abduction-adduction. A personal computer receives and stores the postural information for future retrieval and analysis.

The computer-assisted nature of VIRA produces many advantages over the other

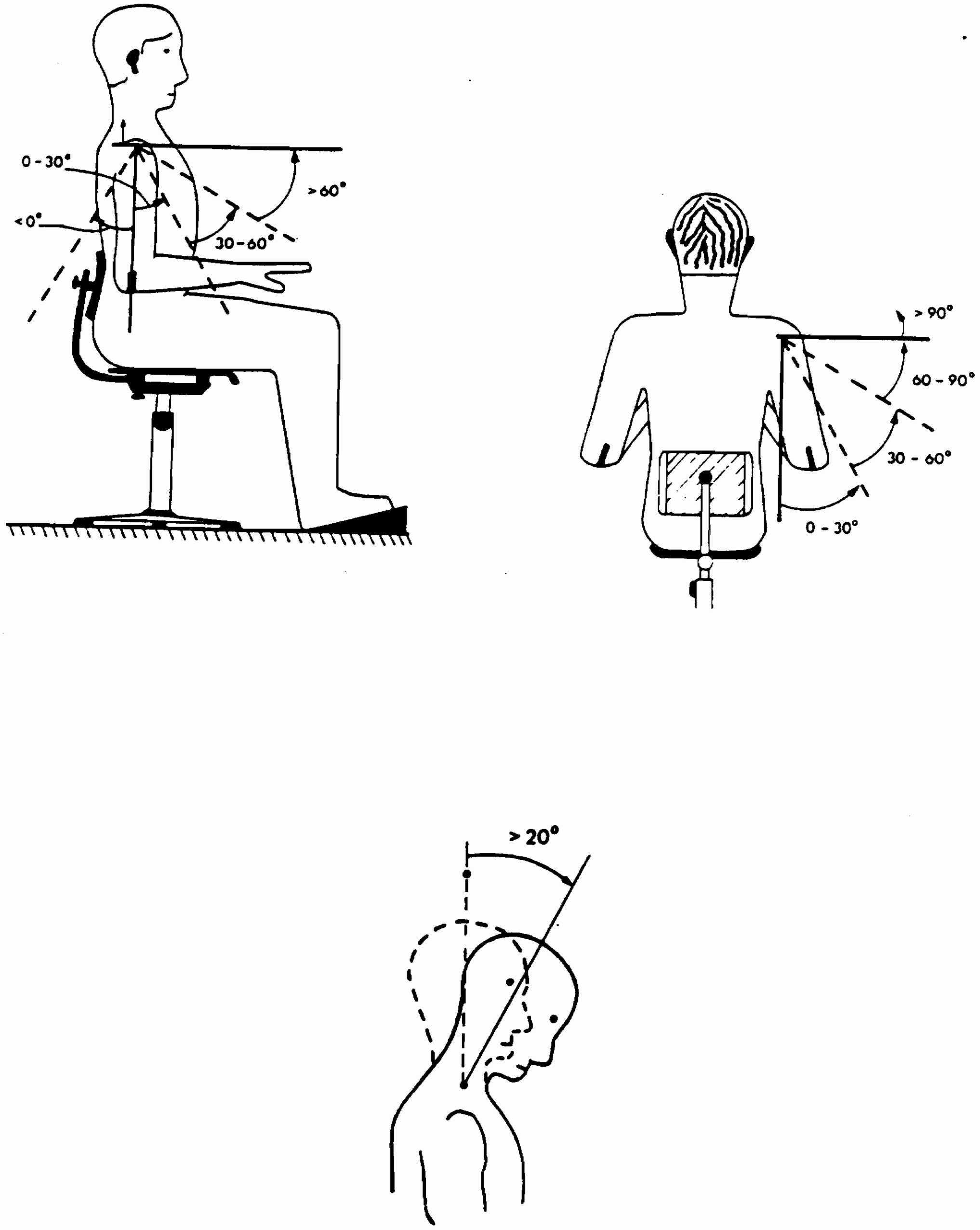


Figure 2.4 VIRA (Kilbom, et al., 1986).

categorical methods. Most importantly, the system reduces the encoding time and facilitates data entry by reducing the input of postural information to simple keystrokes that can be memorized. Training time is minimal because the procedure is quite simple and only involves memorizing the keys assigned to each postural category. Also, by recording the work activity on videotape, the analyst can view the posture at his or her convenience, and is not constrained by the duration of the task. Finally, in comparison to the categorical methods presented earlier (OWAS and CPM), more categories are provided, which can make VIRA a more accurate method, at least for some parts of the body.

Along with the many advantages of VIRA, there are still some inherent disadvantages, based on the categorical nature of the method. Most importantly, the comprehensiveness of the method is still insufficient for accurate recordings even though more categories are used. Another factor reducing the accuracy of the method is that videotaped recordings of the worker are taken from both the side and back views, but posture recordings are only made in the sagittal plane. Providing only two positions for the neck in the sagittal plane is not sufficient for a detailed analysis of stresses on the neck, because it doesn't account for twisting in the transverse plane, or deviation in the frontal plane.

Also, using this method, postural data cannot be collected for other parts of the body (i.e. arms, legs, trunk, etc.), though Persson and Kilbom have indicated that the method can be expanded to include these areas. If the other areas of the body were described with the same lack of detail, however, the expanded VIRA would still be inadequate for recording detailed postural information.

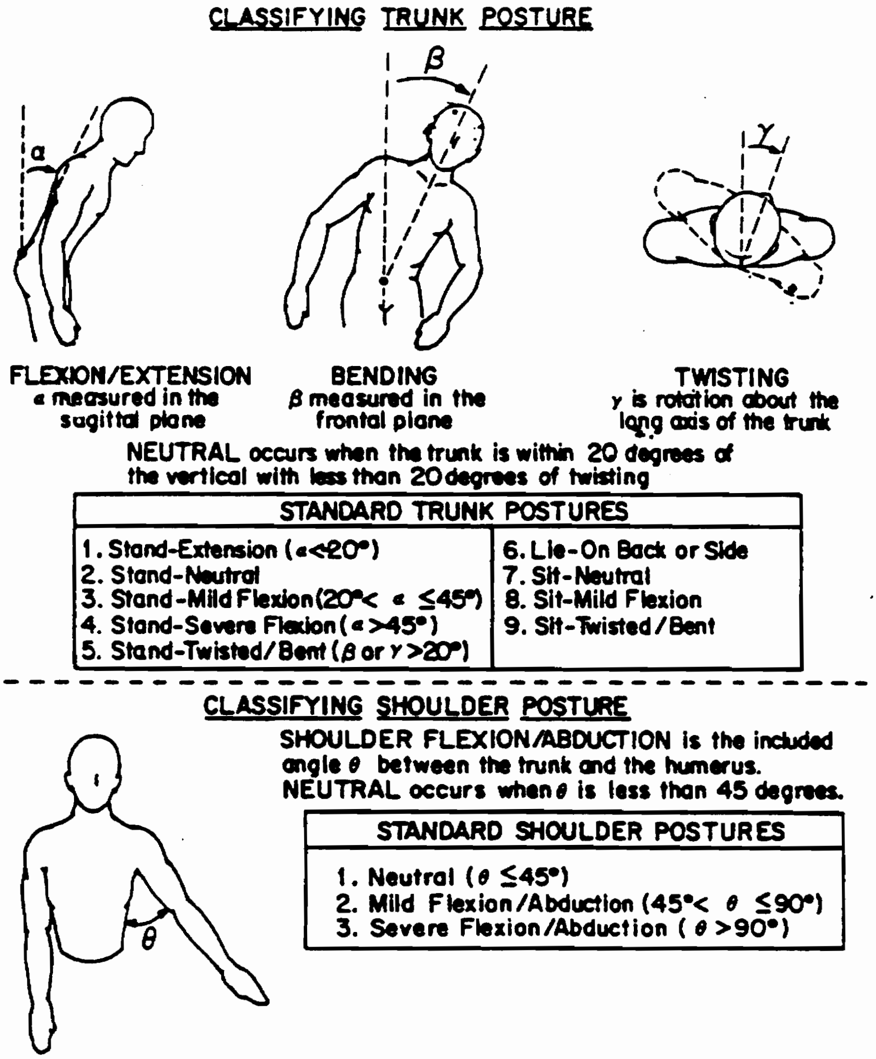
2.2.2 Posture Classification System

Keyserling (1986) has developed a method to describe the posture of the trunk, shoulders, and lower extremities (see Figure 2.5). The method is specifically designed for recording postures and postural changes in real time to evaluate the postural demands of a work cycle. The goal was to design a method that was easy to learn and use, reliable, and easily interfaced with a computer for data reduction, storage, and analysis. The method is similar to OWAS and VIRA because users can select from a menu of standard postures. It is also similar to VIRA, because it uses a personal computer to assist the user in recording posture, and a key is assigned to each postural category.

Keyserling found that more standard posture categories were needed to accurately record posture during a work cycle. Therefore, he included nine standard positions of the trunk, as well as five standard neck positions. This provides greater accuracy than the OWAS method, which has four back categories and no neck categories. The method also describes both shoulders independently, providing three standard positions for each. This allows for greater accuracy than VIRA, where the shoulders are assumed to move in parallel. In addition, the lower extremities are defined by various activities such as walking, squatting, and kneeling, rather than appendage positions.

The videotaped recording of the task is viewed multiple times, with the analyst recording each joint separately. Posture categories are defined as deviations from ergonomically neutral postures, as opposed to VIRA, where categories are defined by levels of flexion/extension, and adduction/abduction (see Figure 2.4). Some links such as the trunk and neck can be described in all three planes using such terms as "flexion/extension" for movements in the sagittal plane, "bending" for movements in the frontal plane, and "twisting" for movements in the transverse plane (see Figure 2.5).

Keyserling's method has several advantages, many of them resulting from it's computerized nature. One of the most important advantages is that the method produces



α measured in the sagittal plane

β measured in the frontal plane

γ is rotation about the long axis of the trunk

NEUTRAL occurs when the trunk is within 20 degrees of the vertical with less than 20 degrees of twisting

STANDARD TRUNK POSTURES	
1. Stand-Extension ($\alpha < 20^\circ$)	6. Lie-On Back or Side
2. Stand-Neutral	7. Sit-Neutral
3. Stand-Mild Flexion ($20^\circ < \alpha \leq 45^\circ$)	8. Sit-Mild Flexion
4. Stand-Severe Flexion ($\alpha > 45^\circ$)	9. Sit-Twisted/Bent
5. Stand-Twisted/Bent (β or $\gamma > 20^\circ$)	

SHOULDER FLEXION/ABDUCTION is the included angle θ between the trunk and the humerus.
NEUTRAL occurs when θ is less than 45 degrees.

STANDARD SHOULDER POSTURES
1. Neutral ($\theta \leq 45^\circ$)
2. Mild Flexion/Abduction ($45^\circ < \theta \leq 90^\circ$)
3. Severe Flexion/Abduction ($\theta > 90^\circ$)

Figure 2.5 Posture classification system (Keyserling, 1986a).

greater accuracy than the other categorical methods because it provides more standard positions for the analyst to choose from when evaluating certain joints. Also, by allowing the trunk and neck to be described in all three planes, the accuracy of the method is increased to a degree greater than VIRA. As with other computerized recording techniques, such as VIRA, the data that is collected can be immediately encoded and stored in computerized format for future analysis.

According to Keyserling, the method is easy to learn and postures can be recorded quickly. He performed a study in 1986 and found that the time to record posture, using the method, was substantially less than with other systems (30 minutes to record a 75 second work cycle) because the computer assists the analyst in collecting and recording postural data. He determined that the basic components of postural analysis and computer data entry can be learned in a short period of time (a few minutes), providing further support for the use of computer assistance in posture recording. By memorizing the posture categories, and their associated key presses, analysts can quickly record a posture and do so with greater accuracy than the other categorical methods. Another important advantage is that the postural information recorded is instantly encoded, entered, and saved in computerized format, providing storage for future analysis.

In addition to the many advantages of Keyserling's method, there are also a few disadvantages. For example, the reference sheet that includes the definitions for each posture does not provide an angular scaling grid to indicate the degree of rotation of each link. If such a grid were present, superimposed over the associated pictogram, the analyst could determine the angle of deviation of each link more accurately, because the spatial compatibility of the method would be increased. Also, the grids could be limited to the actual range of movement of each link, further reducing the chance for error on the part of the analyst.

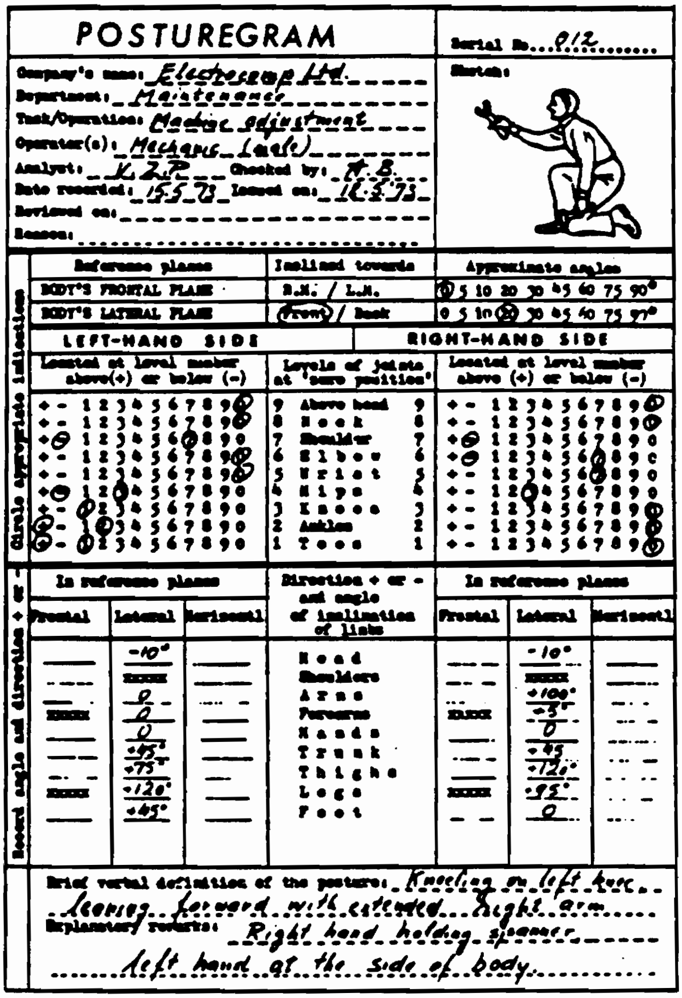
Also, although it appears that the training time should be short, Keyserling found that learning the motor skills required for data entry can take from 5 to 10 hours, and memorizing the standard posture definitions can take even longer. Another disadvantage is that even with more posture categories, the method does not provide the comprehensiveness necessary to adequately record posture. This is partly due to the lack of description of the arms and legs individually, but mostly due to the limited number of categories provided to describe each link. Without a more comprehensive description of posture, an accurate ergonomic analysis of the job cannot be performed.

2.3 Segmental Manipulation Methods

To adequately describe posture for ergonomic analysis, a recording method needs to be highly accurate, and allow the recreation of the posture from the recorded data. Several methods have been developed that provide a template upon which a user can accurately record a posture by identifying specific link positions in terms of joint angles or deviations from a reference plane (Priel, 1974; Corlett, Madeley, and Manenica, 1979). These methods often allow for recording in three dimensions by providing redundant pictograms oriented in each of the three planes, or including targets that allow input of postural information in three dimensions. After sufficient training, these methods provide an extremely accurate description of posture that can be coded into a computer for complex, biomechanical analysis.

2.3.1 *Posturegram*

Priel (1974) made one of the first attempts at creating a highly accurate and comprehensive recording technique. The recording template he developed is called a *Posturegram*, and by using this method a user can describe posture by indicating the amount each link diverges from a defined zero position (see Figure 2.6). Pictograms are used to represent the rotation of links in all three planes, and only realistic ranges of



POSTUREGRAM

Serial No...012.......

Company's name: Electrocomp Ltd.
Department: Maintenance
Task/Operation: Machine adjustment
Operator(s): Mechanic (male)
Analyst: K.Z.P. Checked by: A.B.
Date recorded: 15.5.73 Issued on: 16.5.73
Reviewed on:
Reason:

Sketch:

Circle appropriate indications

Reference planes	Inclined towards	Approximate angles
BODY'S FRONTAL PLANE	R.H. / L.H.	[✓ 0] 5 10 20 30 45 60 75 90°
BODY'S LATERAL PLANE	[✓ Front] / Back	0 5 10 [✓ 20] 30 45 60 75 90°

LEFT-HAND SIDE Located at level number above(+) or below (-)	Levels of joints at 'zero position'		RIGHT-HAND SIDE Located at level number above (+) or below (-)
+ - 1 2 3 4 5 6 7 8 9 [✓ 0]	9 Above head	9	+ - 1 2 3 4 5 6 7 8 9 [✓ 0]
+ - 1 2 3 4 5 6 7 8 9 [✓ 0]	8 Neck	8	+ - 1 2 3 4 5 6 7 8 9 [✓ 0]
+ [✓ -] 1 2 3 4 5 6 [✓ 7] 8 9 0	7 Shoulder	7	+ [✓ -] 1 2 3 4 5 6 7 8 9 0
+ - 1 2 3 4 5 6 7 8 9 [✓ 0]	6 Elbow	6	+ [✓ -] 1 2 3 4 5 6 [✓ 7] 8 9 0
+ - 1 2 3 4 5 6 7 8 9 [✓ 0]	5 Wrist	5	+ - 1 2 3 4 5 6 [✓ 7] 8 9 0
+ [✓ -] 1 2 [✓ 3] 4 5 6 7 8 9 0	4 Hips	4	+ - 1 2 [✓ 3] 4 5 6 7 8 9 0
+ - [✓ 1] 2 3 4 5 6 7 8 9 0	3 Knees	3	+ - 1 2 3 4 5 6 7 8 9 [✓ 0]
[✓ +] - 1 [✓ 2] 3 4 5 6 7 8 9 0	2 Ankles	2	+ - 1 2 3 4 5 6 7 8 9 [✓ 0]
[✓ +] - [✓ 1] 2 3 4 5 6 7 8 9 0	1 Toes	1	+ - 1 2 3 4 5 6 7 8 9 [✓ 0]

Record angle and direction + or -

In reference planes			Direction + or - and angle of inclination of limbs	In reference planes		
Frontal	Lateral	Horizontal		Frontal	Lateral	Horizontal
—	-10°	—	Head	—	-10°	—
—	XXXX	—	Shoulders	—	XXXX	—
—	0	—	Arms	—	+100°	—
XXXX	0	—	Forearms	XXXX	+5°	—
—	0	—	Hands	—	0	—
—	+45°	—	Trunk	—	+45	—
—	+75°	—	Thighs	—	+120°	—
XXXX	+120°	—	Legs	XXXX	+95°	—
—	+45°	—	Feet	—	0	—

Brief verbal definition of the posture: Kneeling on left knee, leaning forward with extended Right arm

Explanatory remarks: Right hand holding spanner, left hand at the side of body.

Figure 2.6 *Posturegram* - Recording Template (Priel, 1974).

motion are depicted (see Figure 2.7). Users indicate on the template the vertical position of each joint from one of nine reference levels, and numerically describe the angle of rotation of each link in each reference plane. The '+' and '-' symbols indicate the direction of rotation. In addition, a quick sketch is drawn by the analyst, as well as a brief verbal definition of the posture.

The main advantage of the *Posturegram* is that postural information can be recorded at an accuracy level based on the needs of the analyst. Highly accurate recordings can be obtained because the template allows for recording of postural information in all three planes. Also, the template covers 14 joints, as well as the rotation of the shoulders from the twisting of the back, making the technique comprehensive enough to describe a posture for ergonomic analysis. A supplementary sheet is provided that presents pictograms oriented in all three planes to assist the analyst in defining the direction and amount of rotation of each link (Figure 2.7). This sheet also includes the restricted range of movement for each joint, to prevent the analyst from selecting a joint rotation or link position that is physically impossible. Also, when the recording template is used, the information is readily encoded and entered into a computer.

A major disadvantage of the method is that it is time-consuming to enter each joint position and link rotation, while also making a brief sketch and verbal description. Also, the need for a separate reference sheet and template forces the analyst to look back and forth between the two sheets, as well as the posture being recorded. This decreases the spatial compatibility of the task which can increase the time it takes to record a posture and increase the chance of recording error. The pictograms do not provide a template describing the actual degree of rotation of each joint, or even graded ranges of movement surrounding the joint, forcing the analyst to estimate the angles of each joint without any true scaled reference. Finally, the postural information must be manually

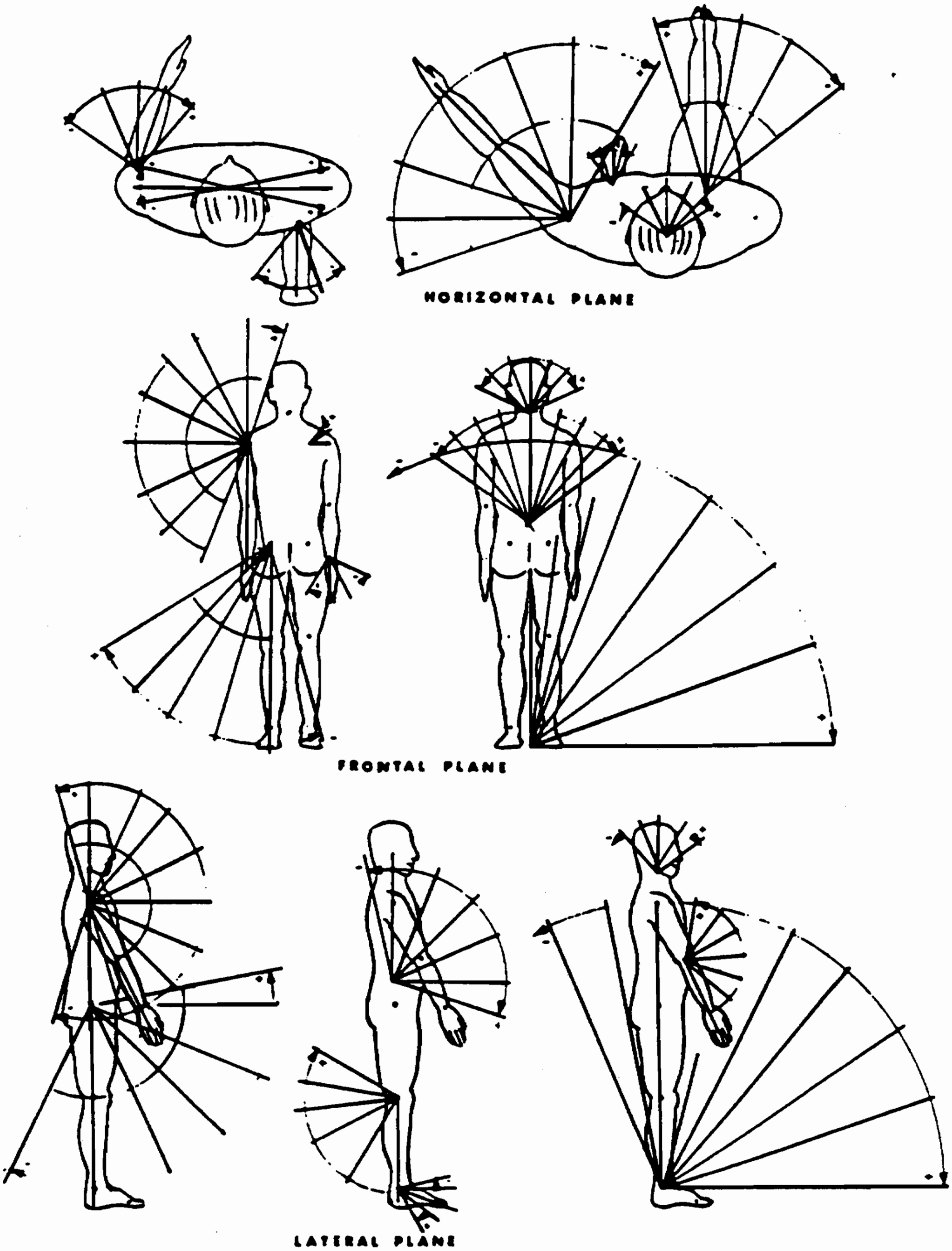


Figure 2.7 *Posturegram* - Reference Sheet (Priel. 1974).

encoded into computerized format if the information is to be entered into a computer for storage or future analysis, which can be difficult and time-consuming.

2.3.2 *Posture Targeting*

Corlett, Madeley, and Manenica (1979) developed a technique called ***Posture Targeting*** that focused on quick, accurate posture recording. They wanted to develop a method that was simple, easily taught, and reliable for use at the technician level. They found that choreographical methods such as *Labanotation* (Laban, 1971) and Benesh notation (Benesh and Benesh, 1956) were comprehensive enough for accurate recordings, but were unsuitable because they took months to learn. The *Posturegram* method (Priel, 1974) was also considered highly accurate but involved many entries and additional tasks (sketches and definitions) to accurately describe a posture, which resulted in lengthy recording times.

The template used in *Posture Targeting* allows a posture to be quickly and accurately recorded with just ten marks. Concentric circles (targets) are provided for each moveable part of the body shown in standard anatomical position, representing successive deviations from the standard position in the vertical plane (see Figure 2.8). Each target also has radial lines within the concentric circles, representing movements in the horizontal plane, as if the analyst were viewing the posture from above. In the example provided (see Figure 2.9), the cross on the target represents a 90° deviation from the standard position in the vertical plane, and a 45° deviation from the standard position in the horizontal plane. Verbal descriptors are also used to describe the distal extremities and the type of activity the worker is performing.

An experiment was done to test the reliability of the method, and Corlett et al. found that the correlation between the analysts was significant ($p<.05$) indicating that the system was reliable. They also found that postures took approximately 30 seconds to

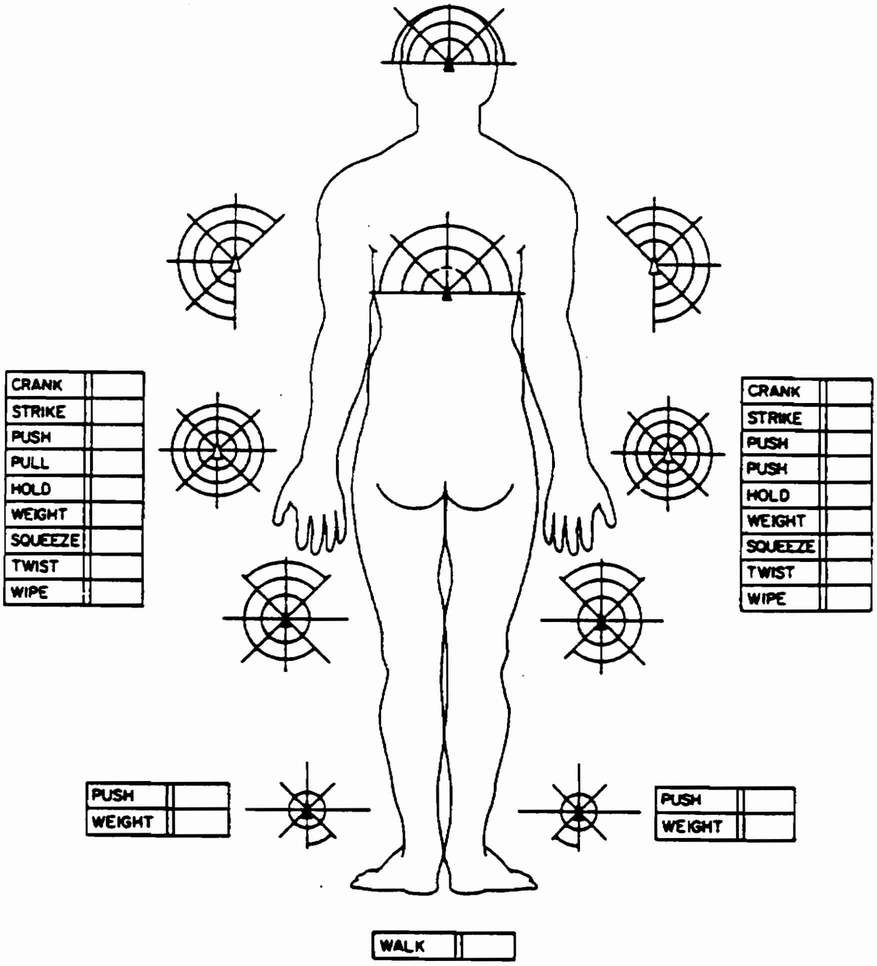
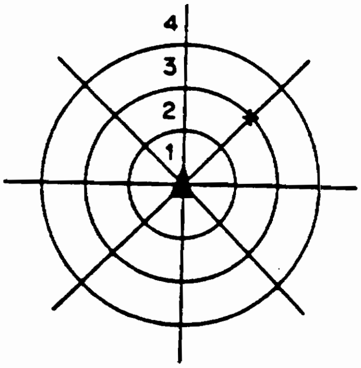


Figure 2.8 *Posture Targeting* (Corlett et al., 1979).



1 = 0 – 45°
2 = 45 – 90°
3 = 90 – 135°
4 = 135 – 180°

Figure 2.9 *Posture Targeting* - Sample Target (Corlett et al., 1979).

record, but no accuracy data were presented, and sufficiently accurate recordings would probably take longer. Even without the accuracy data, it can be concluded, given the comprehensiveness of the recording template, that accurate posture recordings could be obtained if sufficient recording time was provided.

Presenting the targets on the same sheet as the pictogram, and placing them on or near the joints they represent, provides a more spatially compatible recording template than the one found in *Posturegram* (Priel, 1974). Also, three-dimensional postures can be accurately recorded because the targets allow for recording in both the horizontal and vertical planes. Another advantage is that only ten marks need to be made to adequately describe an entire posture. Finally, the angular coordinates of the dots on the targets can be calculated, and the information can be fed into a computer for storage and analysis.

Posture Targeting does provide many advantages over the *Posturegram* method, but there are still some disadvantages. While this method includes the measuring scale directly on the postural representation, it only provides a view in the frontal plane, and the radial lines of the targets are oriented to record positions in the transverse plane. This spatial incompatibility forces the user to imagine they are observing the subject from above without a representative pictogram, and increases the chance of recording error. Also, converting the dots on the targets to three-dimensional angular coordinates can be very time-consuming, and increases the chance of a mistake that could reduce the accuracy of the method.

2.4 *Posture Taxonomy*

In response to the problems with the paper and pencil techniques, Malone (1991) developed a method for recording static postures designed to be highly accurate and comprehensive, without exceeding the capabilities of the recorder. While other methods tended to neglect the cognitive and perceptual issues related to posture recording, Malone focused on developing a technique that matched the recording method to the user's capabilities and limitations. He also considered the anthropometric characteristics of the pictograms, and their effects on the realism of the postural representations. Malone hoped to create a technique that was highly detailed, like the more segmental manipulation methods, but easy to use like the categorical methods.

2.4.1 Cognitive and Perceptual Considerations

Two basic components were emphasized by Malone concerning the cognitive and perceptual abilities of human recorders. First addressed was the process of encoding, which is important in both recording postural information and retrieving that information when recreating the recorded posture. The second referred to the sensitivity of the measuring scale, which can affect the users ability to make accurate estimates of the angle of rotation of a link.

The encoding of postural information can be performed using either verbal or visual descriptors. In most instances, it is apparent that visual descriptors are the most effective because they are more quickly encoded than verbal descriptors, and they are more objective and universally acceptable (see Fisher and Tarbutt, 1988). Also, visual descriptors can provide more information, in the same amount of time, than verbal descriptors (Sanders and McCormick, 1987). In some instances, however, verbal descriptors are more appropriate because they can more accurately describe specific positions of links that are difficult to represent pictorially, like crossed legs, or a particular hand position. From this information, Malone concluded that the best method would contain both verbal and visual descriptors.

Encoding can also be affected by the spatial compatibility of the recording method with the actual posture being recorded. Accuracy and speed of response are improved when the response set is more spatially compatible with the stimulus set

(Sanders and McCormick, 1987). In other words, encoding should be more effective if the postural representations on the recording template are spatially compatible with the posture being recorded. For example, by providing postural representations in each plane, the user does not have to perform as many mental rotations as they would if only one plane were presented. Also, the method should make encoding easier if the recording template itself is presented in a way that is spatially compatible with the postural representations, like in the *Posture Targeting* method of Corlett et al. (see Figure 2.8), here the recording targets are on the template, near the joints they are representing.

The second issue addressed by Malone, concerning the cognitive and perceptual abilities of human recorders, was the sensitivity of the measuring scale. Since humans are better at making comparative judgments than absolute judgments, it is best to use a graded scale (Sanders and McCormick, 1987). The more accurate a recording method is, the better, but if humans can't distinguish between the intervals describing link position, then it is better to adjust the method to the capabilities of the recorders. Gil and Tunes (1989) concluded that a 15° increment is the most sensitive interval humans can distinguish between when estimating joint angles.

2.4.2 Anthropometric Considerations

Another issue addressed by Malone, as well as other developers (Chaffin and Andersson, 1985; Schiro, Karwan, and Dutton, 1987; Fisher and Tarbutt, 1988), was the anthropometric considerations involved in describing a realistic pictorial representation of the human body. Since the body is perceived as a combination of links and joints, the classical link system was determined to be the most appropriate way to describe the human form. This system, as defined by Schiro, Karwan, Dutton, and Brunskill (1987), describes the body as a series of straight links held together by joints with fixed centers of rotation. In addition, Malone determined that enfleshment of the links would further increase the authenticity of the model.

There are some problems with this system, however, including inaccurate joint rotation centers and only one link to describing the back. Some joints, like the hip and shoulder, do not have fixed centers of rotation, making the method slightly inaccurate, but Malone concluded that the differences were small enough to be overlooked. Also, because many injuries in the workplace are associated with the lower back, it is important to describe the back accurately. Therefore, dividing the back into two links, by including the L5/S1 joint, is a way to increase the accuracy of the link system without resorting to the complex series of links and joints that would be necessary to perfectly model the spine.

Another anthropometric consideration addressed by Malone focused on maintaining the proper relationships between link lengths. By determining length based on a percent of stature, it is possible to achieve a rough estimate of the proportional relationships between the links. Anthropometric data demonstrates that people are composed of links from many percentile ranges, making a model based on average link size slightly inaccurate (Chaffin and Andersson, 1984). Malone concluded that since his postural representation was only a rough estimate, it would be accurate enough for modeling posture.

Finally, each joint has a specific range of motion that can be defined according to known data. Although it is not necessary to limit the range of motion on the recording template, it is likely that it would reduce the complexity of the recording method, making it harder to record incorrect postural information. Also, by including the restricted ranges of motion, the accuracy of the method would be increased, because it would be impossible to select positions that were unachievable for the given joint.

2.4.3 Method Description

After considering the cognitive, perceptual, and anthropometric issues related to posture recording, Malone created a method called *Posture Taxonomy* that was based on the positive features of the existing methods. As presented in Figures 2.10, through 2.12, the model is composed of 10 enfleshed links, including the division of the back into two links by a joint at L5/S1. Recording in each of the three planes, sagittal, frontal, and transverse (see Figures 2.10, 2.11, and 2.12, respectively), is accomplished by providing the postural representation on three diagrams, one for each plane. This is to increase the spatial compatibility of the method by more accurately representing the human posture, and it also builds in redundancy which can serve to increase the accuracy of the method. Because it is difficult to determine the position of the calves from the transverse plane, they are not included in the top view

Similar to *Posture Targeting*, targets surrounding each link are used to identify possible positions the link can adopt (see Figure 2.13). To increase spatial compatibility, each link is recorded by matching its actual orientation in space to the associated target element, and all the possible orientations of each link are provided. Link position is not dependent on the position of the adjacent links, and vertical and horizontal references are given using the edges of the recording form. By using a graded range of 15° intervals between each target element, the sensitivity of the method is reduced to a level that matches the cognitive and perceptual abilities of the user. Each target allows for the recording of both left and right links, where applicable, to conserve space on the recording template. To further reduce the complexity, some links have been provided with partial targets to account for the limited range of motion of some joints.

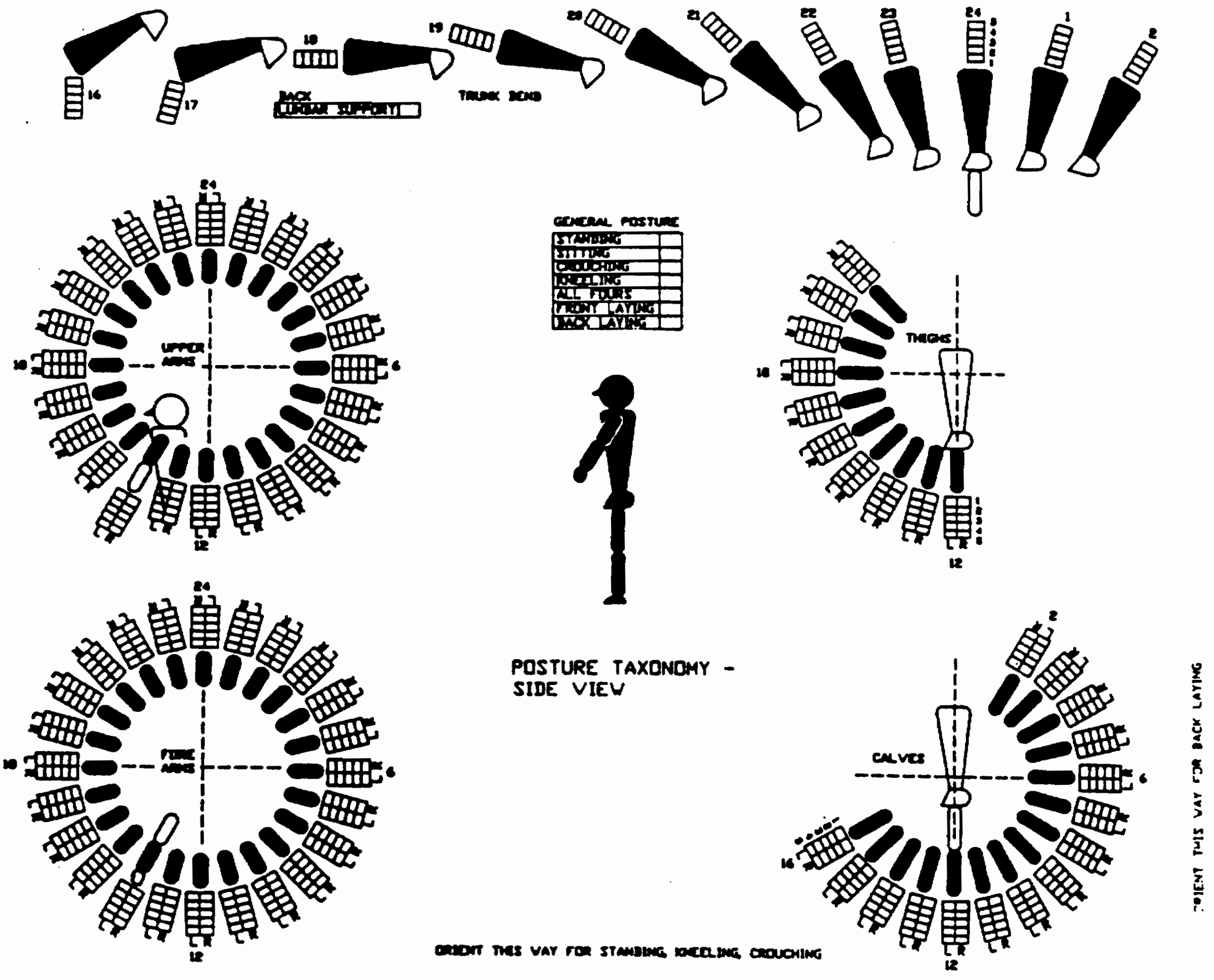


Figure 2.10 *Posture Taxonomy* - Sagittal plane (Malone, 1991).

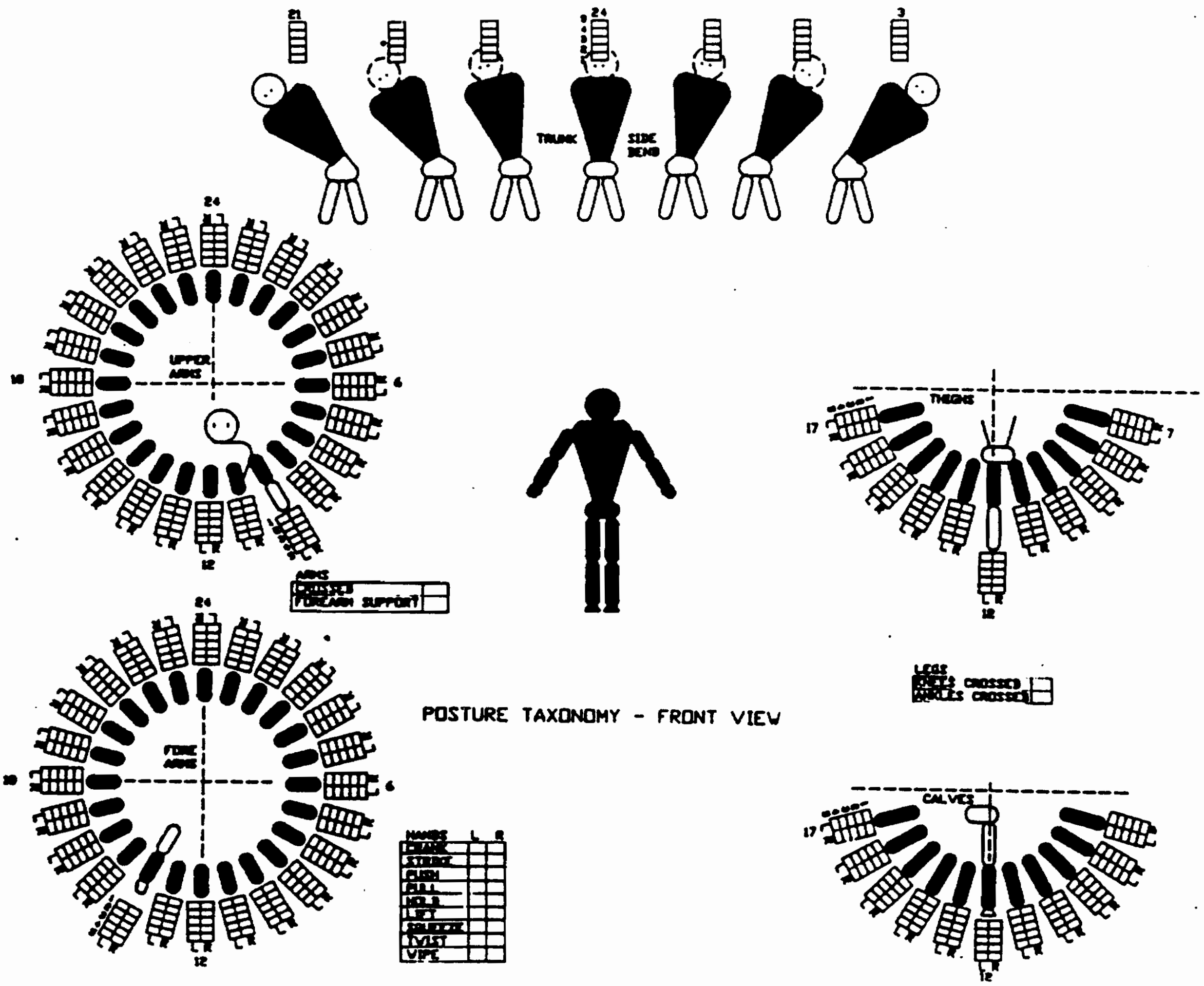


Figure 2.11 *Posture Taxonomy* - Frontal plane (Malone, 1991).

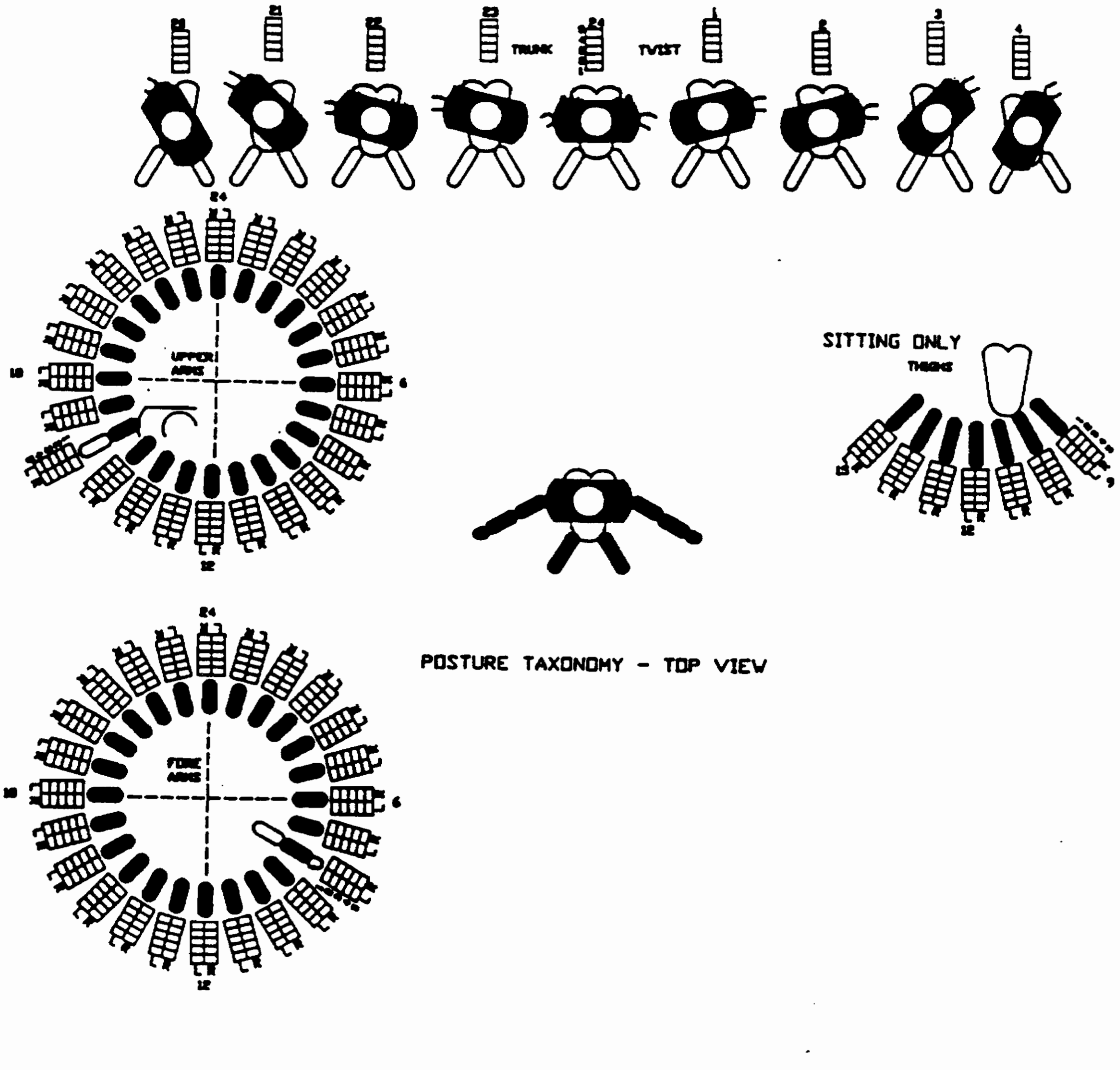


Figure 2.12 *Posture Taxonomy* - Transverse plane (Malone, 1991).

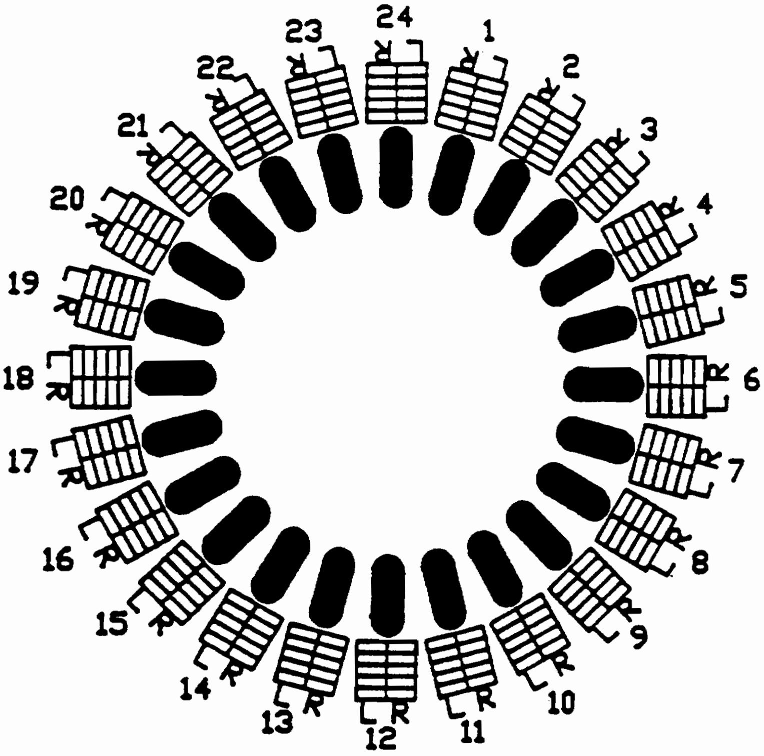


Figure 2.13 Sample *Posture Taxonomy* target (Malone, 1991).

2.4.4 Evaluation of the *Posture Taxonomy* Method

Malone performed a study to validate his model using department store mannequins. After a training session of about one hour, the subjects observed several postures and were asked to record them, using the method. Subjects were instructed to make the recordings as quickly as possible, while maintaining accurate recordings. After the first recording session, a second was performed three weeks later to determine the effect of time and practice on the speed and accuracy of posture recording with the *Posture Taxonomy* method.

Malone found that the method produced statistically significant, but only moderate, reliability between subjects. Using the Kappa statistic, which is described in the Data Analysis section of this Thesis, the reliability between subjects was found to be significant at the $p<.001$ level for all postures during both recording sessions, but the variability between subjects indicated a less than perfect agreement. Accuracy of the recordings were also found to be significantly different at the $p<.001$ level (PI coefficient — also described in the Data Analysis section) for all postures over both recording session, but again, the results were only moderate. Malone also found that the performance over the 21 day period did not decrease, but in fact improved, for all but one posture.

Another positive conclusion drawn from the results was that there was no pattern between posture and the level of agreement between subjects, and no pattern between posture and recording accuracy. This indicates that the method is probably universally applicable, and can be used to accurately and reliably record any posture. Agreement and accuracy did appear to be the best for the posture composed of the most horizontal and vertical links ('sitting' posture), but this is probably true for any posture recording method. Finally, Malone found that the time to record posture improved significantly from the first recording session to the second.

In addition to the positive results, several problems with the method were revealed from Malone's analysis. First, he found that the top view was more difficult for the subjects to record correctly than the other views. This had an effect on the reliability between subjects, as well as the accuracy of the subjects' recordings. Second, Malone hypothesized that there might be some confusion with the recording template because both the left and right counterparts of each link had to be recorded on the same target. This presumably had an effect on the accuracy of the subjects' responses and the time taken to record them. Thirdly, the use of an absolute coordinate system had an effect on the accuracy of the recordings. Finally, Malone found that there was often disagreement between the redundant views when recording a posture, which made it difficult to assess the accuracy of the recordings.

The subjects' responses spanned a range of four to eight categories in the top view, while they had a spread of two to four categories in the front and side views. This indicated that the subjects' responses were more similar in the front and side views than in the top view. It also was shown that the responses in the front and side views were more accurate than in the top view. Malone hypothesized that these differences between the views occurred because the subjects could not physically observe the mannequin from the top, but could move around the mannequin to see it from all sides. This forced a mental rotation of the model posture, which can be a highly variable ability between observers. To compensate for this in the future, Malone developed a modified recording template (see Figure 2.14) where the top view diagrams were omitted, except for the top view of the torso, which is necessary for describing the twisting of the spine in the sagittal plane. By providing only the front and side views to record a posture, the modified recording template should increase the reliability of the method.

In some cases the subjects reversed the right and left categories on the targets, which resulted in the subjects selecting the category on the wrong side of the target. The

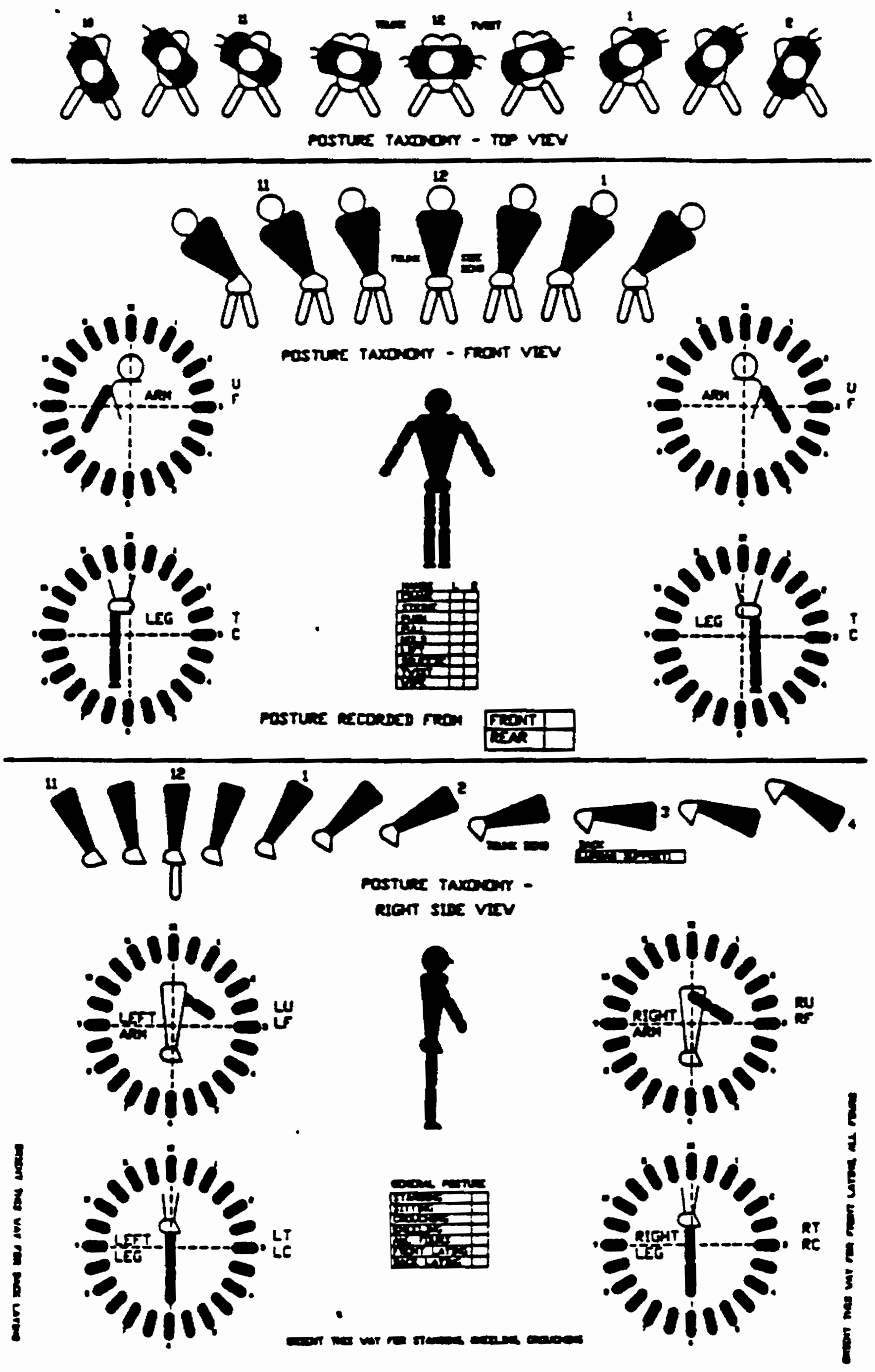


Figure 2.14 Modified Posture Taxonomy recording template (Malone, 1991).

spatial orientation of the chosen category was often correct, but on the opposite side of the target, so it was recorded inaccurately. Malone also hypothesized that the confusion with the left and right categories also increased the time taken to record each posture. The modified recording template also accounts for this problem by providing separate targets for the left and right links.

The *Posture Taxonomy* recording template uses an absolute coordinate system for each target. The target for the lower leg shows a pictorial representation of both the upper and lower leg in standard anatomical position. If the upper leg of the model posture being recorded is not in standard anatomical position, it might be difficult to for the subject to envision the correct orientation of the lower leg in the absolute coordinate plane. When the representation of the lower leg on the recording template is moved into the correct orientation, it will not have the correct orientation with respect to the representation of the upper leg. This inconsistency could result in an inaccurate recording of the lower leg position.

When a posture is recorded in all three planes, there is inherent redundancy, since only two planes are needed to capture all of the three-dimensional information. Malone found that subjects would often record the postures differently between the three views, making it difficult to evaluate the accuracy of the recordings. Nothing in his method forced consistency between the recordings made in different views.

The major disadvantage of the method is that the recording times took significantly longer, for all postures, than the desired objective of 45 seconds. Malone felt that the subjects were forced to pause to determine whether it was the left or right link they were recording, because both links were presented on one target. He also thought that the complexity was increased by the fact that the left and right in the front view were opposite to the subject's left and right. The modified recording template was also designed to help reduce the recording time by providing separate targets for the left and right links. Also, removing the top view from the recording template should decrease the recording time significantly, although the objective of 45 seconds still might not be reached.

Another disadvantage of the method not discussed by Malone refers to the encoding of the postural data. The recorded information on the template must be converted into usable postural data in order to perform analyses, and ideally, it would be in computerized format. Previous developers (Corlett et al., 1979; Keyserling, 1986a), have indicate that an ideal method would produce postural information that is readily entered into a computer. The postural data produced by the *Posture Taxonomy* recording templates is not readily entered into a computer because each target has to be digitized before it can be entered. This will increase the time it takes to perform analyses on the postural information collected, reducing the efficiency of the method.

2.5 Spatial Ability

Spatial ability involves moving the mind's eye to a different perspective, rotating mental images, and complex folding and distortion of the image of the mind's eye (Lohman, 1979). Posture recording involves similar abilities, and the level of spatial ability an observer has can affect that observer's ability to record posture. Ideally, the best method of posture recording would be easily used by those with low spatial ability as well as those with high spatial ability. If such a method is not achievable, then it is possible that posture recording should be limited to users with high spatial ability.

Lohman (1979) breaks spatial ability into three components. These components are spatial orientation, spatial relations, and spatial visualization. Spatial orientation involves the perception of an object from a perspective other than the one in which it was presented. Spatial relations involves the ability to quickly and accurately perform mental rotation processes. Some researchers consider spatial orientation and spatial relations to be the same factor, because they both involve mental rotations, and similar tests are often used for both (Ekstrom, French, and Harman, 1976).

Spatial visualization involves complex folding and manipulation of an object. There is some dispute as to whether or not spatial visualization is a distinct factor of spatial ability, because it involves both mental rotation and serial operations (Egan, 1981). Most researchers agree that it is related to spatial ability, but it is likely that it is not related to the abilities involved in posture recording.

The task of posture recording appears to involve the use of spatial orientation and spatial relations, and these abilities can be evaluated using tests of mental rotation. When considering both of these abilities as a single factor, Ekstrom et al. (1976) define it as the ability to perceive spatial patterns or to maintain orientation with respect to objects in space. Using the Ekstrom Kit of Factor Referenced Cognitive Tests (Ekstrom et al., 1976), two tests can be administered to test this factor: The Card Rotations Test and the Cube Comparisons Test (see Appendix D). In the Card Rotations Test, subjects are shown a drawing of a card cut into an irregular shape. To its right are six other drawings of the same card, sometimes merely rotated and sometimes turned over to its other side. Subjects simply indicate whether or not the card has been turned over. In the Cube Comparisons Tests, subjects are shown two drawings of a cube. Assuming no cube can have two faces alike, the subject is to indicate which items present drawings which can be of the same cube and which cannot be of the same cube.

There are two dependent measures that can be used when performing spatial ability tests. Some tests consider accuracy while others consider the mean latency of response. Egan (1978) has shown that accuracy determines the ability to accurately code a pictorial stimulus while the mean latency scores reflect the ability to mentally transform the code. It is important to employ both dependent measures when testing for spatial ability.

3. METHODS

3.1 Computerized Method

This Thesis was concerned with the development and validation of a computer program to facilitate the input of three-dimensional postural information by non-experienced users. The method was designed to be as comprehensive as possible, while still maintaining a user-friendly interface. The computerized format allows for a greater manipulation of the recording environment enabling the method to be more matched to the cognitive and perceptual abilities of the users than the *Posture Taxonomy* method. A description of the method will be discussed in the following sections.

3.1.1 Description

The program provides the user with six different views of a stick-figure, representing of the posture of the subject. To present these views, the computer screen is divided into seven sections (see Figure 3.1). Along both sides of the screen the six views are presented as small boxes with labels. The three views presented on the right are the 'three-dimensional' ('3-D') view, and the 'front' and 'back' views. The remaining views — 'top', 'right', and 'left' — are positioned on the right side of the screen. The central box, or zoom box, is much larger and contains the template where the views can be enlarged and manipulated.

Each view is a stick figure viewed in the sagittal, transverse, or frontal plane, except for the three-dimensional view which can be viewed in all three planes. Each figure is divided into links separated by 13 joints, with the back divided into two links by a joint at the L5/S1 region. Dividing the back into two links provides the opportunity for greater accuracy by allowing twisting of the spine and bending of the back. As stated

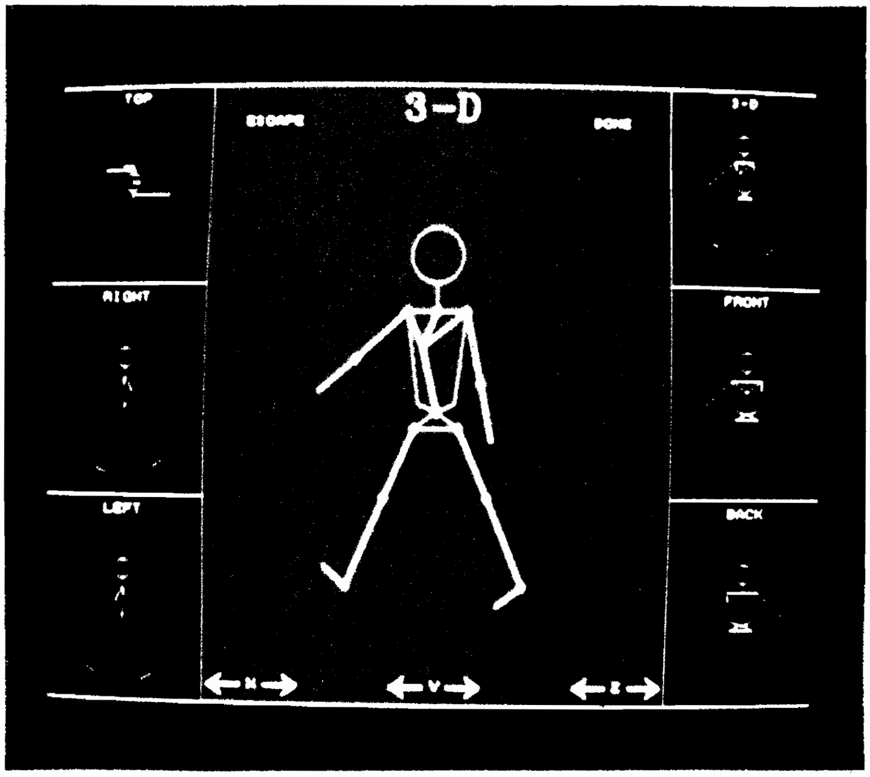


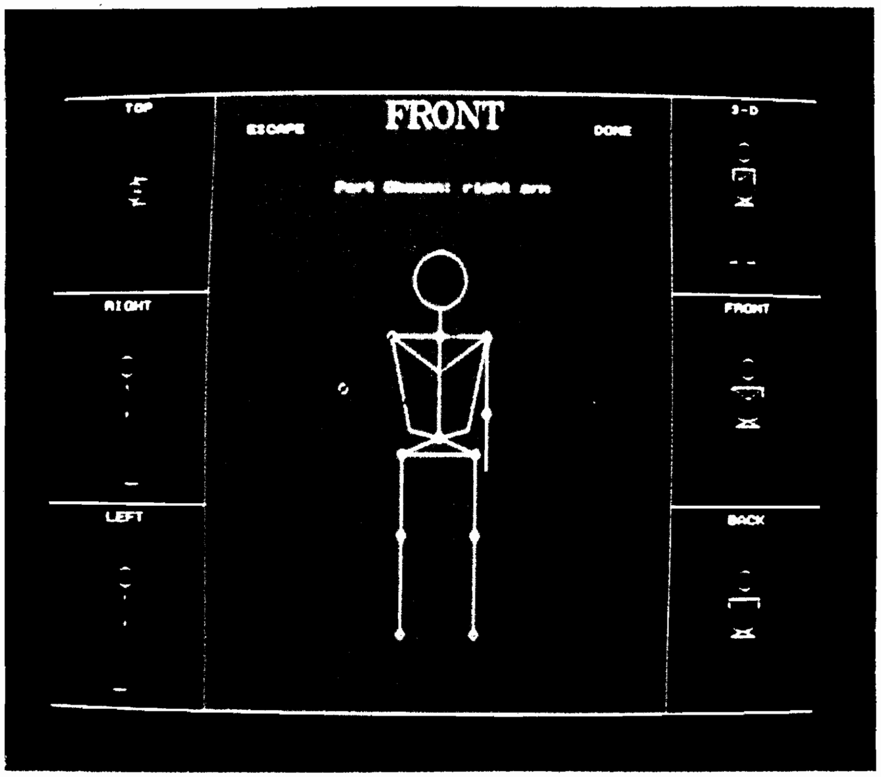
Figure 3.1 Screen display with enlarged '3-D' view.

before, this is essential in the analysis of postures related to low back injuries (Malone, 1991).

A user can select a view to be enlarged with a mouse click anywhere inside the box containing the desired view. When the view is enlarged and centered in the zoom box, the user can manipulate the stick figure using the mouse. The three-dimensional view can be rotated by clicking arrows at the bottom of the screen that appear when the view is enlarged (see Figure 3.1). Spatial compatibility is increased if the posture being manipulated is also represented in the same orientation as the videotaped model.

When the other views are enlarged, the stick figure can be manipulated by selecting a joint with a mouse click. This activates a circle of 24 dots around the selected joint (see Figure 3.2). The 24 dots provide 15 degree intervals around the joint to represent possible link positions. As stated before, it has been shown that observers can only reliably discriminate between joint angles of 15 degrees or greater (Gil and Tunes, 1989). By clicking on one of the dots, the user can move a link to various positions around a selected joint. If one or more joints are overlapping, selecting one of the joints brings up a menu of all the overlapping joints. Then the user must select the desired joint from the menu with a mouse click. The circle of dots for that joint will appear after the menu selection is made. After a joint is rotated, other joints can be selected and rotated until the user achieves the desired posture for that particular view. When another view is selected for manipulation, all views reset to incorporate the changes made in the previous view.

As adjustments are made, the posture of the computer representation changes, providing spatially compatible feedback for comparison with the videotaped posture. In the paper and pencil techniques, a link position is simply identified by its location or angle of rotation, but the representation is not altered to appear in a different posture. In the computerized method, when the shoulder is rotated to a new position, the forearm and



Part Chosen: right arm

Figure 3.2 Enlarged 'front' view with tick marks visible.

upper arm are also rotated and the representation actively takes on a new posture. Because of this a user can easily check and readjust any link that appears inconsistent with the videotaped posture. It is hypothesized that increasing the spatial compatibility in this manner will increase recording accuracy.

3.1.2 Procedures For Use

Specific procedures were developed to assist the user in recording postural information. First, the three-dimensional view is selected and rotated to the correct perspective. By comparing this view to the videotaped posture, the user can manipulate the three-dimensional view until it is presented in the same orientation as the videotaped model. Next, the user selects one of the five adjustable views and attempts to recreate the posture as it would look in that view only. For example, if the user selected the 'right' view, the videotaped posture would have to be mentally rotated so that it could be seen from the right in the sagittal plane. Other views are then selected and manipulated to recreate the videotaped posture. Although only two correctly positioned views are necessary to recreate the videotaped posture, the user can select and manipulate as many views as are desired.

A reset button is included to allow the user to erase all postural manipulations and start from scratch. Also, an escape button is available that allows the user to leave an enlarged view without incorporating any of the postural changes completed in that view. Save and load buttons are also included to save postural information and recall previously recorded information. Data is stored as three-dimensional points for each joint and reference point. This format facilitates the retrieval of postural information and the subsequent analysis of that information.

The proposed method incorporates many of the advantages of the previously developed methods, and attempts to remove some of the disadvantages. By considering the cognitive and perceptual abilities of human recorders, it was hypothesized that the method would be easy to use, even by those with little or no training in anatomy or ergonomics. It was also speculated that the increased usability, along with the computerized format, would reduce the time to record a posture to an acceptable level. The computerized format essentially eliminates the encoding time, and produces data that can be easily stored and retrieved for a reliable recreation of a posture.

3.2 Validation

A validation experiment was performed to determine if the objectives of the method were met. A range of fixed postures were recorded on videotape and presented from several different angles. Subjects viewed and recorded these postures using the computerized method. The accuracy and reliability of the method was tested by comparing the postures recorded to those recorded by other subjects, and the values determined by the experimenter. Recording times were also measured and compared to previously developed methods to determine if the computer technique was efficient. In addition, each subject's spatial ability was measured using standardized tests, and the scores were analyzed to determine the effect of spatial ability on recording accuracy and speed.

3.2.1 Subjects

Thirty subjects, 15 male and 15 female, with no previous experience in posture recording were used. All subjects fell within the ages of 20 to 65 years, because this age range effectively encompassed the working population. Subjects all had at least a high school education, most of them being graduate students. All subjects had at least normal (20/40) or corrected-to-normal vision. This was tested using a Landholt Ring eye chart (see Figure 3.3). Subjects participated approximately 1 hour each, with 15 minutes for

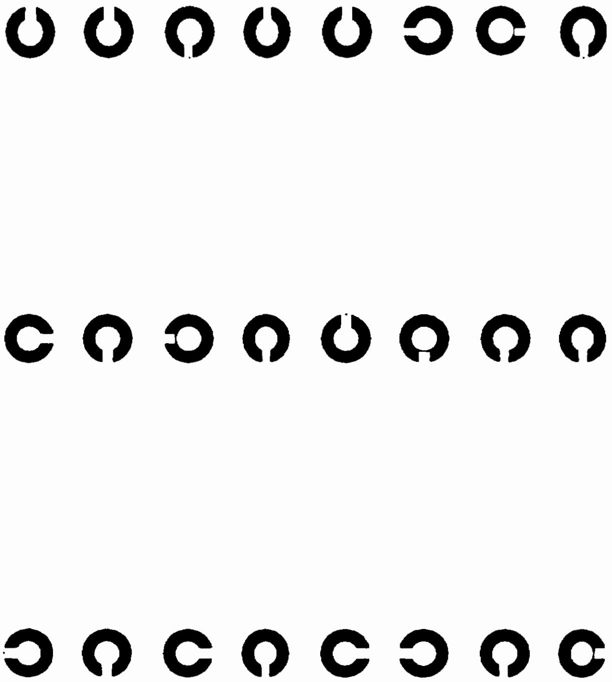


Figure 3.3. Landholt Ring chart.

spatial ability testing, 15 minutes of training, and 30 minutes of posture recording. Subjects were compensated at a rate of $5.00 per hour, for a total of approximately $5.00 per subject.

3.2.2 Apparatus

Subjects sat at a computer workstation which included a chair and table, a 13 inch VGA monitor, a GRID 386 central processing unit, and a mouse input device. They viewed previously videotaped postures using a color monitor located to the right of the computer workstation (see Figure 3.4). The postures were recorded using a SONY 'Handycam' Super 8 video camera recorder, model CCD-TR5. The color monitor used is a GE, 26 inch stereo television monitor, model 8-2886. A SONY Super 8 video cassette recorder, model EV-C3, was used to present the previously recorded postures. The experimenter operated a remote control to present each videotaped posture at the appropriate time.

3.2.3 Spatial Ability Tests

Using the Ekstrom Kit of Cognitive Factors, each subject's spatial ability was assessed. Two tests were given: the Card Rotations Test and the Cube Comparisons Test. Each test had two sections and subjects were given 3 minutes to complete each section. The subjects were instructed to complete each section as quickly as possible, without sacrificing accuracy. The tests lasted approximately 15 minutes, and were performed immediately before the training session. The tests were scored by subtracting the number of incorrect answers from the number of correct answers for each section. Overall spatial ability scores were determined by first taking the total score for each test and dividing it by the number of questions for that test. Then the modified scores for each test were weighted equally and combined so that each subject's spatial ability could be expressed as

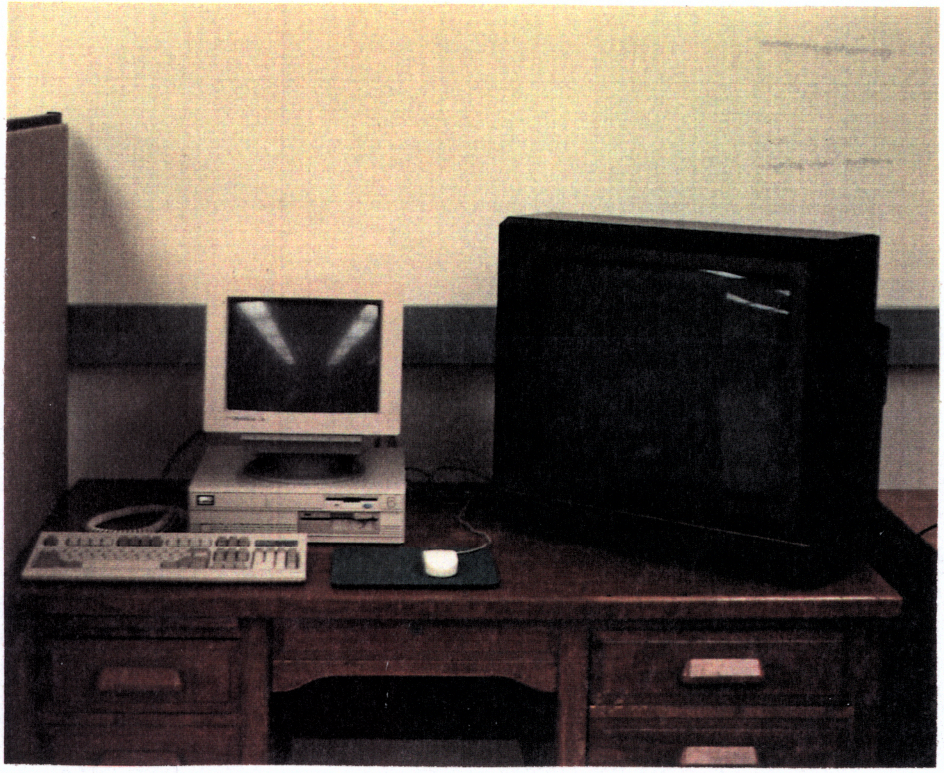


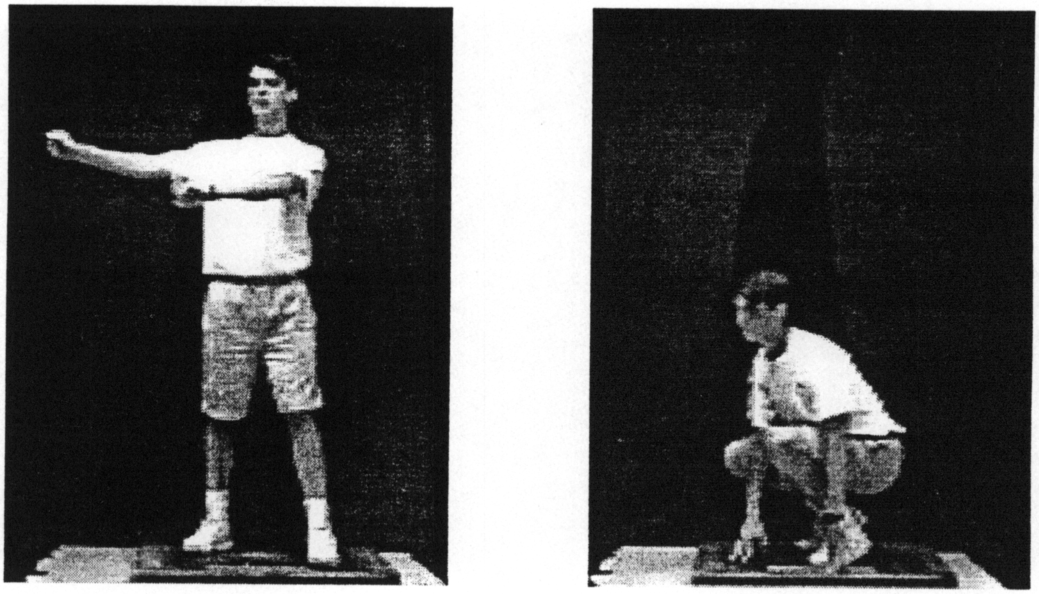
Figure 3.4 Experimental apparatus.

a percentage of the total possible correct responses. The actual tests used can be found in Appendix D.

3.2.4 Training

To assure that each subject understood the basics of using the method, a 15 minute training session was given prior to the actual recording session, and the training was conducted using the actual experimental equipment (See Apparatus). Prior to this training session, each subject was given instructions describing the purpose of the study, how it was to be conducted, and what the subject was going to be asked to do (Appendix A). Each subject also received a copy of the informed consent form (Appendix B), and specific instructions detailing how to use the computerized posture method (Appendix C).

After a subject read the basic instructions and read and signed the informed consent form, the experimenter began the training session. A lecture was given using the detailed instruction sheet. Any questions the subjects may have had were answered at that time. Two pre-recorded videotaped postures were used as the practice postures for the subjects to record to determine their competence at understanding and using the program (see Figure 3.5 (a) and (b)). Accuracy and speed of response data were not collected on the practice trial because each subject's competence was assessed by the experimenter without this information. The subjects were required to demonstrate a basic understanding of the procedures for using the program including selecting and rotating the three-dimensional view, expanding each of the five adjustable views, selecting a joint (including overlapping joints), manipulating a segment around a joint, and using the reset button. By observing each subject while recording the second practice posture, the experimenter was able to determine if the basic understanding was achieved.



(a) (b)

Figure 3.5 Training postures: (a) posture 1, (b) posture 2.

3.2.5 Postures

Five videotaped postures were used as models for each subject to observe and record. One model was a 'sitting' posture (see Figure 3.6 (a)-(c)), the second was a 'pushing' posture (see Figure 3.7 (a)-(c)), the third was a 'lifting' posture (see Figure 3.8 (a)-(c)), the fourth model was a 'reaching' posture (see Figure 3.9 (a)-(c)), and the last model was a "crouched" posture (see Figure 3.10 (a)-(c)). The 'sitting' posture emulated a person at a workstation. The models in the 'pushing' and "standing" positions had a twisted back to increase the complexity of the image. As a result, to accurately record these postures, each subject was required to rotate the torso. The 'pushing' posture was used to simulate a job using a hand tool, and the standing posture represented a reaching task. The 'lifting' posture showed a bending of the back, and the crouched posture simulated a severe bending of the back and legs. These sample postures attempted to cover the more extreme ranges of postures adopted in the workplace.

The model postures for the training session and the actual experiment were recorded in similar fashions. The same model was used for all postures and all viewing angles of the experimental postures, and another model was used for the training postures. One corner of the laboratory was cleared and black sheets were hung to remove any visual environmental distractions. The model for the training postures wore tight fitting clothes, including light-blue shorts, a white t-shirt, and white sneakers. The model for the experimental postures wore a light colored T-shirt and shorts, and sneakers. To maintain an identical posture for each Viewing Angle, each model was required to maintain a posture for approximately 2 minutes, while the video camera was moved to predetermined locations. Each posture and Viewing Angle combination was recorded for approximately 15 seconds. Also, calibration recordings of the left, back, and top views were made using a separate video camera. After the model postures were recorded, title frames were created to separate and identify each posture for the experimenter.

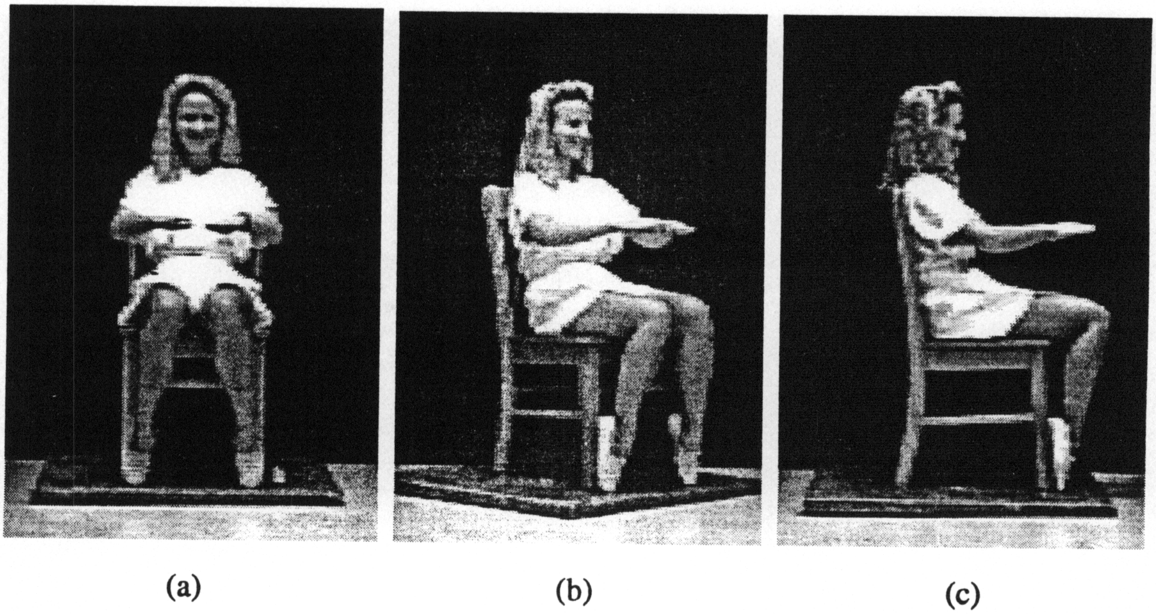
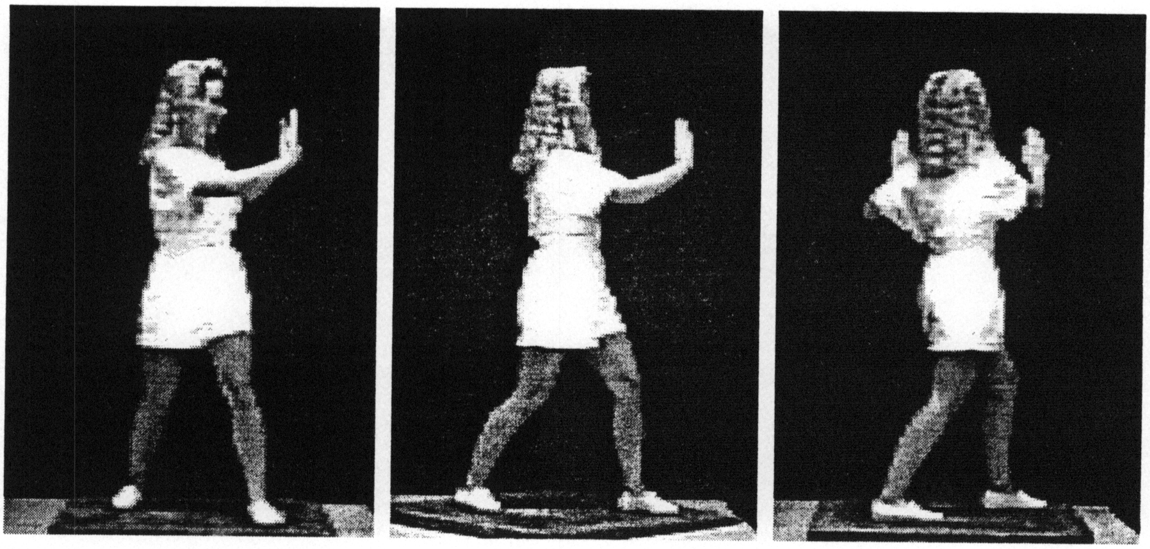

(a) (b) (c)

Figure 3.6 'Sitting' posture examples: (a) 'Front' Viewing Angle, (b) 'Oblique' Viewing Angle, (c) 'Right' Viewing Angle.



(a) (b) (c)

Figure 3.7 'Pushing' posture examples: (a) 'Front' Viewing Angle, (b) 'Oblique' Viewing Angle, (c) 'Right' Viewing Angle.

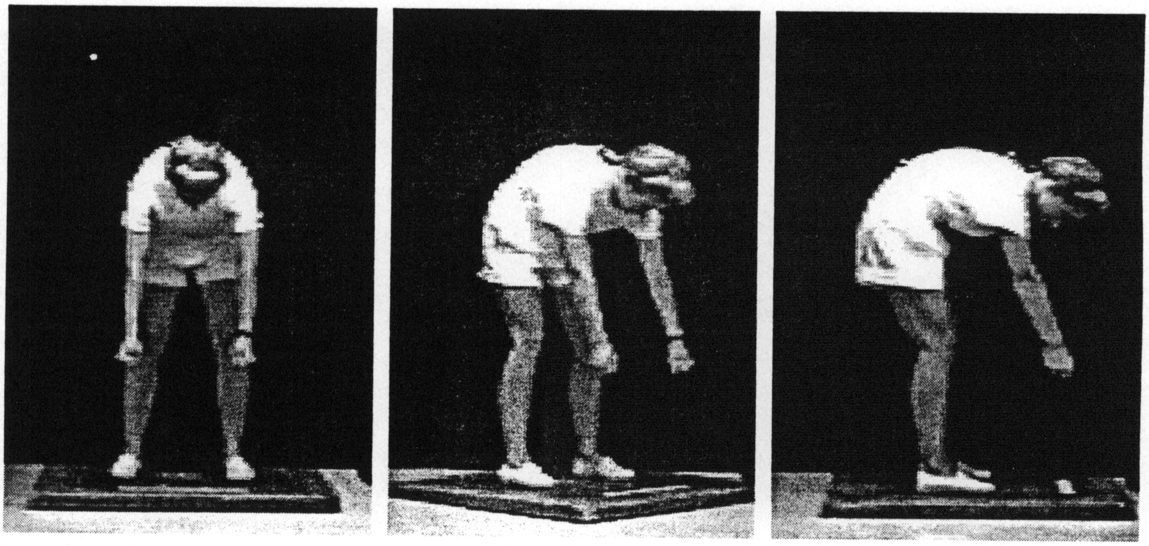
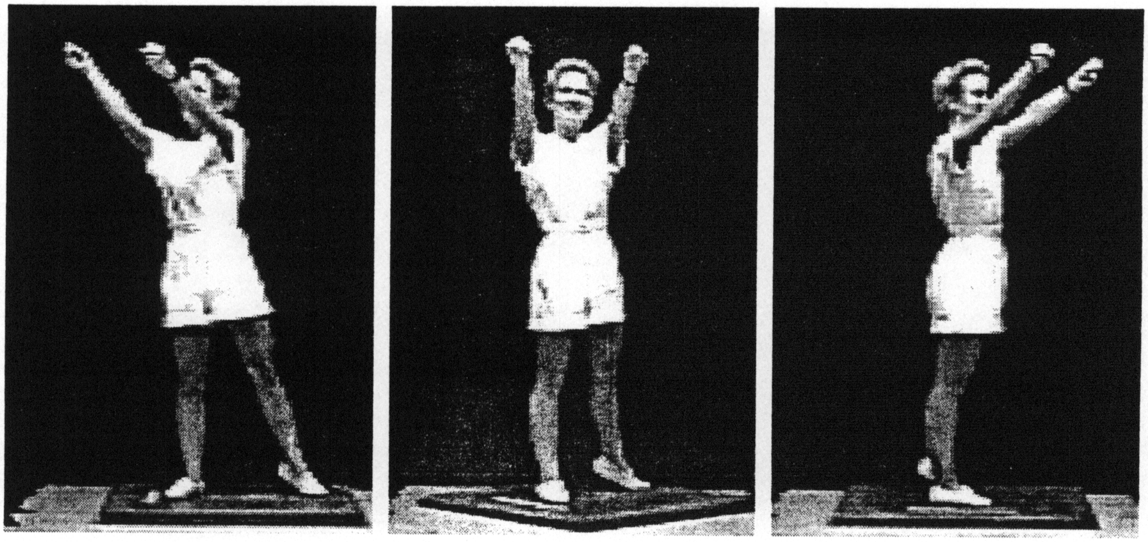
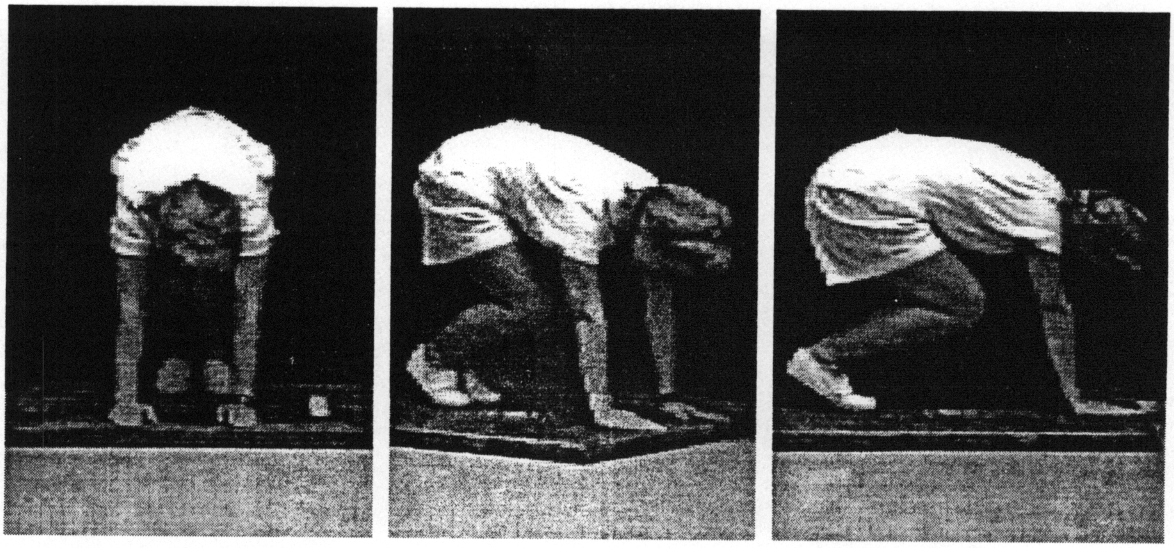

(a) (b) (c)

Figure 3.8 'Lifting' posture examples: (a) 'Front' Viewing Angle, (b) 'Oblique' Viewing Angle, (c) 'Right' Viewing Angle.



(a) (b) (c)

Figure 3.9 'Reaching' posture examples: (a) 'Front' Viewing Angle, (b) 'Oblique' Viewing Angle, (c) 'Right' Viewing Angle.



(a) (b) (c)

Figure 3.10 'Crouching' posture examples: (a) 'Front' Viewing Angle, (b) 'Oblique' Viewing Angle, (c) 'Right' Viewing Angle.

Using the calibration recordings, measurements were made to determine the true posture of the model for each of the five experimental postures. To accurately measure one posture, each of the five views were presented and measured directly on the screen using a protractor. Each joint angle was then estimated and recorded on paper. Finally, the computerized posture program was used to create 'expert' files that were to be compared to the responses of the experimental observers. Each joint angle was carefully entered and measured in each view on the computer monitor, and the 'expert' files were saved for the future comparison.

3.2.6 Viewing Angles

Each posture was presented from three perspectives including 'front,' 'oblique,' and 'right.' The 'front' view presented the posture from the front side of the frontal plane (Figures 3.6 (a)-3.10 (a)), the 'right' view presented the posture from the right side of the sagittal plane (Figures 3.6 (c)-3.10 (c)), and the 'oblique' view presented the posture from a perspective halfway between the other two views (Figures 3.6 (b)-3.10 (b)). To orient the subject correctly during the recording of the sample postures, the subject's hips and pelvis were used as the reference point from which everything else would rotate around. For example, when the 'lifting' posture was recorded, the twisting of the torso played no role in positioning the subject.

3.2.7 Procedure

The experiment lasted about 90 minutes, with each subject performing the test individually and at different times from one another. The fifteen posture and Viewing Angle combinations were recorded on one videotape, and the experimenter fast-forwarded or rewound the tape to the appropriate location and paused while the subject was recording the posture. Subjects were told that they had as long as they wished for each posture, but were encouraged to complete each recording as quickly as possible without sacrificing accuracy. When the subject completed recording one posture, the experimenter saved the postural information for that trial and moved the videotape to the next posture.

Every subject viewed the same five postures from one Viewing Angle, resulting in five posture recordings made by each subject. No subject ever saw the same posture more than once, but the order of presentation was randomized so that no subject observed the postures in the same order.

3.2.8 Experimental Design

The experimental design consisted of two dependent variables, three independent variables, and one regressor variable. The dependent variables were accuracy and time. Postural data was stored in computerized format after the completion of each posture recording, and this data was used to determine the accuracy of each recording. In addition, the stored data was used to determine the amount of time taken to record each posture. One of the three independent variables was Posture, and the five posture categories represented the different Posture levels. Another independent variable was Viewing Angle, and the three viewing angles represented the different Posture levels. Gender was the final independent variable. The regressor variable was spatial ability, which consisted of the scores calculated for each subject, based on the two tests of spatial ability. This regressor variable was a continuous variable used to determine the effect of spatial ability on posture recording, and to isolate its effect from the independent variables.

The study was a mixed factors design with Gender and Viewing Angle as between-subjects variables, and Posture as a within-subjects variable (see Figure 3.11). It was necessary for Viewing Angle to be a between-subjects variable because it was likely

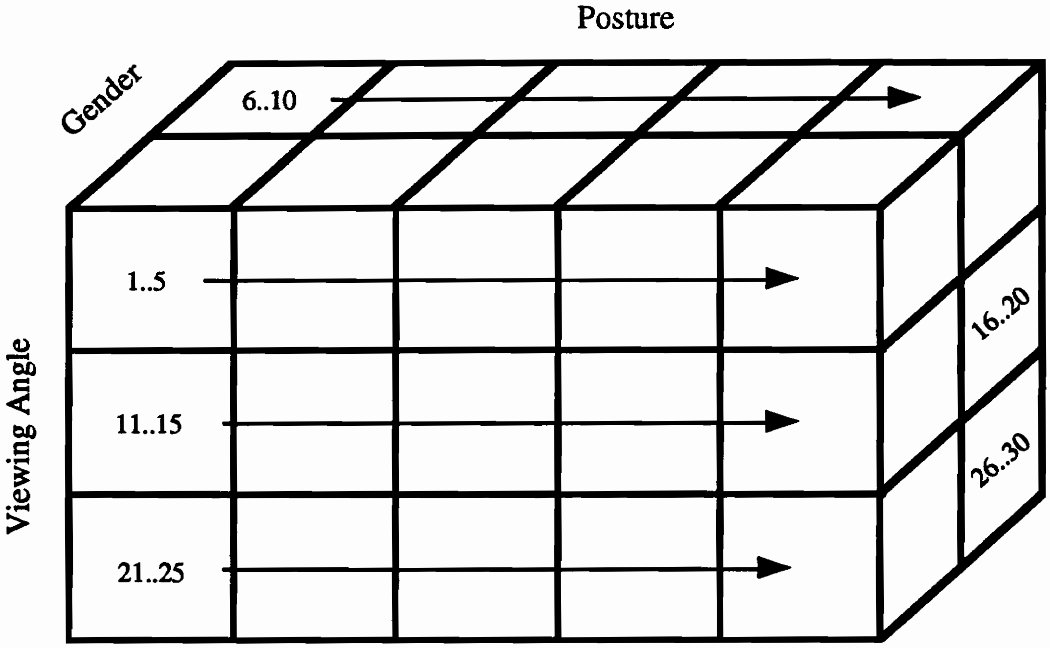


Figure 3.11 Experimental design.

that a bias would occur if a subject was allowed to observe and record the same posture more than once. This could have happened when a subject viewed the same posture from different viewing angles. Even though the viewing angle would be different, it was possible that the posture could be recognized and remembered from a previous recording in a different viewing angle. This previous knowledge could have decreased the time required to analyze and record the posture, and might have influenced the accuracy of the recording.

To randomize the order of presentation of the Posture conditions, a balanced Latin Square design was used (see Table 3.1). Two 5x5 matrices were created so that within each Viewing Angle group, all ten subjects observed the postures in a different order. Also, across all ten subjects, each posture preceded and followed every other posture an equal number of times. To randomize among Gender, each of the ten posture sequences were randomly assigned between the five male and five female subjects in each Viewing Angle group.

Table 3.1 Latin square.

	Subjects									
Trial	1	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	4	5	1	2	3
2	2	3	4	5	1	3	4	5	1	2
3	5	1	2	3	4	5	1	2	3	4
4	3	4	5	1	2	2	3	4	5	1
5	4	5	1	2	3	1	2	3	4	5

4. DATA ANALYSIS & RESULTS

Several analyses were performed in an attempt to validate the model. The results include evaluations of inter-observer reliability, accuracy, speed of response, and the effects of spatial ability. Link positions chosen by each subject were categorized and compared to determine the inter-observer reliability. Accuracy was tested by comparing the subjects responses to predetermined 'correct' responses. The time to record each posture was collected and analyzed to determine the effect of the independent variables on the speed of response. Finally, spatial ability was evaluated to determine its effect on both recording accuracy and speed using the spatial ability scores collected from the subjects.

4.1 Inter-Observer Reliability

The inter-observer reliability was tested to determine if the subjects produced recordings that were similar to one another. This information is necessary to help determine if the method can produce consistent recordings among different users. Also, having reliability between the subjects within each experimental group increases the validity of the accuracy analyses (Siegel and Castellan, 1988).

To begin the analysis, each link in each plane for each posture was categorized by its orientation around its associated joint. The categories that were created were composed of the 24 discrete positions that the subjects could chose from for each link in each plane. A 25th category was also included to account for a link pointing directly toward or away from the observer. These categorized responses were then organized into groups based on the Gender, Viewing Angle, and Posture conditions.

A non-parametric statistical technique employing the Kappa statistic was used to determine the reliability between the subjects within each group (Siegel and Castellan, 1988). For this technique, a coefficient was calculated for each group to indicate how often the subjects in that group selected the same category for a given link and posture. More specifically, these Kappa coefficients (K) determined the ratio of the proportion of times the subjects agreed (*P(A)*), to the total proportion of times the subjects could have agreed, corrected for agreements expected to have occurred by chance (*P(E)*). The formula used for the calculation of the Kappa coefficient was

$$K = \frac{P(A) - P(E)}{1 - P(E)} . \qquad (1)$$

If the Kappa coefficient is 1, it indicates complete agreement between the subjects, and a Kappa coefficient of 0 shows that the agreement is only due to chance.

For the first step in calculating the Kappa coefficients, five data matrices were formed for each subject, one for each posture, that indicated the category chosen for each link in each plane (see Figure 4.1). In this data matrix, the variable q represented the link-plane combination for which the subject chose a particular category, represented by the variable r. The cells with values of '1' indicated the category chosen for that link-plane combination, while the '0' cells represented the categories not chosen by the subject. The abbreviations used for the link-plane combinations are defined in Table 4.1.

The individual subject data were then arranged into groups based on the different experimental conditions so that the reliability between subjects could be analyzed. Three sets of groups were created to test for reliability: two Gender groups, three Viewing Angle groups, and five Posture groups. One matrix was created for each Posture condition that was collapsed across all 30 subjects, since all subjects viewed each posture and made recordings in all 36 categories. Since Gender and Viewing Angle were between-subjects effects, 5 matrices representing the 5 Posture conditions were created for each level so that there were 10 matrices for the Gender analysis and 15 for the Viewing Angle analysis. Next, a data matrix was formed for each group where the

	Category, *r*																								
Link, *q*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
NT	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LUAT	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RUAT	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LFAT	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RFAT	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TT	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LTT	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RTT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
LCT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
RCT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
LFT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
RFT	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
LUAF	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RUAF	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LF	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RF	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TF	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LTF	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RTF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
LCF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
RCF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
LFF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
RFF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
NS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
LUAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
RUAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
LFAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
RFAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
TS	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
LTS	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
RTS	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
LCS	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RCS	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LFS	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
RFS	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4.1 Sample individual subject matrix - Kappa coefficient.

Table 4.1 Abbreviations for sample data matrix - Kappa coefficient.

Abbreviation	Link
NT	Neck Transverse Plane
LUAT	Left Upper Arm Transverse Plane
RUAT	Right Upper Arm Transverse Plane
LFAT	Left Forearm Transverse Plane
RFAT	Right Forearm Transverse Plane
TT	Trunk Transverse Plane
LTT	Left Thigh Transverse Plane
RTT	Right Thigh Transverse Plane
LCT	Left Calf Transverse Plane
RCT	Right Calf Transverse Plane
LFT	Left Foot Transverse Plane
RFT	Right Foot Transverse Plane
NF	Neck Frontal Plane
LUAF	Left Upper Arm Frontal Plane
RUAF	Right Upper Arm Frontal Plane
LF	Left Forearm Frontal Plane
RF	Right Forearm Frontal Plane
TF	Trunk Frontal Plane
LTF	Left Thigh Frontal Plane
RTF	Right Thigh Frontal Plane
LCF	Left Calf Frontal Plane
RCF	Right Calf Frontal Plane
LFF	Left Foot Frontal Plane
RFF	Right Foot Frontal Plane
NS	Neck Sagittal Plane
LUAS	Left Upper Arm Sagittal Plane
RUAS	Right Upper Arm Sagittal Plane
LFAS	Left Forearm Sagittal Plane
RFAS	Right Forearm Sagittal Plane
TS	Trunk Sagittal Plane
LTS	Left Thigh Sagittal Plane
RTS	Right Thigh Sagittal Plane
LCS	Left Calf Sagittal Plane
RCS	Right Calf Sagittal Plane
LFS	Left Foot Sagittal Plane
RFS	Right Foot Sagittal Plane

subjects' responses were collapsed across all the members of that experimental group. In this data matrix, each cell was represented by the variables n_{qr}, which indicated the number of subjects, n, placing link q into category r (see Figure 4.2). For example, when the reliability of Gender was tested the responses of the subjects were collapsed so that for each link-plane combination, there were 15 values, representing the responses of all 15 subjects in the group.

Next, it was necessary to determine how often each category was selected by all of the subjects within a particular group. This provided information for determining the number of classifications expected to have occurred by chance. In situations where S subjects place N links into m categories, the number of classifications into category r (C_r) was calculated by the formula

$$C_r = \sum_{q=1}^{N} n_{qr} . \tag{2}$$

Using the values of n_{qr} from the data matrices, the value of $P(A)$ and $P(E)$ were calculated using the formulas

$$P_r = \frac{C_r}{NS} \tag{3}$$

$$P(E) = \sum p_{r^2} , \tag{4}$$

and

$$P(A) = \frac{1}{NS(S-1)} \left(\sum_{q=1}^{N} \sum_{r=1}^{m} n_{qr}{}^2 \right) - \frac{1}{(S-1)} . \tag{5}$$

The calculated Kappa coefficients are presented in Table 4.2.

Kappa coefficient values between 0 and 1 indicate different levels of agreement that aren't easily definable, so it is often desirable to determine if the observed values are significantly different than the agreement that would have occurred by chance (K=0). To determine the significance of the Kappa coefficients, it was necessary to calculate the

	Category, r																								
Link, q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
NT	0	1	12	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LUAT	0	0	0	0	0	1	1	11	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RUAT	0	0	0	0	1	2	9	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LFAT	0	0	0	0	0	0	0	0	0	10	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RFAT	0	0	0	0	0	0	0	1	1	9	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0
TT	0	0	0	0	0	0	1	1	1	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LTT	0	0	0	0	0	0	0	0	3	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RTT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
LCT	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	14
RCT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	1	1	1	0
LFT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	13	1	0	0	0	0
RFT	0	0	0	0	0	0	0	2	10	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	8	0	0	0	0	0	0	0	0	0
LUAF	0	0	0	0	0	0	0	2	11	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RUAF	0	0	0	0	1	1	9	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LF	0	0	0	0	0	0	0	14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RF	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TF	0	0	0	0	0	0	1	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LTF	0	0	0	0	0	0	0	0	0	13	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
RTF	0	0	0	0	0	0	0	0	0	0	0	0	0	1	14	0	0	0	0	0	0	0	0	0	0
LCF	0	0	0	0	0	0	0	0	0	0	0	0	3	0	12	0	0	0	0	0	0	0	0	0	0
RCF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	1	1	1	0	0	0	0	0	0	0
LFF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
RFF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
NS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	13
LUAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	13
RUAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	12	0
LFAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	12	0
RFAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	12	0
TS	0	0	0	0	0	0	0	0	0	0	0	0	11	4	0	0	0	0	0	0	0	0	0	0	0
LTS	0	0	0	0	0	0	0	0	0	0	0	0	12	0	3	0	0	0	0	0	0	0	0	0	0
RTS	0	0	0	0	0	0	0	0	0	0	0	5	10	0	0	0	0	0	0	0	0	0	0	0	0
LCS	0	0	0	0	0	0	0	0	0	0	12	3	0	0	0	0	0	0	0	0	0	0	0	0	0
RCS	0	0	0	0	0	0	0	0	0	0	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0
LFS	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0
RFS	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4.2 Sample collapsed subject matrix for the 'Male' Gender condition - Kappa coefficient.

Table 4.2 Calculated Kappa coefficients for Gender, Viewing Angle, and Posture.

Condition	Kappa	Z-score	p value
Gender			
Female	0.490	97.55	< .001
Male	0.521	109.25	< .001
Viewing Angle			
Front	0.490	74.11	< .001
Oblique	0.512	80.86	< .001
Right	0.605	92.39	< .001
Posture			
Sit	0.416	65.55	< .001
Push	0.470	95.01	< .001
Lift	0.597	60.04	< .001
Reach	0.488	82.35	< .001
Crouch	0.544	49.19	< .001

variance and z-score for each K value. As in this case, with large sample sizes, K is approximately normally distributed with a mean of 0, and therefore the formulas used to calculate the variances and z-scores were

$$\mathrm{var}(K) = \left(\frac{2}{NS(S-1)}\right)\left(\frac{P(E) - (2S-3)[P(E)]^2 + 2(S-2)\sum_{r=1}^{m} p_r^{\,3}}{[1-P(E)]^2}\right) \tag{6}$$

and

$$z = \frac{K}{\sqrt{\mathrm{var}(K)}}\,. \tag{7}$$

Then using tables of the normal cumulative distribution, a significance value was placed on each Kappa value to determine whether the coefficient was greater than would have been expected by chance.

The significance of each coefficient is also presented in Table 4.2 and in all cases the coefficients were significant at the $p < .001$ level. A significant Kappa coefficient indicates that the subjects in a group produced similar responses. The results presented in this section demonstrate that the recordings made by the subjects were similar to one another.

Although all of the Kappa coefficients in Table 4.2 were statistically significant, they ranged from .416 to .605 indicating less than perfect agreement (1.000). The reason for the statistical significance of the coefficients is that they represent similarities between the subjects that were unlikely to have occurred by chance, and not necessarily that they were anything more than moderately reliable. From an inspection of the individual subject matrices, it can be seen that there is often a large spread of categories chosen for each link in each plane, again indicating only moderate reliability.

Since the postures viewed by the subjects were not visible from the transverse plane, and because Malone found similar problems, further analyses were conducted to determine the effect of the transverse plane on the inter-observer reliability. These calculations are presented in Table 4.3. All three Kappa coefficients are significant at the $p < .001$ level, indicating that the transverse plane is not really the cause of the less-than-perfect reliability between subjects.

4.2 Accuracy

After careful consideration, two methods were chosen to evaluate the accuracy of the recordings made by the subjects. The first technique for determining the accuracy of the method was the PI coefficient, which converted the subjects' responses into categories and compared them to the 'correct' categories determined from the accurately measured postures. The second measure of accuracy compared the exact angle of orientation of each link in each plane of each posture to the 'correct' orientations determined from the videotaped postures.

A third technique was considered but not used because the previous two methods proved to be adequate, and because the units used made the level of accuracy hard to quantify. This technique was not concerned with angles of orientation, but with the three-dimensional deviations of certain joints from their expected positions. Using the correct measurements obtained from the videotaped postures, the three-dimensional distances that 13 reference joints deviated from their 'correct' positions were to be calculated. The reason behind using this analysis of the data was to account for a situation where a large difference in angular deviation was represented by a small difference in positional deviation. For example, in some situations, when a link was pointing almost directly toward or away from an observer, it was possible for the angle or category chosen to be as much as 180° off the expected orientation, while the associated joints only showed slight positional deviations.

Table 4.3 Calculated Kappa Coefficients for Plane

Condition	Kappa	Z-score	p-value
Plane			
Front	.500	33.04	< .001
Sagittal	.444	103.49	< .001
Transverse	.404	37.62	< .001

4.2.1 Measuring the Videotaped Postures

For both accuracy analyses it was necessary to have an accurate measurement of the videotaped postures. Since the method only provided discrete positions for each link it was not possible for the subject to perfectly record a posture, so the most accurate recordings would be those that used the discrete positions that were closest to the actual positions of each link. Therefore, to create the accurate recordings the links were measured and rounded to the nearest discrete position. A measuring tool was created on a clear plastic sheet that was placed directly on the monitor where the videotaped postures were presented (See Figure 4.3). By placing the intersection of the lines directly on top of a joint, the closest discrete position of the associated link was determined. Then the 'correct' link positions for each posture were entered using the computerized program. This produced a set of data for each posture that could then be compared to the data sets produced by the subjects.

4.2.2 PI Coefficient

To determine the categorical accuracy of the recordings, the PI coefficient was used. This statistical technique is similar to the Kappa statistic, but it is designed to provide a coefficient of agreement between two observers. In this case, one observer's responses were those made by a subject, or group of subjects, and the other observer's responses were the true posture measurements. The link positions chosen by the subjects were converted into categories and then PI coefficients were calculated to determine the similarity between the categories chosen by the subjects and the 'correct' categories determined from the videotaped postures.

Several 25x25 data matrices were formed for each subject, with each cell in the matrix, n_{ij}, referring to the number of responses where category j was chosen when the 'correct' category was i (see Figure 4.4). Each matrix represented responses in one of the

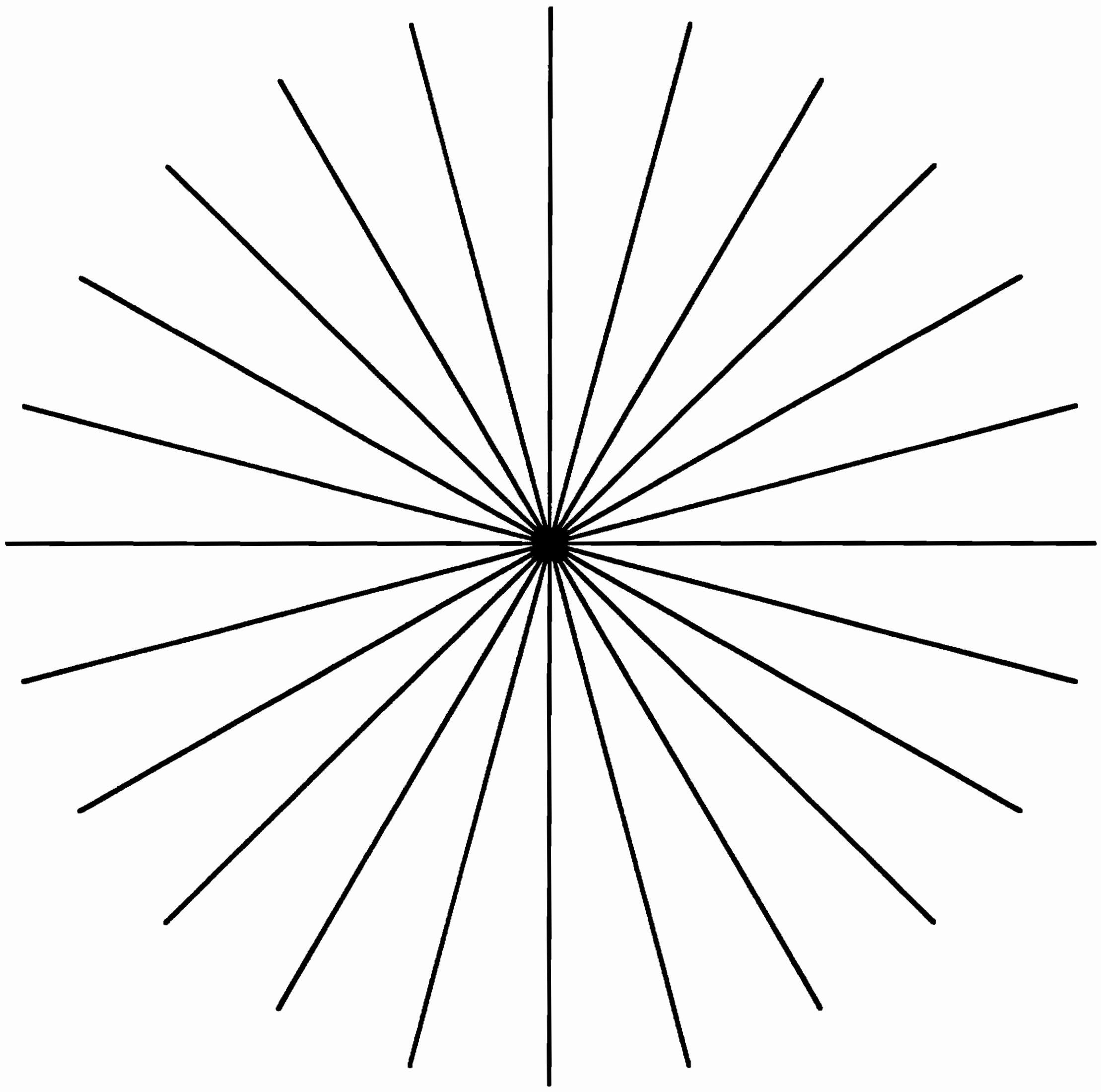


Figure 4.3 The tool used to determine the closest discrete position of a link.

	Correct Category *i*																								
Chosen Category, *j*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2

Figure 4.4 Sample individual subject matrix - PI coefficient.

three planes of one of the five postures, resulting in 15 data matrices for each subject. These responses were then collapsed across all subjects, while maintaining separate matrices for each plane of each posture (See Figure 4.5). As with the Kappa calculations, the data matrices were arranged in groups according to Gender, Viewing Angle, and Posture to determine the effect of these independent variables on accuracy.

The data points contained in the diagonal cells of the matrix, occurring where $i = j$, indicated the number of correct responses for each plane in each posture. These cells were underlined in the data matrix for emphasis. The number of data points in the diagonal cells was calculated by

$$P_o = \frac{\sum_{i=1}^{m} n_{ii.}}{C} , \tag{8}$$

where C was the total number of categorizations made by all the subjects, and m was the number of categories. To determine the total number of categorizations, C, the formula

$$C = mS \tag{9}$$

was used, where S was the number of subjects in that group. Using the same matrices, the formula for determining the number of data points expected to be in the diagonal cells caused by chance was

$$P_e = \frac{\sum_{i=1}^{m} n_{i.} n_{.i}}{C^2} . \tag{10}$$

Given these values, the PI coefficient was calculated by the formula

$$PI = \frac{P_o - P_e}{1 - P_e} . \tag{11}$$

The data matrices were arranged so that PI coefficients could be calculated for each Gender, Viewing Angle, Posture group, and the various interactions of these independent variables (see Table 4.4).

	Correct Category *i*																								
Chosen Category, *j*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	5	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	5	5	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	27	3	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	5	10	90	10	5	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	3	27	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	20	5	5	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	5	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60

Figure 4.5 Sample collapsed subject matrix for the frontal plane of the 'Sitting' posture - PI coefficient.

Table 4.4 Calculated PI coefficients.

Gender

Female	0.405
Male	0.433

Viewing Angle

Right	0.461
Oblique	0.422
Front	0.375

Posture

Sit	0.347
Push	0.396
Lift	0.385
Reach	0.381
Crouch	0.535

Gender X Viewing Angle

	Female	Male
Right	0.471	0.451
Oblique	0.400	0.443
Front	0.343	0.406

Posture X Gender

	Female	Male
Sit	0.337	0.358
Push	0.381	0.410
Lift	0.374	0.395
Reach	0.353	0.409
Crouch	0.527	0.543

Posture X Viewing Angle

	Right	Oblique	Front
Sit	0.379	0.334	0.329
Push	0.433	0.379	0.377
Lift	0.401	0.471	0.285
Reach	0.378	0.367	0.398
Crouch	0.671	0.508	0.428

Posture X Gender X Viewing Angle

	Female			Male		
	Right	Oblique	Front	Right	Oblique	Front
Sit	0.397	0.309	0.305	0.361	0.358	0.354
Push	0.432	0.360	0.351	0.434	0.398	0.403
Lift	0.426	0.466	0.236	0.377	0.476	0.335
Reach	0.373	0.363	0.322	0.397	0.371	0.473
Crouch	0.677	0.452	0.454	0.664	0.564	0.402

4.2.3 Gamma Statistic

As with the Kappa coefficient, a PI coefficient of 1 indicates perfect agreement between a subject's responses and the correct responses (true positions of the segments). A PI coefficient of 0 indicates that the agreement only occurred by chance. Values between 0 and 1 indicate less that perfect agreement, but the actual level of agreement is hard to define. As a result, it is useful to place a significance on the calculated PI coefficients to determines whether a PI coefficient is greater than would be expected to have occurred by chance. The Gamma statistic (Light, 1971) was used to determine the significance of the PI coefficients and was calculated by the formula

$$G = \frac{[t_s - E(t_s)]}{Ft_{s^{1/2}}}, \tag{12}$$

where t_S was the sample average, $E(t_S)$ was the population mean, and $F(t_S)$ was the sample variance. The sample average was the actual number of data points, collapsed across subjects, that lay in the diagonal cells, and was calculated using the formula

$$t_s = \sum_{k=1}^{s} \sum_{i=1}^{m} n_{iik} \,. \tag{13}$$

The population mean was the number of data points that were expected to fall in the diagonal cells by chance alone, and the formula used to determine this was

$$E(t_s) = \left(\frac{1}{N}\right) \sum_{i,j=1}^{m} \left(\sum_{j=1}^{m} \sum_{k=1}^{s} n_{ijk} \right) \left(\sum_{i=1}^{m} \sum_{k=1}^{s} n_{ijk} \right), \tag{14}$$

or more concisely,

$$E(t_s) = \left(\frac{1}{N}\right) \sum_{i=1}^{m} n_{i..} n_{.i.}$$

The sample variance was calculated by the formula

$$
\begin{aligned}
Ft_s = {} & \left(\frac{1}{N-1}\right)\sum_{i=1}^{m} n_{i..}n_{.i.} \\
& + \left(\frac{1}{N^2(N-1)}\right)Z \\
& - \left(\frac{1}{N(N-1)}\right)\sum_{i=1}^{m}\left[\left(\sum_{k=1}^{S}(n_{i.k})^2\right)n_{.i.}\right] \\
& - \left(\frac{1}{N(N-1)}\right)\sum_{i=1}^{m}\left[n_{i..}\left(\sum_{k=1}^{S}(n_{.ik})^2\right)\right],
\end{aligned}
\tag{15}
$$

where N was the number of posture categories recorded by each subject in the associated group, m was the number of posture categories, and S was the number of subjects in the group. The value of Z was calculated using the following formula

$$
\begin{aligned}
Z = {} & n_{1..}\left(n_1\left(n_{.1}n_{.1.}\right) + n_2\left(n_{.1}n_{.2.}\right) + \cdots + n_m\left(n_{.1}n_{.m.}\right)\right) \\
& + n_{2..}\left(n_1\left(n_{.2}n_{.1.}\right) + n_2\left(n_{.2}n_{.2.}\right) + \cdots + n_m\left(n_{.2}n_{.m.}\right)\right) \\
& \vdots \\
& + n_{m..}\left(n_1\left(n_{.m}n_{.1.}\right) + n_2\left(n_{.m}n_{.2.}\right) + \cdots + n_m\left(n_{.m}n_{.m.}\right)\right)
\end{aligned}
\tag{16}
$$

The significance levels of the Gamma statistic (G) were then determined from the tables of the cumulative normal distribution. In all cases, each PI coefficient was significant beyond the $p < .001$ level (see Table 4.5). This indicated that the recordings made by the subjects were accurate because they were significantly similar to the 'correct' recordings.

Table 4.5 Calculated Gamma statistic values.

Gender

Female	71.19
Male	76.75

Viewing Angle

Right	65.61
Oblique	26.39
Front	42.08

Gender X Viewing Angle

	Female	Male
Right	44.26	38.53
Oblique	32.40	42.51
Front	42.40	39.44

Posture

Sit	40.07
Push	44.04
Lift	30.08
Reach	45.96
Crouch	41.88

Posture X Gender

	Female	Male
Sit	28.10	30.14
Push	30.50	33.76
Lift	22.73	24.37
Reach	30.76	35.62
Crouch	33.11	33.98

Posture X Viewing Angle

	Right	Oblique	Front
Sit	24.77	22.81	21.98
Push	27.32	24.38	24.71
Lift	17.74	20.17	14.25
Reach	25.67	26.48	27.80
Crouch	29.44	23.44	20.06

Posture X Gender X Viewing Angle

	Female			Male		
	Right	Oblique	Front	Right	Oblique	Front
Sit	18.66	15.49	14.33	17.34	17.35	17.45
Push	19.77	16.70	16.31	20.07	18.76	19.60
Lift	13.99	15.50	9.31	13.33	15.70	12.92
Reach	18.52	18.68	16.00	18.69	19.00	24.03
Crouch	23.43	16.70	17.00	23.16	20.53	14.99

4.2.4 Angular Deviation Data.

To further evaluate the accuracy of the subjects' responses, a program was written to convert the data into specific angles of orientation for each link in each plane of each posture. Each link in each plane of each posture was defined by two points in two-dimensional space. One of the points represented the joint the link rotated around and the other represented opposite end of the link. Using these two points, the angle of orientation was determined, using the "12 o'clock" position as 0 degrees (see Appendix F)

The more precise information was a more quantifiable measure of accuracy than the PI coefficient, and because the data was continuous, it was analyzed using an analysis-of-covariance (ANCOVA) procedure. The PI coefficient calculations provided information about the similarities between the categories the subjects chose and the 'correct' categories, but they did not quantify the level of accuracy of the subjects' responses. In other words, the PI coefficients did not provide an indication of how close the subjects' responses were to the true postures.

The calculated angular orientations of 12 links (see Table 4.6) in each plane of each posture were compared with the true angular orientations measured from the videotaped postures, and the differences between them were calculated. This produced a data set of the angular deviations of the links from their 'correct' positions in each plane of each posture, for each subject. Table 4.7 shows that the average deviations ranged from 10 to 13 degrees across the Viewing Angle conditions, from 5 to 19 degrees across the Posture conditions, from 9 to 13 across the Plane conditions, and from 2 to 23 across the Link conditions.

To determine the effect of the interactions between these conditions, an ANCOVA was conducted using the angular deviations as the dependent variable. The independent variables included Link (L) (12 levels), Plane (Pl) (3 levels) and Posture (P) (5 levels) as the between-subjects variables, and Gender (G) and

Table 4.6 List of the 12 reference links and their abbreviations.

Link	(Abbreviation)
Neck	(N)
Torso	(T)
Right Upper Arm	(RUA)
Left Upper Arm	(LUA)
Right Lower Arm	(RLA)
Left Lower Arm	(LLA)
Right Upper Leg	(RUL)
Left Upper Leg	(LUL)
Right Lower Leg	(RLL)
Left Lower Leg	(LLL)
Right Foot	(RF)
Left Foot	(LF)

Table 4.7 Average angular deviations of the significant main effects with their associated standard deviations.

Effect	Condition	Angular Deviation (degrees)	S.D. (degrees)
Viewing Angle	Front	11.32	18.59
	Oblique	12.68	21.27
	Right	9.59	16.61
Posture	Sit	11.51	16.72
	Push	18.26	28.44
	Lift	6.39	9.46
	Reach	14.90	19.85
	Crouch	4.93	10.04
Plane	Transverse	12.06	20.46
	Frontal	9.07	16.73
	Sagittal	12.46	19.33
Link	N	1.40	4.49
	T	1.93	5.05
	RUA	18.74	25.26
	LUA	21.43	26.77
	RLA	18.15	21.23
	LLA	22.34	29.52
	RUL	7.36	11.64
	LUL	7.98	10.76
	RLL	9.61	14.46
	LLL	9.35	12.88
	RF	6.89	13.50
	LF	9.17	14.85

Viewing Angle (VA) (3 levels) as the within-subjects variables. Spatial Ability was included as a regressor variable, and consisted of the spatial ability scores compiled for each subject. The source table is presented in Table 4.8.

The ANCOVA table shows the main effects and interactions of the independent variables along with the regressor variable and its interaction with the main effect conditions. The F-ratios are listed along with the associated p-values, and for the within-subject effects, the Greenhouse-Geisser (G-G) and Huynh-Feldt (H-F) p-value corrections are included. Both the Greenhouse-Geisser and the Huynh-Feldt corrections were used to check for sphericity violations and to make the necessary adjustments to the degrees of freedom. For this study, Greenhouse-Geisser corrections were used to test for significance because of its more conservative estimates. The epsilon values used in the calculations of the Greenhouse-Geisser and Huynh-Feldt corrections are presented at the end of the ANCOVA table. These statistical analyses were computed on the Apple Macintosh computer using the statistical software SuperANOVA (Abacus Concepts, SuperANOVA, 1989).

Several significant effects were revealed in the ANCOVA including a four-way interaction of Posture*Plane*Link*Viewing Angle (F=1.882, G-G p=0.0180). The Sum of Squares value for this interaction was greater than the Sum of Squares for all of the other significant effects, indicating that it accounted for most of the variance and should be interpreted, but the complexity of the interaction made that difficult to do. To simplify the evaluation of the interaction, the data was rearranged so that separate ANCOVAs could be performed for each Posture condition. This was also done because it was determined that it was not necessary to evaluate the differences between the Posture conditions. The breakdown of the ANCOVA in this manner was not that different from how Posture*Plane*Link*Viewing Angle interaction would have been evaluated, but by

Table 4.8 ANCOVA source table for the angular deviation data.

Source of Variance	df	SS	MS	*F**	*p*	G-G	H-F
Between							
G	1	1666	1666	3.001	0.0966		
VA	2	9145	4573	8.237	0.0020		
G * VA	2	141	70	0.127	0.8814		
SA	1	1509	1509	2.719	0.1128		
Subject(G,VA)	23	12768	555				
Within							
P	4	14611	3653	7.134	0.0001	0.0002	0.0001
P * G	4	2849	712	1.391	0.2433	0.2513	0.2433
P * VA	8	7989	999	1.950	0.0617	0.0802	0.0617
P * G * VA	8	6331	791	1.546	0.1525	0.1720	0.1525
P * SA	4	2480	620	1.211	0.3115	0.3124	0.3115
P * Subject(G,VA)	92	47106	512				
Pl	2	2676	1338	3.838	0.0287	0.0328	0.0287
Pl * G	2	2169	1084	3.111	0.0540	0.0592	0.0540
Pl * VA	4	9629	2407	6.907	0.0002	0.0003	0.0002
Pl * G * VA	4	1053	263	0.756	0.5595	0.5493	0.5595
Pl * SA	2	1155	578	1.657	0.2018	0.2045	0.2018
Pl * Subject(G,VA)	46	16033	349				
L	11	23293	2118	17.343	0.0001	0.0001	0.0001
L * G	11	2075	189	1.545	0.1160	0.1928	0.1605
L * VA	22	10726	488	3.993	0.0001	0.0003	0.0001
L * G * VA	22	1161	53	0.432	0.9888	0.9058	0.9573
L * SA	11	988	90	0.736	0.7035	0.5761	0.6341
L * Subject(G,VA)	253	30891	122				
P * Pl	8	4260	532	2.451	0.0152	0.0397	0.0158
P * Pl * G	8	2763	345	1.590	0.1304	0.1708	0.1317
P * Pl * VA	16	8219	514	2.364	0.0032	0.0152	0.0034
P * Pl * G * VA	16	3744	234	1.077	0.3798	0.3858	0.3801
P * Pl * SA	8	1120	140	0.644	0.7398	0.6613	0.7374
P * Pl * Subject(G,VA)	184	39972	217				
P * L	44	29740	676	4.322	0.0001	0.0006	0.0001
P * L * G	44	8130	185	1.182	0.1973	0.3205	0.3048
P * L * VA	88	44284	503	3.218	0.0001	0.0006	0.0001
P * L * G * VA	88	12279	140	0.892	0.7483	0.5530	0.5960
P * L * SA	44	5100	116	0.741	0.8936	0.6115	0.6830
P * L * Subject(G,VA)	1012	158256	156				

Table 4.8 ANCOVA Source Table for the angular deviation data (continued).

Source of Variance	df	SS	MS	F*	p	G-G	H-F
Within (continued)							
Pl * L	22	3680	167	1.086	0.3582	0.3741	0.3738
Pl * L * G	22	6110	278	1.803	0.0144	0.1036	0.0584
Pl * L * VA	44	19836	451	2.926	0.0001	0.0013	0.0001
Pl * L * G * VA	44	4947	112	0.730	0.9018	0.7192	0.7984
Pl * L * SA	22	5207	237	1.536	0.0570	0.1714	0.1243
Pl * L * Subject(G,VA)	506	77961	154				
P * Pl * L	88	21974	250	1.854	0.0001	0.0591	0.0144
P * Pl * L * G	88	14783	168	1.247	0.0630	0.2669	0.2117
P * Pl * L * VA	176	44617	254	1.882	0.0001	0.0180	0.0013
P * Pl * L * G * VA	176	16752	95	0.707	0.9984	0.8054	0.9104
P * Pl * L * SA	88	22657	257	1.911	0.0001	0.0505	0.0107
P * Pl * L * Subject(G,VA)	2024	272640	135				
Total	5399						

Dependent: Angular Deviations

Epsilon Factors for df Adjustment

	G-G Epsilon	H-F Epsilon
P	0.794	1.176
Pl	0.915	1.249
L	0.382	0.601
P * Pl	0.605	0.985
P * L	0.130	0.224
Pl * L	0.271	0.471
P * Pl * L	0.104	0.225

*The denominator (error term) used for each F-ratio was the last term in each grouping of the sources of variation.

detecting the insignificant differences within each Posture condition, it reduced the number of combinations that needed to be interpreted.

4.2.4.1 Evaluation of the 'Sitting' Posture

An ANCOVA was run for the 'Sitting' posture and it revealed significant results ($\underline{p} \leq .05$) for the Link ($\underline{F}$=5.615, G-G $\underline{p}$=0.0015) main effect, as well as the Plane*Link interaction ($\underline{F}$=3.043, G-G $\underline{p}$=0.0133) (See Table 4.9). The Plane*Link interaction was evaluated first to determine if the accuracy of the recorded links varied depending on the plane in which the were recorded. From the chart in Figure 4.6, it can be seen that for each joint, the angular deviations were similar in each plane, with a few exceptions, such as the lower legs. Recordings made in the transverse plane, however, were less accurate than those made in the frontal and sagittal planes. Another dissimilarity occurred when the feet were recorded in the sagittal plane. In both the transverse and frontal planes, the feet were recorded more accurately than the lower legs, but in the sagittal plane the opposite was true. Another exception occurred for the arms where the recordings in the sagittal plane tended to be more accurate than in the other two planes. Finally, recordings of the upper legs in the frontal and sagittal plane were flawless, but in the transverse plane, they somewhat less accurate. Generally, the neck, torso, upper legs, and feet were recorded very accurately, between 0 and 5 degrees, while recordings of the arms were in error of between 15 and 30 degrees, and the lower legs between 5 and 15 degrees.

The Link main effect demonstrated differing levels of accuracy between the individual links, but these results should not be interpreted independently of the Plane*Link interaction (See Figure 4.7). A Neuman-Keuls analysis was performed and is presented in Table 4.10 to determine the statistical significance of the differences in accuracy between the links. The Neuman-Keuls post-hoc test was chosen because it provides the most sensitivity without unnecessarily inflating the alpha (Type I) error. It

Table 4.9 ANCOVA source table for the angular deviation data - 'Sitting' posture.

Source of Variance	df	SS	MS	F*	p	G-G	H-F
Between							
G	1	2337	2337	2.635	0.1182		
VA	2	4634	2317	2.613	0.0949		
G * VA	2	3197	1598	1.802	0.1874		
SA	1	3134	3134	3.534	0.0728		
Subject(G,VA)	23	20397	887				
Within							
Pl	2	697	349	1.327	0.2753	0.2749	0.2753
Pl * G	2	1462	731	2.782	0.0723	0.0761	0.0723
Pl * VA	4	620	155	0.590	0.6715	0.6614	0.6715
Pl * G * VA	4	781	195	0.743	0.5677	0.5602	0.5677
Pl * SA	2	961	481	1.829	0.1720	0.1747	0.1720
Pl * Subject(G,VA)	46	12084	263				
L	11	9555	869	5.615	0.0001	0.0015	0.0002
L * G	11	812	74	0.477	0.9166	0.7048	0.7762
L * VA	22	5866	267	1.723	0.0255	0.1260	0.0917
L * G * VA	22	5565	253	1.635	0.0393	0.1481	0.1137
L * SA	11	2260	205	1.328	0.2090	0.2719	0.2610
L * Subject(G,VA)	253	39140	155				
Pl * L	22	9108	414	3.043	0.0001	0.0133	0.0030
Pl * L * G	22	2827	129	0.944	0.5355	0.4544	0.4818
Pl * L * VA	44	9183	209	1.534	0.0177	0.1374	0.0908
Pl * L * G * VA	44	4991	113	0.834	0.7687	0.5960	0.6475
Pl * L * SA	22	5545	252	1.852	0.0109	0.1093	0.0692
Pl * L * Subject(G,VA)	506	68850	136				

Dependent: Angular Deviations

Epsilon Factors for df Adjustment

	G-G Epsilon	H-F Epsilon
Pl	0.939	1.287
L	0.281	0.414
Pl * L	0.224	0.367

*The denominator (error term) used for each F-ratio was the last term in each grouping of the sources of variation.

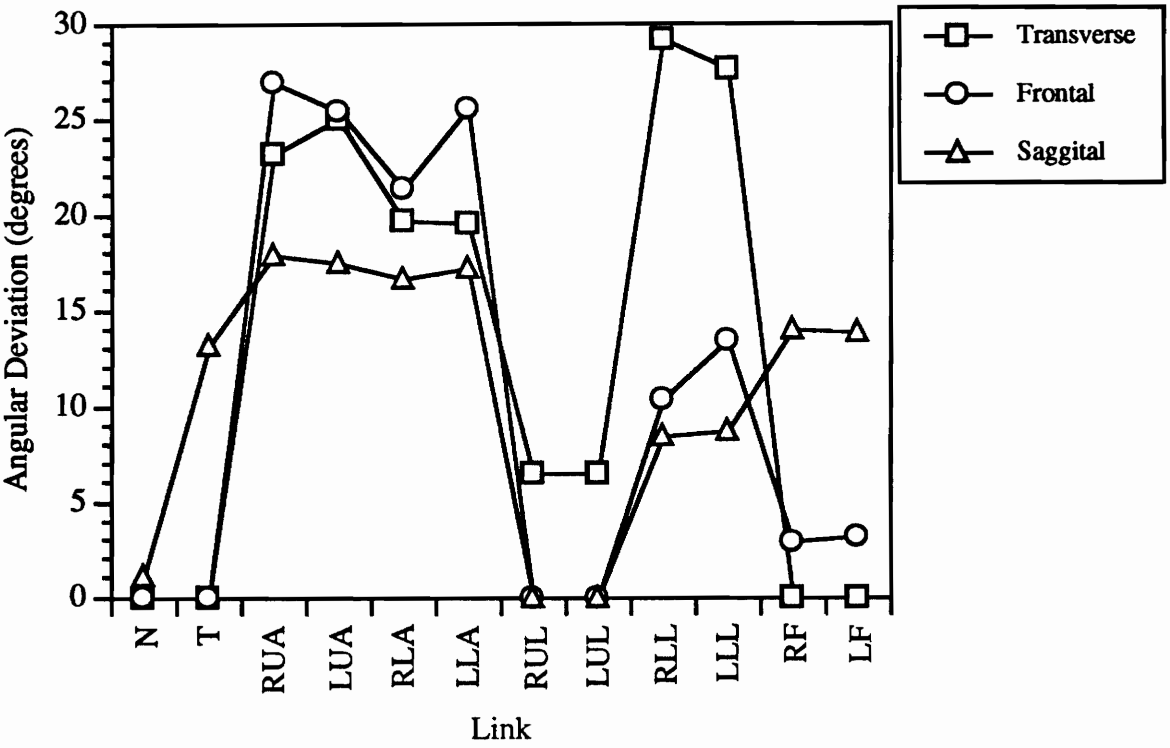


Figure 4.6 Plot of the Plane*Link interaction - 'Sitting' posture.

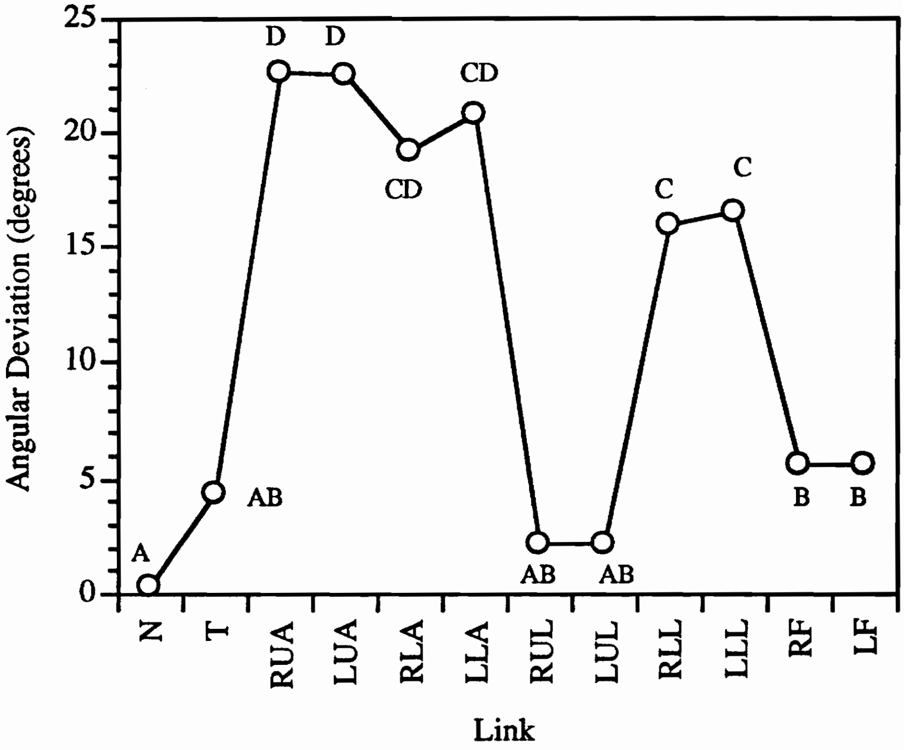


Figure 4.7 Plot of the Link main effect - 'Sitting' posture.

Table 4.10 Results of the Neuman-Keuls analysis of the Link main effect - 'Sitting' posture.

Link	Angular Deviation (degrees)	S.D. (degrees)	Significance*
Neck	0.36	1.69	A
Torso	4.36	7.22	A B
Right Upper Arm	22.67	18.93	D
Left Upper Arm	22.58	19.60	D
Right Lower Arm	19.21	16.67	C D
Left Lower Arm	20.78	17.71	C D
Right Upper Leg	2.16	10.44	A B
Left Upper Leg	2.16	10.44	A B
Right Lower leg	16.00	16.19	C
Left Lower Leg	16.57	15.10	C
Right Foot	5.62	14.55	B
Left Foot	5.67	14.59	B

*Levels of the factor with the same letters are not significantly different from each other.

distributes the alpha error across the possible comparisons and saves the most power for the comparisons with the smallest differences, while controlling the alpha error.

As can been seen from the table, the arms and lower legs were recorded less accurately than all of the other links with average deviations between 16 and 23 degrees. The upper arms were recorded with an average error of about 23 degrees, and were significantly less accurate than the recordings of the lower legs, which had an average error of about 16 degrees. Of the six remaining links, the feet were recorded less accurately than the neck. but the torso and upper legs did not significantly differ from either the neck or the feet. Despite the differences, the average error of these six links only ranged from 0 to 6 degrees.

4.2.4.2 Evaluation of the 'Lifting' Posture

An ANCOVA was also performed on the accuracy data recorded for the 'lifting' posture and it revealed several significant effects including the Link main effect (F=5.174, G-G p=0.0051), the Plane*Viewing Angle (F=8.268, G-G p=0.0007) and Plane*Link (F=4.683, G-G p=0.0021) interactions, and the Plane*Link*Viewing Angle (F=3.781, G-G p=0.0009) interaction (See Table 4.11). The Plane*Link*Viewing Angle was evaluated first because it provided the most detailed breakdown of the 'lifting' posture data. It was followed by an evaluation of the less detailed Plane*Viewing Angle and Plane*Link interactions, and then the general Link main effect was assessed.

The Plane*Link*Viewing Angle interaction was divided into three groups, one for each Viewing Angle condition, and the plots of each group are presented in Figures 4.8-4.10. As can be seen from the plots, there is a complex relationship between the three factors, but a few general trends can be seen. When the neck, torso, and arms were seen from the 'front' viewing angle, they were recorded perfectly in the transverse and frontal planes, but they produced angular deviations from 5 to 28 degrees when recorded in the

Table 4.11 ANCOVA source table for the angular deviation data - 'Lifting' posture.

Source of Variance	df	SS	MS	F*	p	G-G	H-F
Between							
G	1	71	71	0.859	0.3637		
VA	2	366	183	2.225	0.1308		
G * VA	2	123	62	0.750	0.4838		
SA	1	128	128	1.559	0.2243		
Subject(G,VA)	23	1894	82				
Within							
Pl	2	508	254	3.330	0.0446	0.0691	0.0546
Pl * G	2	26	13	0.172	0.8421	0.7410	0.8033
Pl * VA	4	2522	630	8.268	0.0001	0.0007	0.0001
Pl * G * VA	4	140	35	0.458	0.7664	0.6834	0.7331
Pl * SA	2	299	150	1.962	0.1521	0.1698	0.1606
Pl * Subject(G,VA)	46	3508	76				
L	11	1473	134	5.174	0.0001	0.0051	0.0014
L * G	11	254	23	0.890	0.5504	0.4359	0.4640
L * VA	22	1226	56	2.153	0.0026	0.0719	0.0460
L * G * VA	22	757	34	1.330	0.1518	0.2646	0.2461
L * SA	11	206	19	0.723	0.7163	0.5187	0.5635
L * Subject(G,VA)	253	6549	26				
Pl * L	22	2709	123	4.683	0.0001	0.0021	0.0003
Pl * L * G	22	969	44	1.675	0.0284	0.1658	0.1337
Pl * L * VA	44	4373	99	3.781	0.0001	0.0009	0.0001
Pl * L * G * VA	44	1198	27	1.035	0.4134	0.4148	0.4201
Pl * L * SA	22	606	28	1.049	0.4017	0.3851	0.3962
Pl * L * Subject(G,VA)	506	13303	26				

Dependent: Angular Deviations

Epsilon Factors for df Adjustment

	G-G Epsilon	H-F Epsilon
Pl	0.6	0.833
L	0.2	0.324
Pl * L	0.2	0.265

*The denominator (error term) used for each F-ratio was the last term in each grouping of the sources of variation.

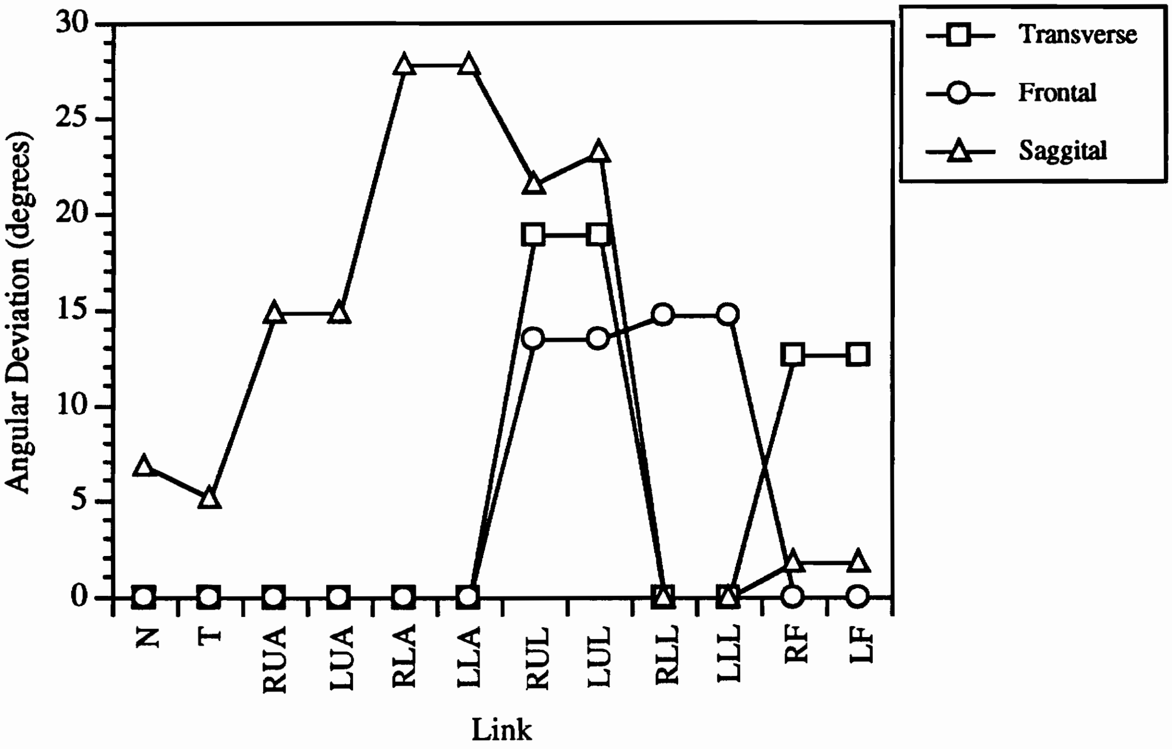


Figure 4.8 Plot of the Plane*Link*Viewing Angle interaction for the 'Front' viewing angle - 'Lifting' posture.

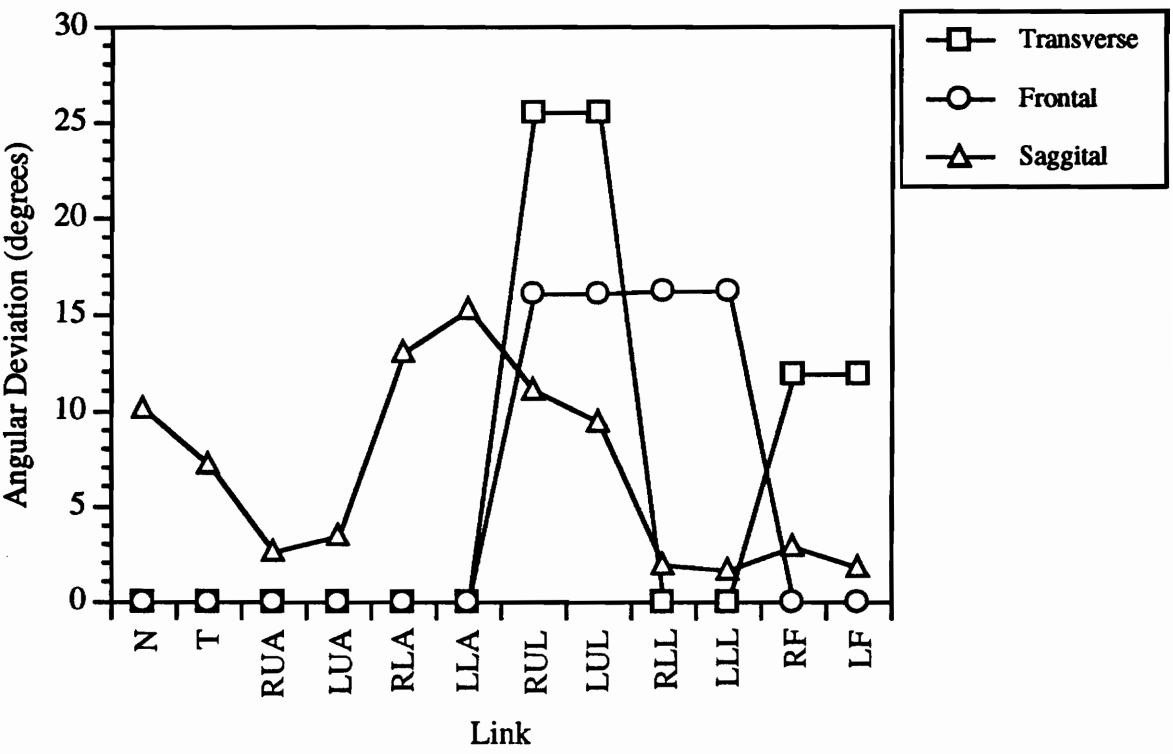


Figure 4.9 Plot of the Plane*Link*Viewing Angle interaction for the 'Oblique' viewing angle - 'Lifting' posture.

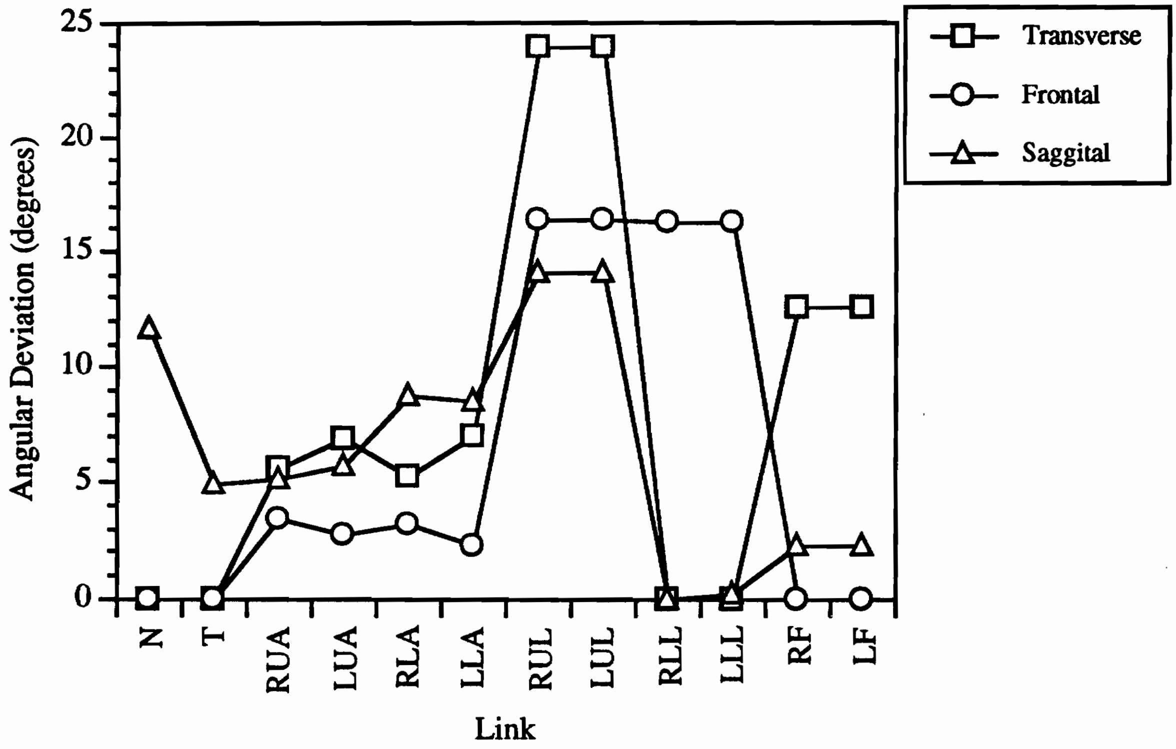


Figure 4.10 Plot of the Plane*Link*Viewing Angle interaction for the 'Right' viewing angle - 'Lifting' posture.

sagittal plane. Similar conditions existed for these links when they were viewed from the 'oblique' viewing angle, but the range of errors in the sagittal plane was smaller, producing deviations between 2 and 15 degrees. When viewed from the 'right' viewing angle, the neck and torso were recorded perfectly in the transverse plane, while generating errors of 5 to 12 degrees in the sagittal plane. The arms were recorded with similar accuracy for all planes, ranging from 2 to 8 degrees.

The upper legs were generally the most inaccurately recorded links, especially in the transverse plane when viewed from the 'oblique' and 'right' viewing angles, and the errors ranged from about 10 to 25 degrees. The lower legs were recorded almost perfectly in the transverse and sagittal planes for all viewing angles, but always averaged about 15 degrees of deviation in the frontal plane. Finally, for all viewing angles, the feet were recorded with an average of about 13 degrees of deviation in the transverse plane, but were recorded nearly perfectly in the frontal and sagittal planes.

The Plane*Viewing Angle interaction was evaluated next to determine how accurate the recordings were in each plane, based on the viewing angle from which the postures were observed. The plot in Figure 4.11 shows that the angular deviations were similar for all conditions, except for recordings made in the sagittal plane when the posture was viewed from the 'front' viewing angle. For this exception the average angular deviation was about 12 degrees, while the average errors of all the other combinations ranged from 4 to 8 degrees.

The Plane*Link interaction was also analyzed to determine the influence of the two factors on the accuracy of the recordings. Not surprisingly, the average deviations were similar to the general trend of the Plane*Link*Viewing Angle interaction, (See Figure 4.12). For the neck, torso, and arms, recordings in the transverse and frontal planes were nearly perfect, while the errors made in the sagittal plane ranged from 5 to 10 degrees for the neck, torso, and upper arms, and averaged about 17 degrees for the

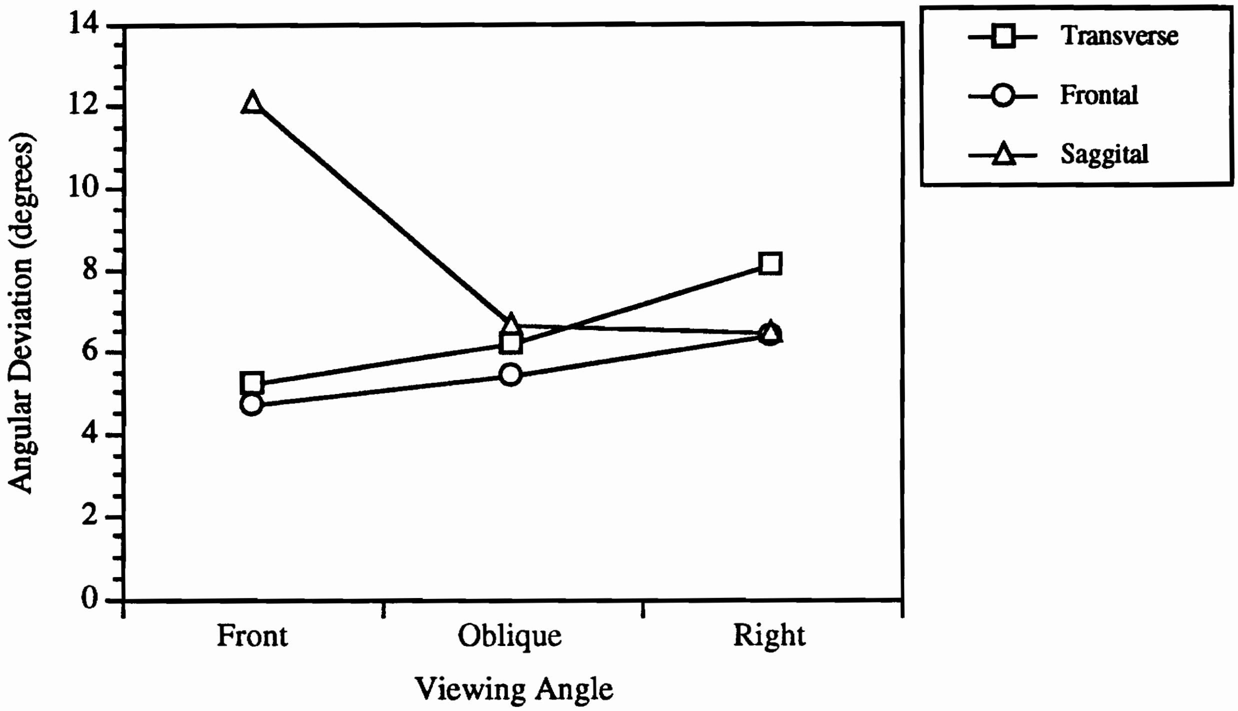


Figure 4.11 Plot of the Plane*Viewing Angle interaction - 'Lifting' posture

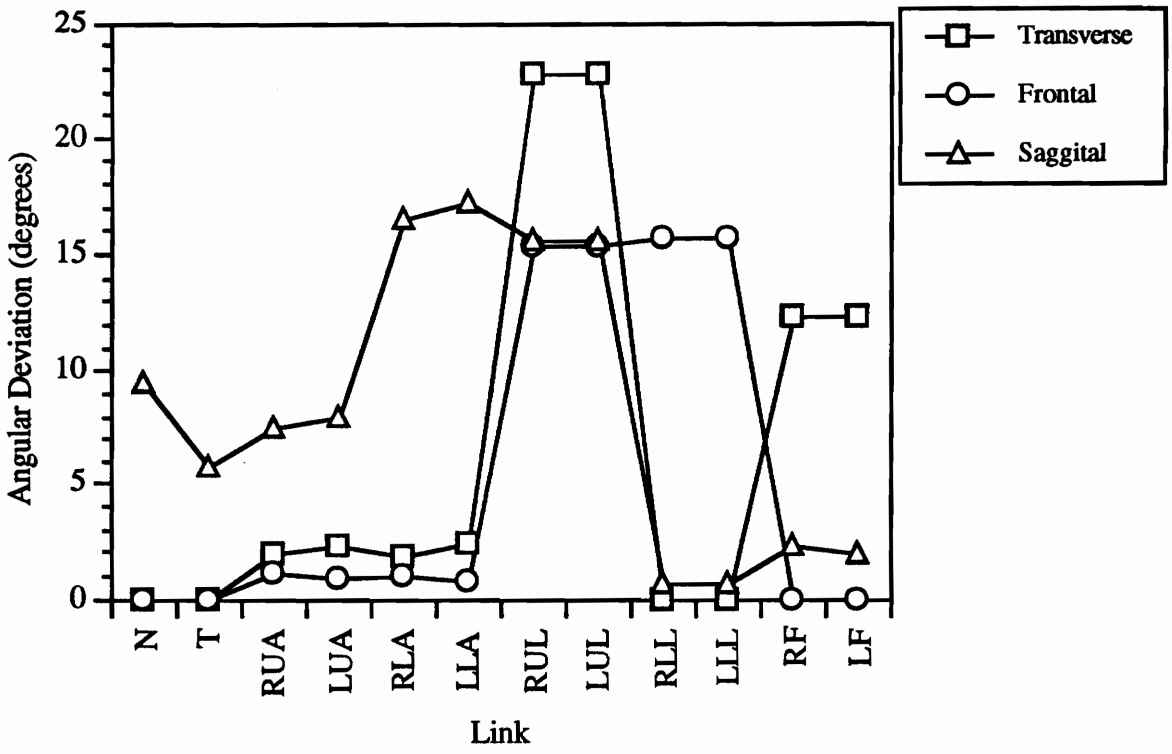


Figure 4.12 Plot of the Plane*Link interaction - 'Lifting' posture.

lower arms. Recordings of the upper legs averaged from about 15 degrees of angular deviation in the frontal and sagittal planes, and about 23 degrees in the transverse plane. The lower legs were almost perfect in the transverse and sagittal planes, but averaged almost 15 degrees of error in the frontal plane. Finally, the feet were recorded nearly perfectly in the frontal an sagittal planes, but averaged 12 degrees of angular deviation in the transverse plane.

Lastly, the Link main effect was evaluated, but it is important to consider the contributions of the previously described interactions when interpreting the angular deviations of the individual links. Figure 4.13 illustrates the differences in the average recording error calculated for each link. A Neuman-Keuls analysis was performed to determine the differences between the angular deviations of the links and the results are presented in Table 4.12. From the table it can be seen that the upper legs were recorded significantly less accurately than the other links with an average deviation of about 18 degrees. The torso, on the other hand, was recorded significantly more accurately than any of the other links, with an average error of about 2 degrees. The remaining links did not significantly differ from each other, nor did they differ from the upper legs or the torso. The average errors of the remaining links ranged between 3 and 7 degrees.

4.2.4.3 Evaluation of the 'Crouching' Posture

The ANCOVA revealed many significant effects including the Viewing Angle (F=8.397, G-G p=0.0018) and Plane (F=31.615, G-G p=0.0001) main effects, the Plane*Viewing Angle (F=7.709, G-G p=0.0027) interaction, and the Plane*Link*Viewing Angle (F=2.996, p=0.0246) interaction (See Table 4.13). The three-way interaction involved factors from each of the lower-order effects and so it was evaluated first because it provided the most detailed information about the accuracy of the 'crouching' posture recordings. The Plane*Viewing Angle interaction was then

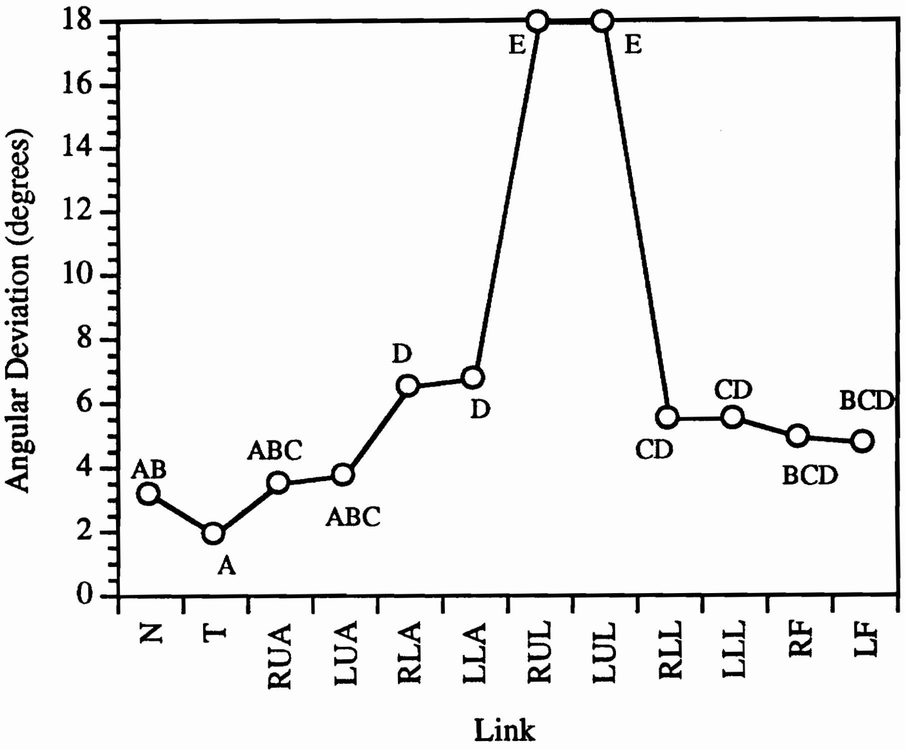


Figure 4.13 Plot of the Link main effect - 'Lifting' posture.

Table 4.12 Results of the Neuman-Keuls analysis of the Link main effect - 'Lifting' posture.

Link	Angular Deviation (degrees)	S.D. (degrees)	Significance*				
Neck	3.164	6.917	A	B			
Torso	1.911	4.658	A				
Right Upper Arm	3.505	7.047	A	B	C		
Left Upper Arm	3.721	7.457	A	B	C		
Right Lower Arm	6.432	10.313				D	
Left Lower Arm	6.752	10.929				D	
Right Upper Leg	17.854	10.001					E
Left Upper Leg	17.854	10.001					E
Right Lower leg	5.451	7.645			C	D	
Left Lower Leg	5.451	7.645			C	D	
Right Foot	4.871	5.660		B	C	D	
Left Foot	4.744	5.704		B	C	D	

*Levels of the factor with the same letters are not significantly different from each other.

Table 4.13 ANCOVA source table for the angular deviation data - 'Crouching' posture.

Source of Variance	df	SS	MS	F*	p	G-G	H-F
Between							
G	1	59	59	0.435	0.5162		
VA	2	2280	1140	8.397	0.0018		
G * VA	2	22	11	0.081	0.9224		
SA	1	22	22	0.161	0.6916		
Subject(G,VA)	23	3122	136				
Within							
Pl	2	4435	2218	31.615	0.0001	0.0001	0.0001
Pl * G	2	24	12	0.168	0.8458	0.6864	0.7457
Pl * VA	4	2163	541	7.709	0.0001	0.0027	0.0010
Pl * G * VA	4	147	37	0.524	0.7188	0.5998	0.6412
Pl * SA	2	274	137	1.951	0.1537	0.1757	0.1710
Pl * Subject(G,VA)	46	3227	70				
L	11	644	59	1.178	0.3028	0.3211	0.3255
L * G	11	458	42	0.839	0.6016	0.4554	0.4880
L * VA	22	2076	94	1.898	0.0104	0.1128	0.0838
L * G * VA	22	476	22	0.435	0.9883	0.8135	0.8712
L * SA	11	102	9	0.187	0.9982	0.8647	0.9223
L * Subject(G,VA)	253	12575	50				
Pl * L	22	1758	80	2.238	0.0011	0.1125	0.0900
Pl * L * G	22	1346	61	1.714	0.0232	0.1878	0.1708
Pl * L * VA	44	4660	106	2.966	0.0001	0.0246	0.0116
Pl * L * G * VA	44	1210	27	0.770	0.8575	0.5606	0.5987
Pl * L * SA	22	631	29	0.803	0.7236	0.4640	0.4989
Pl * L * Subject(G,VA)	506	18067	36				

Dependent: Angular Deviations

Epsilon Factors for df Adjustment

	G-G Epsilon	H-F Epsilon
Pl	0.500	0.639
L	0.200	0.306
Pl * L	0.100	0.139

*The denominator (error term) used for each F-ratio was the last term in each grouping of the sources of variation.

evaluated, followed by the Viewing Angle and Plane main effects.

The Plane*Link*Viewing Angle interaction was broken into three two-way interactions, one for each Viewing Angle condition, which are illustrated in Figures 4.14-4.16. As can be seen from the graphs, the Plane*Link interactions were quite similar for each Viewing Angle condition. Recordings made in the transverse and frontal planes were almost always perfect, with the only notable exceptions occurring in the recordings of the upper legs. In any case, the errors in these two planes ranged from 0 to 5 degrees, while the errors made in the sagittal plane were much greater.

When the posture was viewed from the 'front' viewing angle, errors in the sagittal plane averaged about 15 degrees for the neck, torso, and arms, while the lower legs and feet averaged about 35 degrees and 20 degrees, respectively. Errors in the sagittal plane for the upper legs were similar to the other two planes, averaging about 5 degrees.

Recording errors for the torso and arms in the sagittal plane ranged from 8 to 13 degrees when the 'crouching' posture was viewed from the 'oblique' viewing angle, and the neck was almost always recorded perfectly. Recordings of the legs resulted in angular deviations ranging from 17 to 20 degrees, while the feet averaged nearly 28 degrees.

When viewed from the 'right' viewing angle, the torso and arms averaged about 4 degrees of error, while the neck and upper legs were recorded incorrectly by an average of almost 10 degrees. The lower legs and feet were recorded the most incorrectly, with average deviations of about 18 and 11 degrees, respectively.

The next effect that was evaluated was the Plane*Viewing Angle interaction to determine how each Viewing Angle condition affected each Plane condition in terms of the accuracy of the recordings (See Figure 4.17). From the plot it can be seen that there were virtually no errors in the transverse and frontal planes for any of the Viewing Angle conditions. Errors did occur in the sagittal plane, however, with an average of about 16

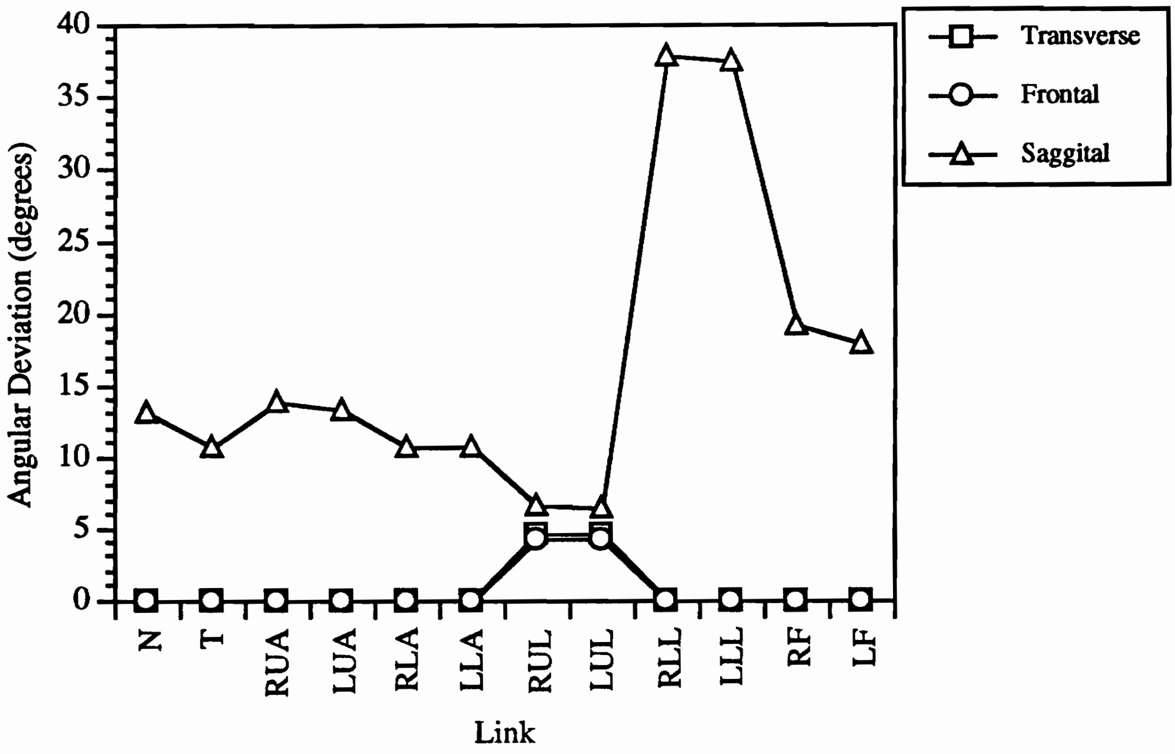


Figure 4.14 Plot of the Plane*Link*Viewing Angle interaction for the 'Front' viewing angle - 'Crouching' posture.

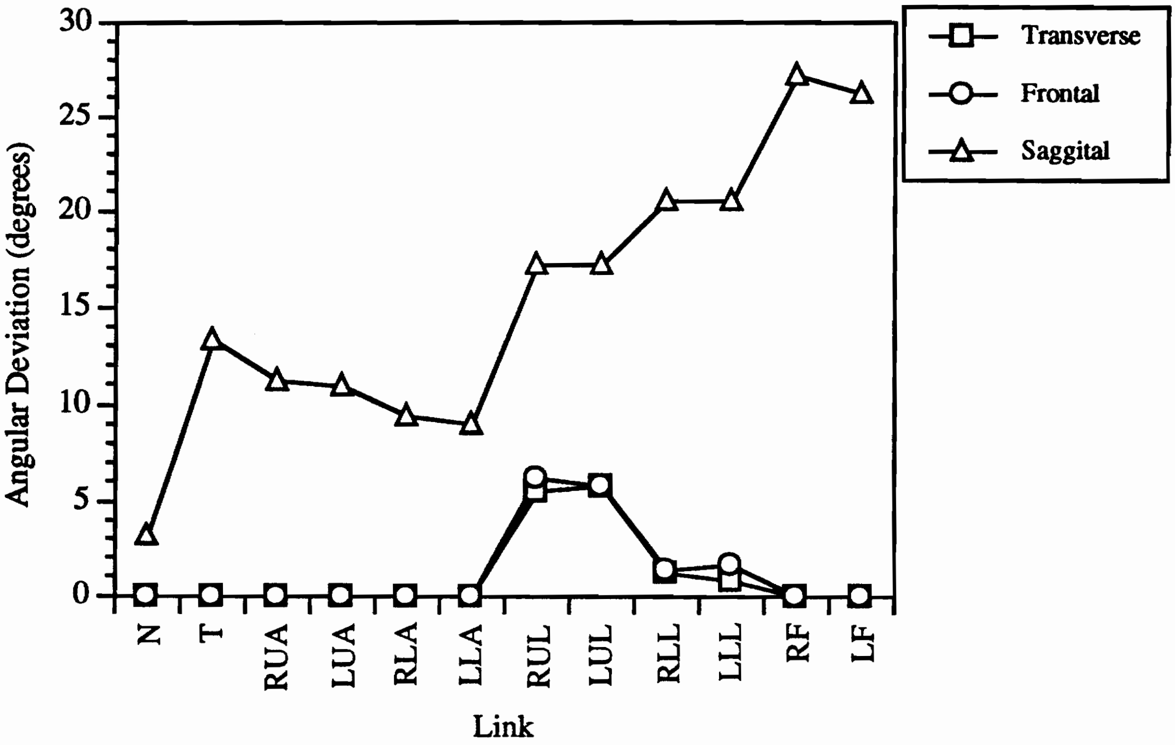


Figure 4.15 Plane*Link*Viewing Angle interaction for the 'Oblique' viewing angle - 'Crouching' posture.

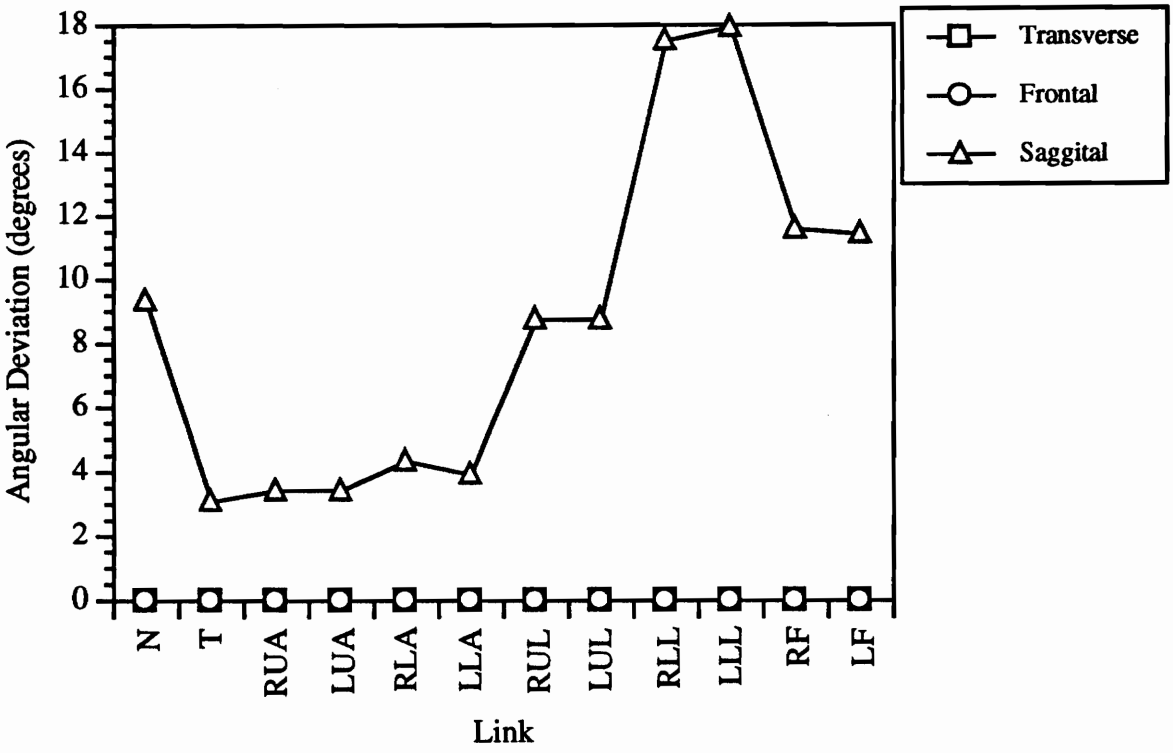


Figure 4.16 Plot of the Plane*Link*Viewing Angle interaction for the 'Right' viewing angle - 'Crouching' posture.

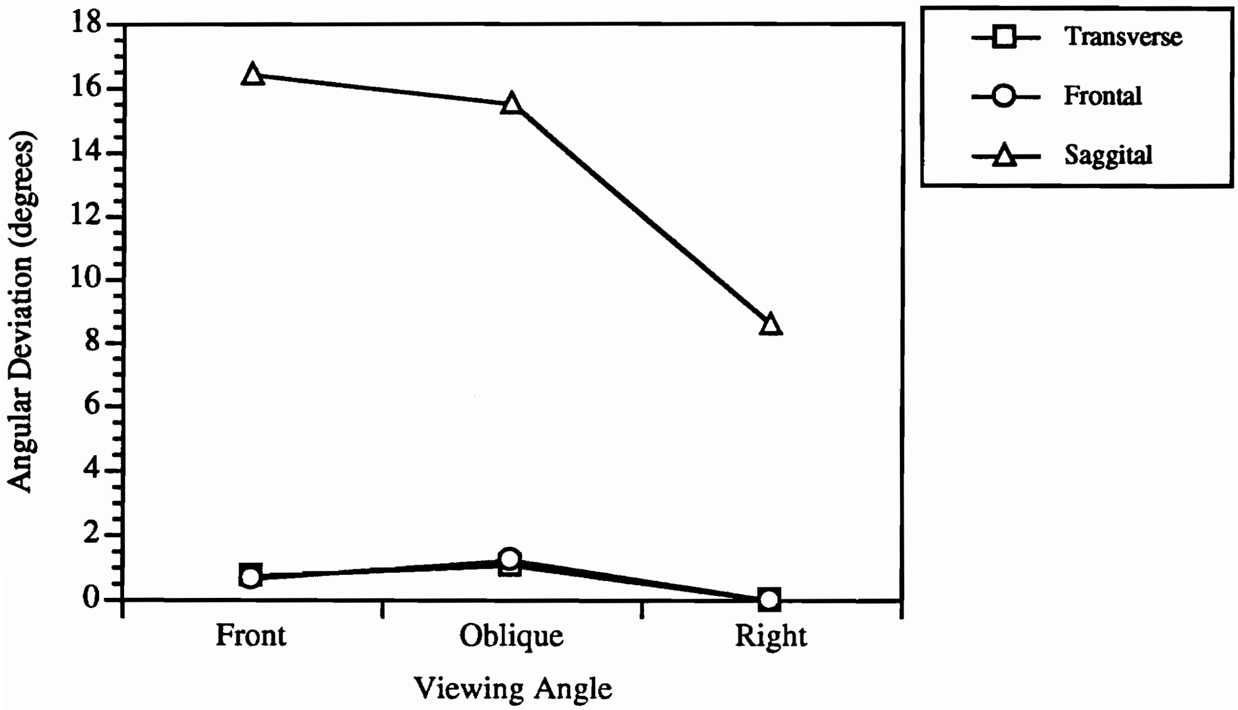


Figure 4.17 Plot of the Plane*Viewing Angle interaction - 'Crouching' posture.

degrees for the 'front' and 'oblique' Viewing Angle conditions, and an average of 8 degrees when viewed from the 'right' viewing angle.

The Viewing Angle main effect was then evaluated to determine the effect of the three Viewing Angle conditions on the accuracy of the recordings. A plot of the main effect can be found in Figure 4.18 and the Neuman-Keuls analysis is presented in Table 4.14. The post-hoc analysis revealed that the recordings were significantly more accurate when the posture was viewed from the 'right' viewing angle than when it was viewed from either the 'front' or 'oblique' viewing angles. It is important to consider the higher-order interactions when evaluating this main effect because there were many errors greater than those represented in the overall averages produced for this effect, which ranged from 2 to 6 degrees.

Finally, the Plane main effect was evaluated and again the averaged accuracy values were much lower than those found when evaluating the higher-order interactions (See Figure 4.19). A Neuman-Keuls analysis was performed and it was determined that recordings made in the sagittal plane were significantly less accurate than recordings made in the other two planes (See Table 4.15). Angular deviations in the sagittal plane averaged about 14 degrees while the recordings made in the transverse and frontal were almost perfect.

4.2.4.4 Evaluation of the 'Reaching' Posture

From Table 4.16, it can be seen that the ANCOVA of the 'reaching' posture data revealed several significant effects including the Link main effect (F=12.692, G-G p=0.0001), the Plane*Viewing Angle interaction (F=5.301, G-G p=0.0061), and the Link*Viewing Angle interaction (F=2.408, G-G p=0.0450). To explain the effect of the independent variables on the accuracy of the recordings, the more complex two-way interactions were evaluated first, followed by the significant main effect. It is important

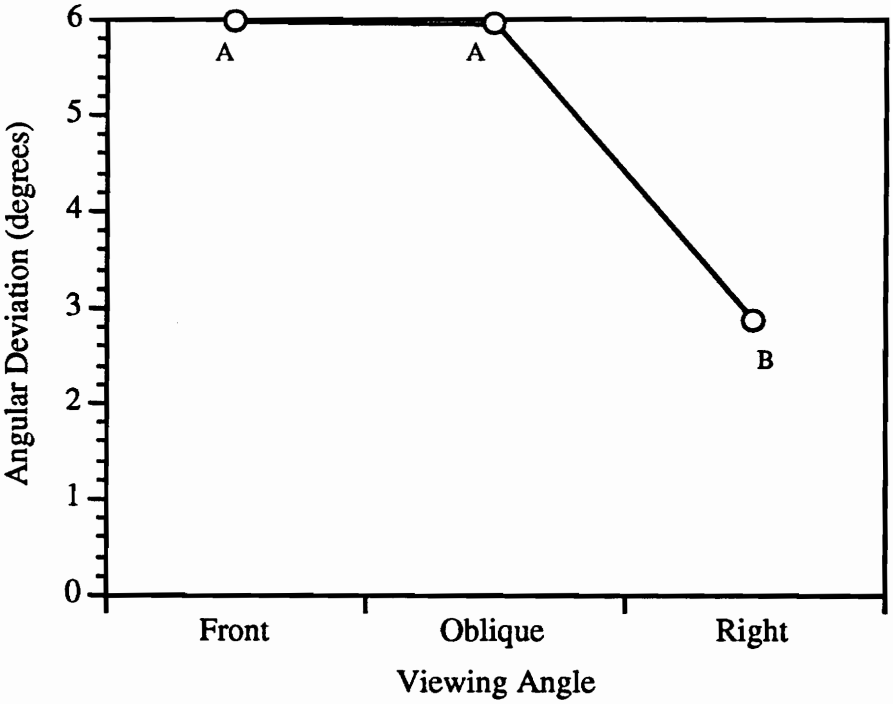


Figure 4.18 Plot of the Viewing Angle main effect - 'Crouching' posture.

Table 4.14 Results of the Neuman-Keuls analysis of the Viewing Angle main effect - 'Crouching' posture.

Viewing Angle	Angular Deviation (degrees)	S.D. (degrees)	Significance*	
Front	5.97	11.67		B
Oblique	5.94	10.68		B
Right	2.87	6.78	A	

*Levels of the factor with the same letters are not significantly different from each other.

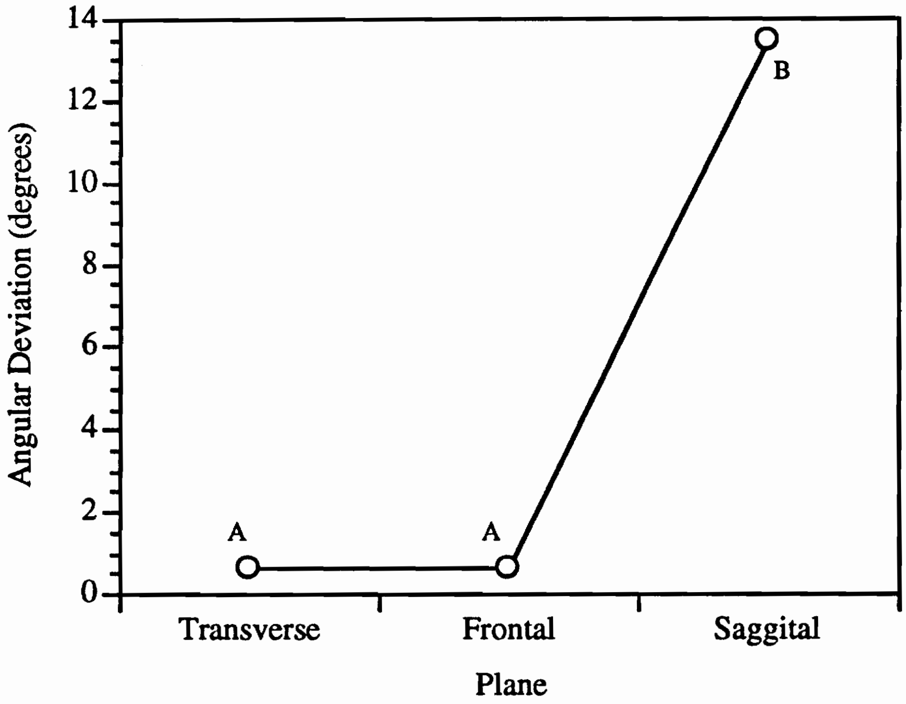


Figure 4.19 Plot of the Plane main effect - 'Crouching' posture.

Table 4.15 Results of the Neuman-Keuls analysis of the Plane main effect - 'Crouching' posture.

Link	Angular Deviation (degrees)	S.D. (degrees)	Significance*
Transverse	0.63	3.61	A
Frontal	0.65	3.68	A
Sagittal	13.50	12.87	B

*Levels of the factor with the same letters are not significantly different from each other.

Table 4.16 ANCOVA source table for the angular deviation data - 'Reaching' posture.

Source of Variance	df	SS	MS	F*	p	G-G	H-F
Between							
G	1	1804	1804	2.128	0.1581		
VA	2	1549	775	0.914	0.4150		
G * VA	2	2025	1013	1.195	0.3209		
SA	1	336	336	0.396	0.5353		
Subject(G,VA)	23	19496	848				
Within							
Pl	2	1256	628	1.570	0.2190	0.2244	0.2218
Pl * G	2	2869	1434	3.586	0.0357	0.0569	0.0427
Pl * VA	4	8481	2120	5.301	0.0013	0.0061	0.0024
Pl * G * VA	4	1307	327	0.817	0.5211	0.4816	0.5079
Pl * SA	2	577	288	0.721	0.4917	0.4401	0.4745
Pl * Subject(G,VA)	46	18400	400				
L	11	17677	1607	12.692	0.0001	0.0001	0.0001
L * G	11	1910	174	1.371	0.1866	0.2616	0.2527
L * VA	22	6707	305	2.408	0.0006	0.0450	0.0244
L * G * VA	22	1669	76	0.599	0.9229	0.7066	0.7644
L * SA	11	2703	246	1.941	0.0349	0.1406	0.1158
L * Subject(G,VA)	253	32035	127				
Pl * L	22	2692	122	0.775	0.7576	0.5032	0.5447
Pl * L * G	22	5709	259	1.644	0.0334	0.1912	0.1696
Pl * L * VA	44	15658	356	2.254	0.0001	0.0534	0.0299
Pl * L * G * VA	44	4786	109	0.689	0.9365	0.6484	0.7011
Pl * L * SA	22	1746	79	0.503	0.9724	0.6677	0.7348
Pl * L * Subject(G,VA)	506	79878	158				

Dependent: Angular Deviations

Epsilon Factors for df Adjustment

	G-G Epsilon	H-F Epsilon
Pl	0.663	0.871
L	0.236	0.338
Pl * L	0.126	0.183

*The denominator (error term) used for each F-ratio was the last term in each grouping of the sources of variation.

to note that the explanation of the Link*Viewing Angle interaction should not be neglected when interpreting the Link main effect.

The Plane*Viewing Angle interaction was first evaluated to determine the effect of the Plane and Viewing Angle combinations on the accuracy of the recordings. From the graph in Figure 4.20 it is demonstrated that the recordings were in error an average of 5 to 20 degrees. Recordings made in the transverse plane were generally less accurate than those made in the frontal and sagittal planes, averaging about 20 degrees over the three Viewing Angle conditions. For both the 'front' and 'oblique' Viewing Angle conditions, errors in the frontal and sagittal planes ranged between 12 and 15 degrees, with the errors in the sagittal plane being slightly higher in both conditions. In the 'right' Viewing Angle condition, the errors in the frontal and transverse planes were almost identical, at about 18 degrees, while the average error of recordings made in the sagittal plane was around 5 degrees.

The second effect that was evaluated was the Plane*Link interaction to determine each Plane condition affected the accuracy of the recordings for each Link condition. From the plot in Figure 4.21, it can be seen that the average errors were quite similar for each Viewing Angle condition, with the only exception occurring when the posture was viewed from the 'right' viewing angle. For this Viewing Angle condition, the arms were recorded more accurately than when the posture was viewed from either the 'front' or 'oblique' viewing angles, with average errors ranging between 20 and 25 degrees, instead of 25 to 35 degrees. Also, the left foot was recorded less accurately when viewed from the 'right' viewing angle with an average angular deviation of about 28 degrees as opposed to the deviations of about 20 degrees for the 'front' and 'oblique' Viewing Angle conditions.

When evaluating the individual Link conditions for this two-way interaction, it can be seen that the neck and torso were recorded almost perfectly, as was the right upper

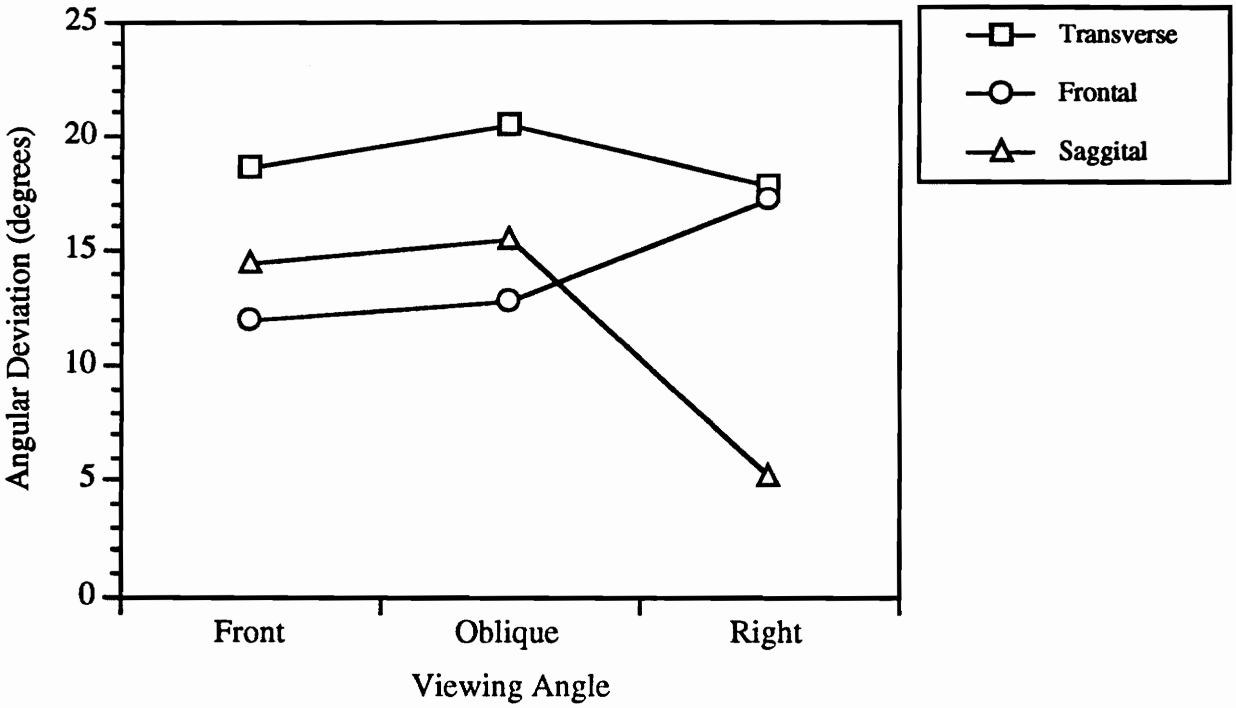


Figure 4.20 Plot of the Plane*Viewing Angle interaction - 'Reaching' posture.

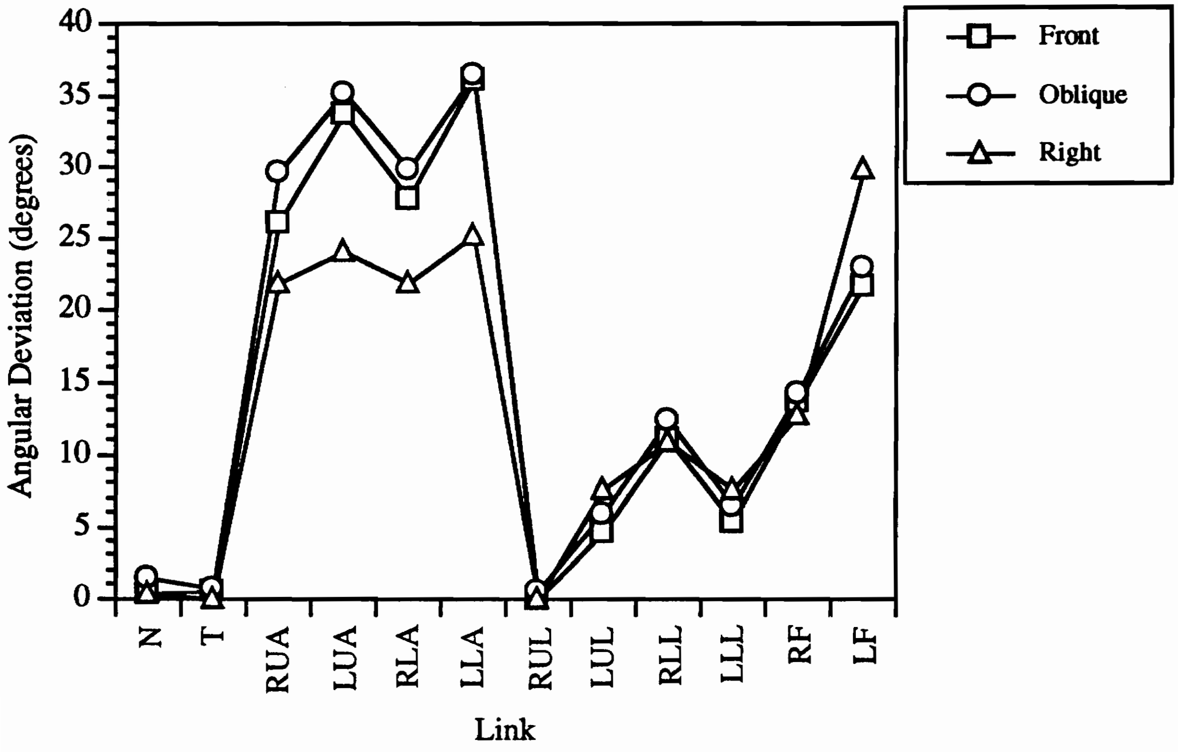


Figure 4.21 Plot of the Link*Viewing Angle interaction - 'Reaching' posture.

leg. When considering only the 'front' and 'oblique' Viewing Angle conditions, the right arms were recorded more accurately than the left arms, averaging 30 and 35 degrees of angular deviation, respectively. Finally, the left upper and lower legs were recorded with an average of about 6 degrees of error, while recordings of the right lower leg and the right foot resulted in average angular deviations of about 10 degrees.

Lastly, the Link main effect was evaluated to determine the effect of the individual Link conditions on the accuracy of the recordings (See Figure 4.22). As was expected, the results were quite similar to the Link*Viewing Angle interaction because of the similarities between the Viewing Angle conditions. Nevertheless, a Neuman-Keuls analysis was performed to locate the significant differences between the average errors of the individual Link conditions (See Table 4.17). The most accurately recorded links were the neck, torso, and the right upper leg which were recorded almost perfectly. The left upper and lower legs were the second most accurately recorded links with average deviations of about 6 degrees, and the right lower leg and the right foot were the next most accurately recorded links with average errors between 12 and 14 degrees. The second least accurately recorded links were the right upper and lower arms, averaging around 26 degrees of deviation, and the least accurately recorded links were the left upper and lower arms with average errors between 31 and 33 degrees.

4.2.4.5 Evaluation of the 'Pushing' Posture

An ANCOVA was run for the 'pushing' posture and several significant effects were revealed including the Viewing Angle main effect (*F*=6.382, G-G *p*=0.0062), the Link main effect (*F*=5.511, G-G *p*=0.0027), the Link*Viewing Angle interaction (*F*=4.553, G-G *p*=0.0010), and the Plane*Viewing Angle*Link interaction (*F*=2.062, G-G *p*=0.0414) (See Table 4.18). The more complex three-way interaction was evaluated first, followed by the two-way interaction and then the main effects.

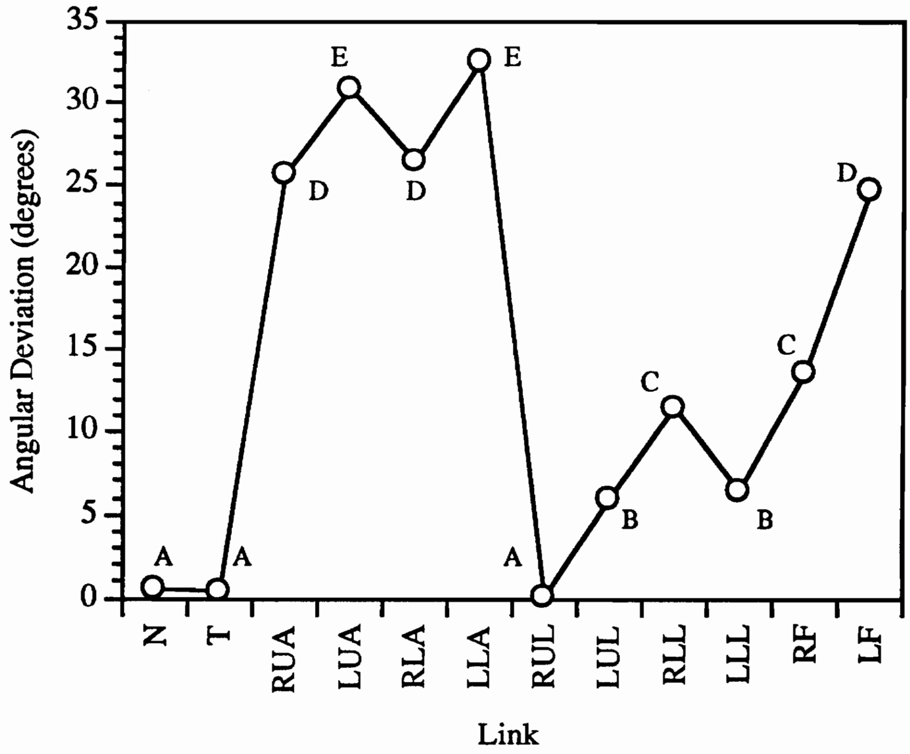


Figure 4.22 Plot of the Link main effect - 'Reaching' posture.

Table 4.17 Results of the Neuman-Keuls analysis of the Link main effect - 'Reaching' posture.

Link	Angular Deviation (degrees)	S.D. (degrees)	Significance*
Neck	0.63	2.48	A
Torso	0.37	2.13	A
Right Upper Arm	25.73	19.28	D
Left Upper Arm	30.88	22.41	E
Right Lower Arm	26.45	19.44	D
Left Lower Arm	32.50	22.84	E
Right Upper Leg	0.16	1.55	A
Left Upper Leg	5.96	7.35	B
Right Lower leg	11.38	18.94	C
Left Lower Leg	6.41	7.32	B
Right Foot	13.51	20.34	C
Left Foot	24.76	19.51	D

*Levels of the factor with the same letters are not significantly different from each other.

Table 4.18 ANCOVA source table for the angular deviation data - 'Pushing' posture.

Source of Variance	df	SS	MS	F*	p	G-G	H-F
Between							
G	1	244	244	0.376	0.5459		
VA	2	8304	4152	6.382	0.0062		
G * VA	2	1104	552	0.849	0.4410		
SA	1	369	369	0.567	0.4590		
Subject(G,VA)	23	14964	651				
Within							
Pl	2	39	20	0.048	0.9532	0.9478	0.9532
Pl * G	2	551	276	0.675	0.5141	0.5079	0.5141
Pl * VA	4	4061	1015	2.486	0.0564	0.0596	0.0564
Pl * G * VA	4	2423	606	1.483	0.2228	0.2252	0.2228
Pl * SA	2	164	82	0.201	0.8187	0.8091	0.8187
Pl * Subject(G,VA)	46	18786	408				
L	11	23684	2153	5.511	0.0001	0.0027	0.0006
L * G	11	6771	616	1.575	0.1062	0.2075	0.1885
L * VA	22	39137	1779	4.553	0.0001	0.0010	0.0001
L * G * VA	22	4973	226	0.579	0.9358	0.7303	0.7903
L * SA	11	818	74	0.190	0.9980	0.8866	0.9409
L * Subject(G,VA)	253	98849	391				
Pl * L	22	9386	427	1.266	0.1876	0.2870	0.2706
Pl * L * G	22	10042	456	1.355	0.1305	0.2524	0.2286
Pl * L * VA	44	30579	695	2.062	0.0001	0.0414	0.0167
Pl * L * G * VA	44	9515	216	0.642	0.9649	0.7548	0.8258
Pl * L * SA	22	19337	879	1.608	0.0101	0.1354	0.1144
Pl * L * Subject(G,VA)	506	170501	337				

Dependent: Angular Deviations

Epsilon Factors for df Adjustment

	G-G Epsilon	H-F Epsilon
Pl	0.956	1.312
L	0.248	0.357
Pl * L	0.199	0.316

*The denominator (error term) used for each F-ratio was the last term in each grouping of the sources of variation.

The Plane*Link*Viewing Angle interaction was broken down into three two-way interactions by evaluating the Plane*Link interaction for each Viewing Angle condition, and the plots are presented in Figures 4.23-4.25. As can be seen from these graphs, the interactions between the Link and Plane conditions are quite complex, and only generally the same across Viewing Angle conditions. In general, the legs and feet were recorded more accurately than the arms with errors ranging from 20 to 90 degrees for the arms and 0 to 20 for the legs and feet. The neck and torso were more consistent as recordings of these links were perfect in all planes and across all Viewing Angle conditions. Also, the legs and feet were consistent across Viewing Angle conditions, while widely varied over the Plane conditions. Other than these general observations, no distinguishable pattern could be established from the results of the interaction.

The next effect that was evaluated was the Link*Viewing Angle interaction which provided more consistent values across the different factor levels (See Figure 4.26). The neck and torso were recorded perfectly across each Viewing Angle condition while the lower legs and feet averaged between 2 and 15 degrees of deviation. The feet were the most accurately recorded links in this group, with an average deviation of about 2 degrees, and the left lower leg was the least accurately recorded, averaging about 15 degrees of error. Recordings of the arms when viewed from the 'right' viewing angle tended to be more accurate than when viewed from the 'front' or 'oblique' viewing angles, averaging between 25 and 40 degrees. Angular deviations of the arms when viewed from the 'front' and 'oblique' viewing angles ranged from 40 to 50 degrees, except for the left lower arm when viewed from the 'oblique' viewing angle, which averaged nearly 80 degrees of deviation.

The Viewing Angle main effect was evaluated next and although the results were quite similar for each condition, it is important to remember the significant higher-order interactions when interpreting the averaged values (See Figure 4.27). A Neuman-Keuls

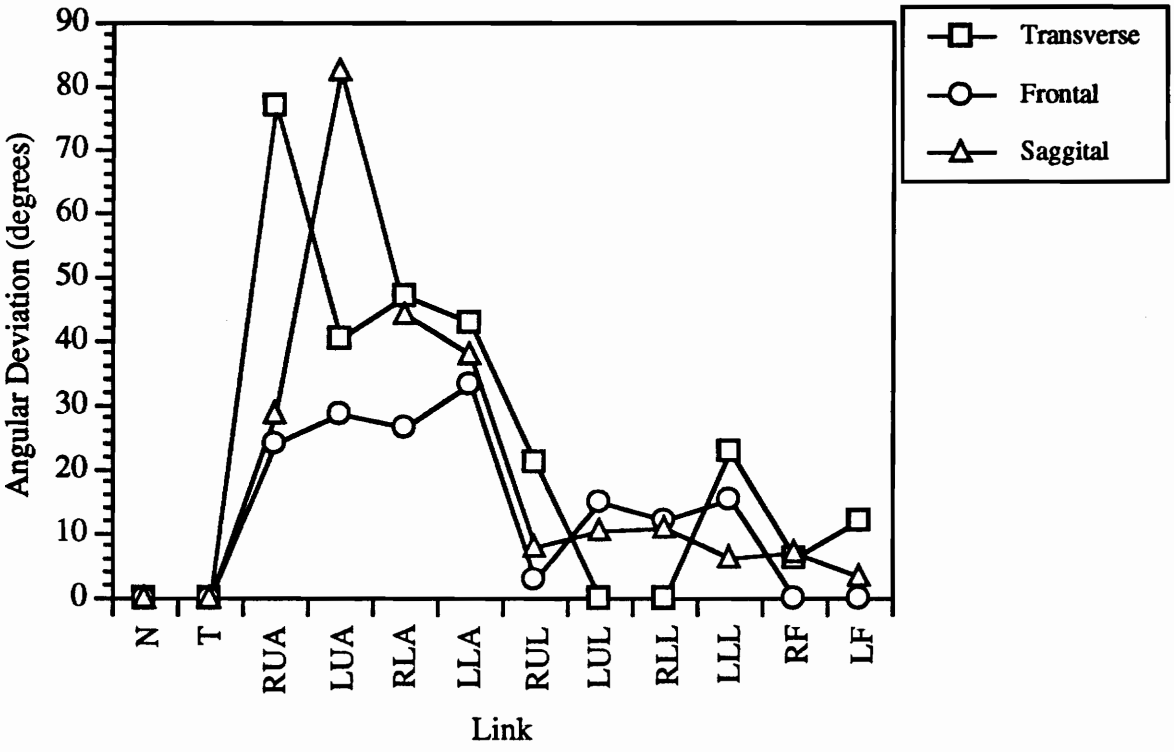


Figure 4.23 Plot of the Plane*Link*Viewing Angle interaction for the 'Front' viewing angle - 'Pushing' posture.

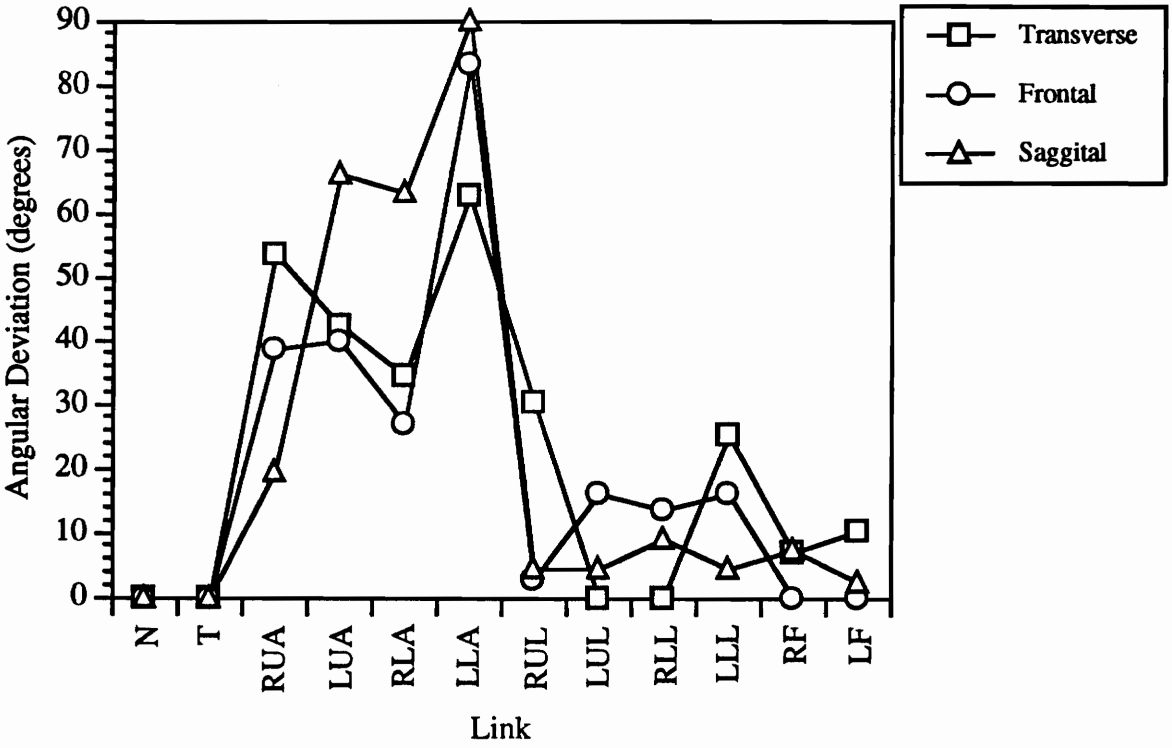


Figure 4.24 Plot of the Plane*Link*Viewing Angle interaction for the 'Oblique' viewing angle - 'Pushing' posture.

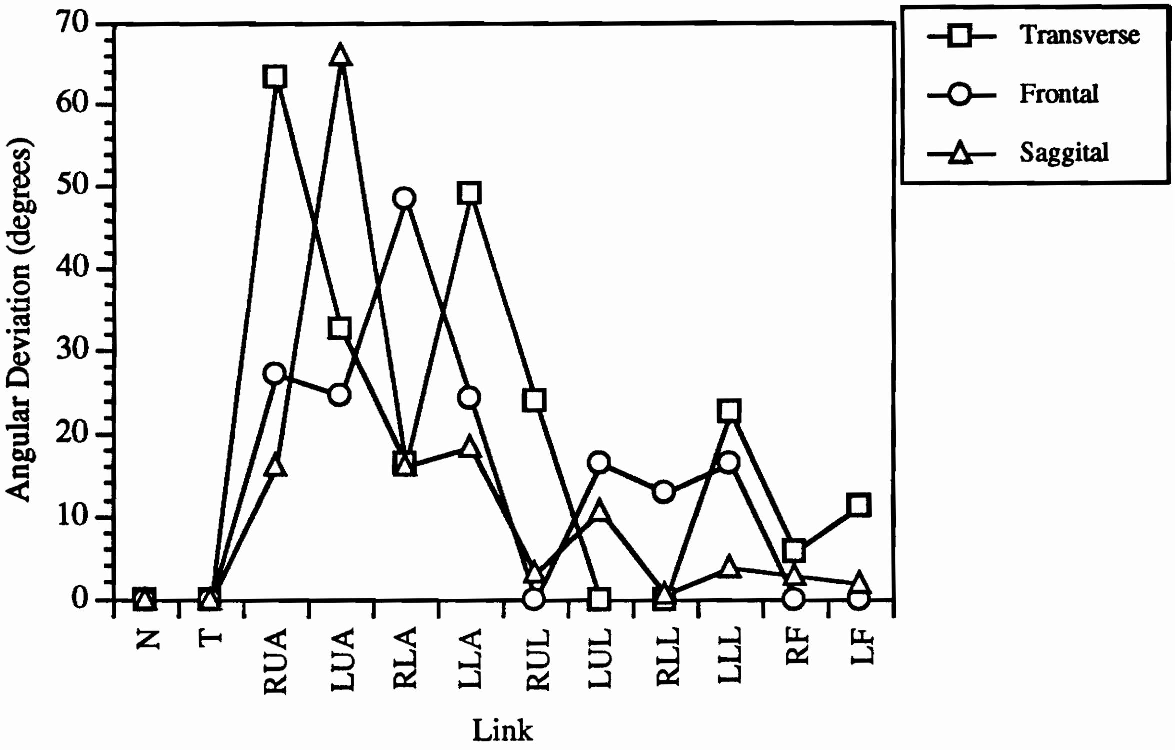


Figure 4.25 Plot of the Plane*Link*Viewing Angle interaction for the 'Right' viewing angle - 'Pushing' posture.

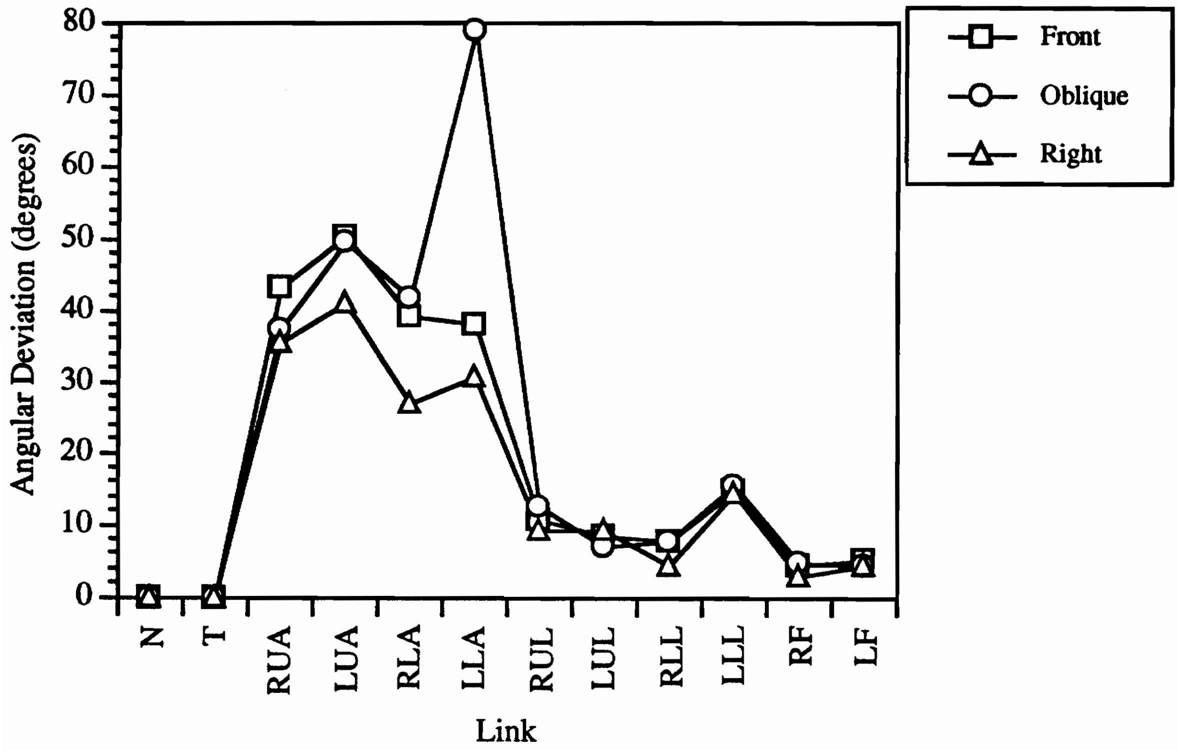


Figure 4.26 Plot of the Link*Viewing Angle interaction - 'Pushing' posture.

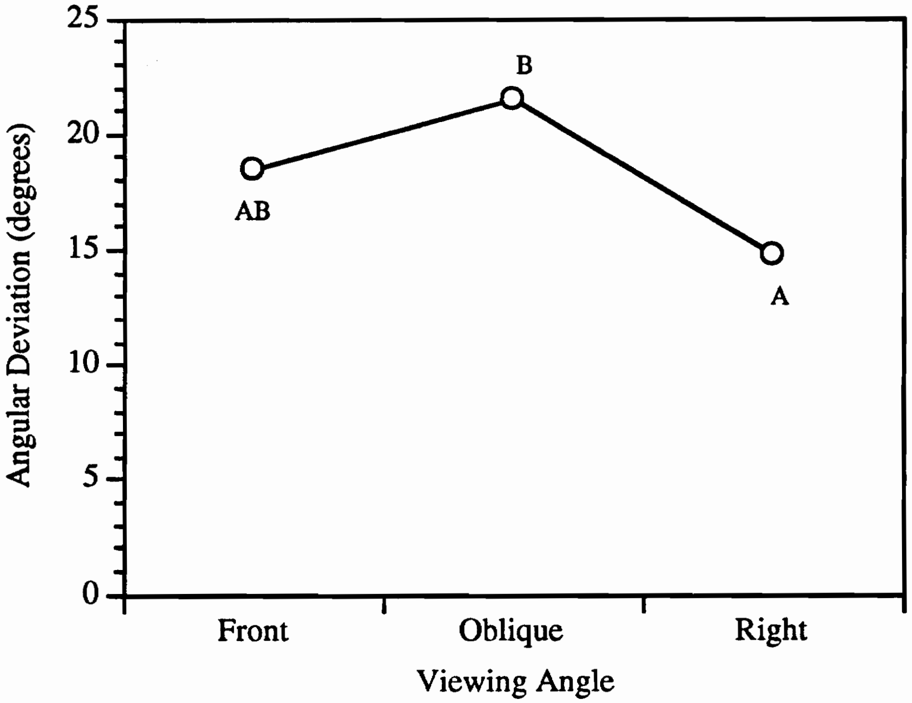


Figure 4.27 Plot of the Viewing Angle main effect - 'Pushing' posture.

analysis was performed to determine the significant differences between the Viewing Angle conditions and the results are presented in Table 4.19. From the table it can be seen that the recordings made when the posture was viewed from the 'oblique' viewing angle were significantly less accurate than when the posture was viewed from the 'right' viewing angle. When the posture was viewed from the 'front' viewing angle, however, the recording errors did not significantly differ from the other two Viewing Angle conditions.

Finally, the Link main effect was evaluated to determine the difference in angular deviations between the individual links, but again, the higher-order interactions should be considered when interpreting the results of this main effect. The plot of the Link main effect is presented in Figure 4.28, and the Neuman-Keuls analysis that was performed to test for significance between the Link conditions is presented in Table 4.20. From the table it was determined that the neck and torso were recorded significantly more accurately than the arms, the right upper leg, and the left lower leg, because they were recorded with 0 degrees of angular deviation. The left upper and lower arms were recorded the least accurately of all the links with average deviations between 47 and 49 degrees. The right upper and lower arms were recorded more accurately than the left upper and lower arms, with average errors ranging from 36 to 39 degrees, but were recorded less accurately than the other links. The feet were recorded with an average error of about 4 degrees and were also more accurately recorded than the right upper and left lower legs.

4.2.5 Effect of Spatial Ability

As mentioned previously, spatial ability was included in the ANCOVA as a covariate to remove its effects from the overall analysis. In other words, if the accuracy of the recordings were correlated with the spatial ability scores, a correction would be

Table 4.19 Results of the Neuman-Keuls analysis of the Viewing Angle main effect - 'Pushing' posture.

Link	Angular Deviation (degrees)	S.D. (degrees)	Significance*
Front	18.43	27.54	A B
Oblique	21.52	32.59	B
Right	14.83	24.25	A

*Levels of the factor with the same letters are not significantly different from each other.

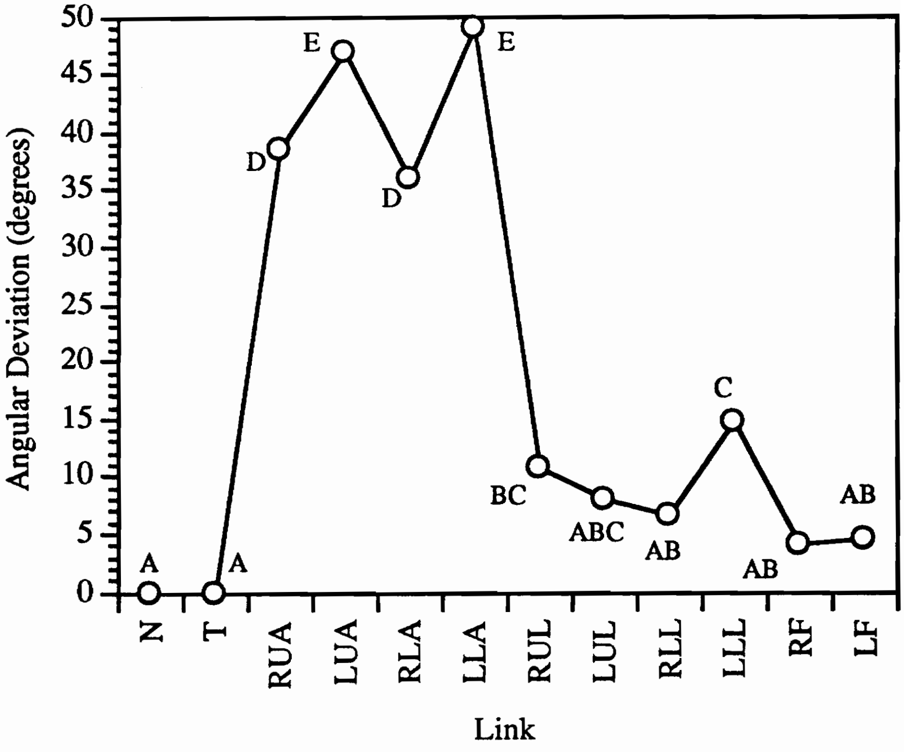


Figure 4.28 Plot of the Link main effect - 'Pushing' posture.

Table 4.20 Results of the Neuman-Keuls analysis of the Link main effect - 'Pushing' posture.

Link	Angular Deviation (degrees)	S.D. (degrees)	Significance*				
Neck	0.00	0.00	A				
Torso	0.00	0.00	A				
Right Upper Arm	38.61	38.19				D	
Left Upper Arm	46.91	35.11					E
Right Lower Arm	35.94	26.74				D	
Left Lower Arm	49.03	44.20					E
Right Upper Leg	10.76	13.09		B	C		
Left Upper Leg	8.09	9.16	A	B	C		
Right Lower leg	6.55	7.75	A	B			
Left Lower Leg	14.70	11.74			C		
Right Foot	4.00	7.22	A	B			
Left Foot	4.51	5.80	A	B			

*Levels of the factor with the same letters are not significantly different from each other.

made by the ANCOVA to account for the variation in ability of the subjects. Therefore, when an interaction including the spatial ability covariate was significant, it indicated that spatial ability was a good predictor of accuracy for that interaction. If the spatial ability covariate was significant as a main effect, it indicated that the accuracy of the recordings in general were dependent on the spatial ability of the subjects.

The ANCOVA for the angular deviation data did not reveal any significant interactions involving spatial ability, nor were any present when the five smaller ANCOVAs were run for the Posture conditions. These results indicated that there was no correlation between spatial ability and accuracy, but to be confident a regression was performed to illustrate the relationship (See Figure 4.29). As can be seen from the regression plot, accuracy does increase as spatial ability increases, but with a correlation coefficient (R^2) of 0.008 indicating that there was no significant relationship between spatial ability and accuracy.

4.3 Speed of Response

Data were also collected to determine the time it took for a subject to record a posture using the computerized method. Subjects were timed from the moment a posture was presented on videotape to the point at which they finished recording and were ready for the next posture. This time included both the observing and recording actions of the subjects, and a separate time was collected for each posture. The average times to record a posture ranged from 2.55 to 5.98 minutes, and the average times for each Posture condition, as well as each Viewing Angle and Gender condition are presented in Table 4.21.

An ANCOVA was conducted on the speed of response data, and the independent variables included Gender, Viewing Angle (3 levels), and Posture (5 levels). As with the accuracy data, spatial ability was included as a covariate. The ANCOVA table is

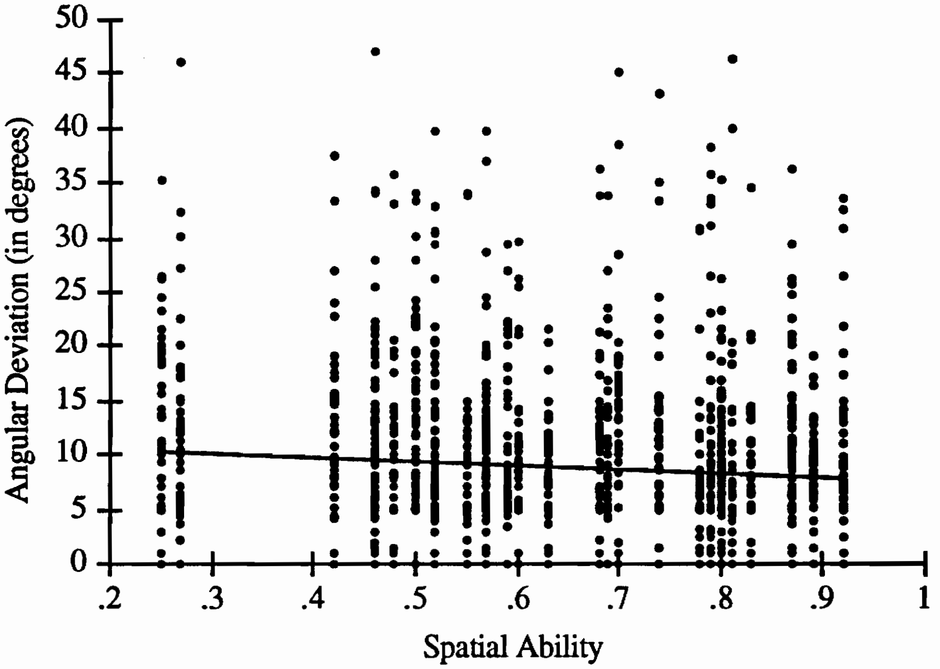


Figure 4.29 Regression plot of Spatial Ability versus Angular Deviations.

Table 4.21 Average time (in minutes) for the Gender, Viewing Angle, and Posture conditions.

Gender		Viewing Angle		Posture	
Male	4.23	Right	3.57	Sit	4.43
Female	3.85	Oblique	4.28	Push	5.98
		Front	4.28	Lift	2.55
				Reach	3.66
				Crouch	3.59

presented in Table 4.22 and it was demonstrated that no main effects or interactions were significant.

As with accuracy, spatial ability was included in the ANCOVA as a regressor variable to correct for the influence of the subjects' spatial ability on the speed of their recordings. None of the effects from the ANCOVA that involved spatial ability were significant, indicating that this ability does not influence the speed at which postures are recorded using the method. As a final test of the relationship, a regression was performed to determine if there was a significant correlation between spatial ability and speed of response (see Figure 4.30). As can be seen from the regression plot, the time taken to record a posture decreases slightly as spatial ability increases, but with a correlation coefficient (R^2) of 0.09, indicating there was no significant relationship between spatial ability and the time necessary to record posture.

Table 4.22 ANCOVA Source table for the speed of response data.

Source of Variance	df	SS	MS	*F**	*p*	G-G	H-F
Between							
G	1	5.341	5.341	0.569	0.4583		
VA	2	16.876	8.438	0.899	0.4208		
G * VA	2	31.899	15.949	1.699	0.2049		
SA	1	0.159	0.159	0.017	0.8976		
Subject(G,VA)	23	215.858	9.385				
Within							
P	4	23.158	5.789	2.442	0.0522	0.0585	0.0522
P * G	4	15.810	3.953	1.667	0.1643	0.1706	0.1643
P * VA	8	19.063	2.383	1.005	0.4377	0.4350	0.4377
P * G * VA	8	7.766	0.971	0.410	0.9125	0.8993	0.9125
P * SA	4	5.297	1.324	0.559	0.6932	0.6769	0.6932
P * Subject(G,VA)	92	218.076	2.370				

Dependent: Speed of Response

Epsilon Factors for df Adjustment

	G-G Epsilon	H-F Epsilon
P	.909	1.383

*The denominator (error term) used for each *F*-ratio was the last term in each grouping of the sources of variation.

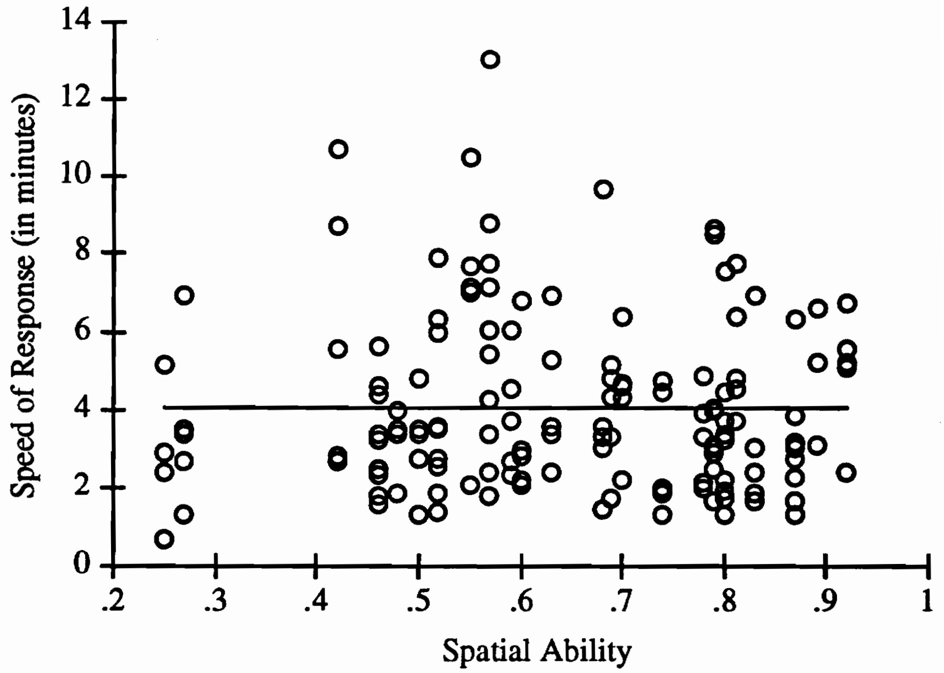


Figure 4.30 Regression plot of Spatial Ability versus Speed of Response.

5. DISCUSSION

5.1 Objectives

The four objectives were defined in the Introduction section. These objectives stated that a posture recording method should:

1) be usable by people with little or no training in anatomy or ergonomics;
2) be relatively fast and easy to use;
3) provide an accurate representation of the posture observed which could also be reliably recreated;
4) and be coded easily into computerized format.

By creating a posture method that was easy to use, it was hypothesized that it would produce relatively fast posture recordings (45-60 seconds). More importantly, however, the method was designed to be comprehensive enough to allow for the accurate recording of any posture that was achievable given the range of motion of the human body, and given the cognitive and perceptual limitations of the human recorder (Fisher and Tarbutt, 1988). In addition, the recording method was designed to be reliable enough so that the posture could be accurately recreated from the recorded information (Corlett et al., 1979). Finally, it was advantageous for the method to be easily interfaced with a computer for data reduction, storage, and analysis (Keyserling, 1986a).

The results of the validation experiment indicated that most of these objectives were met. All subjects in the experiment had little or no training in anatomy or ergonomics, and they produced relatively accurate recordings after 15 minutes of training, indicating that the method could be learned by people with no experience in posture recording. The speed with which the postures were recorded was a longer than expected (2 to 6 minutes), but it is likely that with more training and experience, the subjects would have produced faster times. The method was also found to be very accurate, with average errors remaining less than 20 degrees for each posture overall. It is likely that with more training and experience, the subjects would have produced more accurate results. All the analyses were performed using the data stored by the program, indicating that the information can be easily converted into computerized format for storage, retrieval, and analysis.

5.1 Inter-Observer Reliability

When a Kappa coefficient was calculated for a particular group, it indicated how often the subjects in that group selected the same category for a given link and posture. More specifically, it was the ratio of the proportion of times the subjects agreed to which category each link belonged, to the total proportion of times the subjects could have agreed, corrected for agreements expected to have occurred by chance. As presented in Table 4.2 all the calculated coefficients calculated were significant at the $p < .001$ level which indicated that the subjects produced reliable responses among one another.

As indicated in the Results section, the Kappa coefficients were significant but only indicated moderate reliability. Individual subject differences not accounted for in the study could have had an effect on the reliability among subjects. For example, the spatial ability tests used only tested the mental rotation component of spatial ability. The other two components, spatial orientation and spatial transformation, might have had an effect on the categories chosen by the subjects, providing a better explanation for the differences in the subject's responses.

Also, possible misinterpretations during the training might have influenced the subjects to record postures differently. For example, some subjects were under the impression that the orthogonal views in the program were supposed to be oriented in the same view as the posture presented on the videotape. Some of these subjects indicated this during the training and were corrected, but others may have not mentioned it during the training, and recorded the experimental postures with the wrong intent.

5.2 Accuracy

The results of the accuracy tests indicated that the method produced moderately accurate results. The PI coefficient and Gamma statistic analyses indicated that the recordings made by the subjects were significantly similar to the 'correct' recordings for each posture over all conditions, but there were some limitations to these analyses. The angular deviation data provided a more quantifiable measure of accuracy, and on the average, errors generally remained below 30 degrees. In general, the accuracy of the method proved to be moderate with subjects generally producing results no more than 2 positions away from the 'correct' position. The ANCOVA results demonstrated that in many cases the accuracy of the recordings depended on the Posture, Plane, Viewing Angle, and/or Link conditions under which the recordings were made. The following discussion of the accuracy results begins with an evaluation of the different methods of measuring accuracy, followed by some potential reasons for the inaccuracy of the recordings, an explanation of the limitations of the PI coefficient and Gamma statistic techniques, and some general conclusions about the ANCOVA results.

5.2.1 Measuring the Accuracy of Posture Recordings

This Thesis presented two techniques for measuring the accuracy of posture recordings, and discussed the advantages and disadvantages of using a third. Essentially, two measurement units were considered including the angular orientation of the segments and the three-dimensional position of each joint or reference point. When a link was recorded by an observer, its angular orientation in a specific plane was estimated and compared to the 'correct' orientation of the link in that plane. The difference between the two angles provided the measure of accuracy for that particular link. For the second measure of accuracy, the position of a joint on the screen was to be determined and compared to its 'correct' position. Then the differences in three-dimensional distance between the two positions would be calculated to provide another measure of accuracy. This second measure of accuracy was considered, but not used because of some limitations of the data and the manner in which the postures were recorded.

Angular information is useful because a limb can be evaluated independently of the other limbs since its orientation does depend on the orientation of the other links. This is not true for the positional information because if a link such as the torso is incorrectly recorded, it is likely that the shoulders, elbows and wrists will be in the wrong position in space, even if they are in the correct angular orientation. Also, angular information can be evaluated regardless of the length of the links. Positional data can only be accurately recorded if the postural representation has the same anthropometric characteristics as the videotaped model. If the characteristics are different, there is really no way for a subject to accurately record the positions of the joints. Angular information can also be misleading however because if a link is pointed almost directly towards an observer in a particular plane, a small positional deviation can result in a large angular deviation.

Each measurement provides important and unique information about the accuracy of the recordings, but neither provide a complete description. It would probably be more useful to calculate the three-dimensional angles to define the deviation between the subjects' responses and the true positions of the links. This technique essentially combines both the positional and angular deviations into one measure.

5.2.2 Potential Reasons for the Inaccurate Recordings

It is possible that the recording errors were simply due to the inability of the subjects to determine the 'correct' orientation of the links, but it is likely that other factors were involved. The characteristics of the method and the nature of the experiment may have produced situations for the subjects that reduced their ability to accurately record the postures. Regardless of their level of influence, these factors should be considered when reviewing the results of the accuracy analyses.

Several factors that could have influenced the accuracy of the recordings relate to the physical characteristics of the links themselves, and the anatomical inaccuracies of the postural representation. The stick-figure model does not represent the body accurately because the links are not actually straight lines, and the shape of the bones within the links, as well as the surrounding flesh, can make it difficult to determine where the imaginary line should be drawn to determine the 'correct' orientation of a link.

For example, the torso is a difficult link to measure because the spine is composed of many joints, and the postural representation only divides the back into two segments. Therefore, when the back was curved in the frontal or sagittal planes, it may have been difficult for the subjects to determine the 'correct' orientation for the torso. The foot is another example because on the stick figure model the ankle appears to be hinged at the back of the foot, when in actuality the foot bones extend in 'front' of and behind the ankle joint. Also, the foot is not a straight link when viewed from the sagittal plane, as it is represented on the template, and is normally curved at the arch. These physical characteristics of the foot may have made it difficult for the subjects to perceive the appropriate straight line through the foot that was necessary to determine its angular orientation in the sagittal plane.

The arms and legs are more similar to the stick-figure representation than the other links because their bones are relatively straight, but the surrounding flesh still might have made it difficult to determine the correct line of orientation. For example, at both the shoulder and hip joints, it may have been very difficult to determine where the link began, which was necessary to determine the orientation of the imaginary line. To further complicate this, the shoulder and hips were obscured by the shirt and shorts worn by the model, possibly making it even more difficult to determine the location of the shoulder and hip joints.

Another factor that could have influenced the accuracy of the recordings occurred when a link was pointing roughly straight toward or away from an observer. For example, in the frontal plane of the 'sitting' posture, the arms are pointed almost directly at the observer, making both the upper and lower arm segments appear much shorter than they actually are. It is possible that viewing links from such extreme perspectives might have made it more difficult for the subjects to determine the orientation of the links. An important issue to consider, however, is that the incorrect adjustment of links in these orientations might only result in a small positional deviation of the link itself. In this case, the angular deviations of the link might not be good predictors of the accuracy of the recordings.

Another situation that may have reduced the accuracy of the recordings occurred when links were obscured by other links. For example, when the 'pushing' posture was viewed from the 'oblique' viewing angle, the lower left arm was obscured by the right arm (See Figure 3.7 (b)). The average angular deviations of this link were nearly 80 degrees when viewed from this viewing angle, and should probably be ignored because the link was obscured. There were a few other occurrences of links being obscured by other links and should be considered when interpreting the accuracy results.

Finally, subjects might have attempted to place the joints in the 'correct' positions instead of adjusting the angles of the links. This would produce errors because the postural representation did not have the same anthropometric characteristics as the videotaped model. For example, in the videotaped version of the 'crouching' posture, the hands are touching the floor, but if the posture is recorded using the computerized template with the 'correct' angular orientations of the links, the arms do not reach as far down as the feet. If the subjects attempted to match the height of the feet and the ends of the lower arms, there would be an error in the angular orientations of some of the links.

5.2.3 PI Coefficient and Gamma Statistic

The PI coefficient measured accuracy in much the same way the Kappa coefficient measured reliability because it compared responses between observers. It measured the accuracy of the responses by considering one of the observers to be the accurate recordings for a particular experimental group, and the other to be the subjects' responses for that group. It was also similar to the Kappa coefficient because responses made by the subjects that did not fall into the 'correct' categories were considered wrong, no matter how close they were to those 'correct' categories. This made the PI coefficient a very strict test of accuracy.

The Gamma Statistic was calculated in much the same manner as the PI coefficients, but provided an indication of the variance of the corresponding PI coefficients. This allowed a significance to be placed on the PI coefficients to determine if the responses of each experimental group were significantly similar to the 'correct' categories. Like the Kappa coefficient, the Gamma statistic simply determined the likelihood that the subjects responses were more accurate than should have occurred by chance so a significant result can be obtained when the accuracy is only moderate.

Table 4.4 shows that the Gamma values for each experimental group are all significant at the $p < .001$ level indicating that the corresponding PI coefficients (see Table 4.4) are significantly accurate. Similar to the Kappa coefficient, a PI coefficient of 1.000 would indicate perfect accuracy, but the calculated coefficients ranged from .236 to .677, indicating only moderate accuracy. Possible reasons for the significance of these less-than-perfect coefficients are the same as those discussed for the Kappa coefficients, but with more emphasis placed on the calculations themselves.

When the PI coefficients were calculated, the only consideration was whether or not the 'correct' categories were chosen. Any response outside the 'correct' category was considered wrong and was not included in the calculations, other than to determine the likelihood of responses occurring by chance. This means that there was no difference in the PI coefficients of two groups as long as they had an identical number of responses in the 'correct' categories. Since there was no consideration for incorrect responses, those groups with responses that fell closely outside the 'correct' categories had a low variance and therefore a greater likelihood of significance. Since all of the calculated PI coefficients were significant at the $p < .001$ level, it can be assumed that the accuracy was somewhat greater than indicated by the PI coefficients. Also, an inspection of the individual subject matrices shows that the groupings of the responses usually spanned a range of two to four categories (an error of 15-45 degrees) supporting the claim that the variances are low.

5.2.4. Angular Deviation Data

From the deviation values presented in Table 4.7, it was demonstrated that the subjects produced average errors no greater than 30 degrees, meaning that they chose positions on the targets that were no more than 2 positions away from the 'correct' positions. It was also implied from these results that to obtain the most accurate recordings, the postures should be viewed from the 'right' instead of the 'front' or 'oblique' viewing angles. Also, it was shown that more complex postures involving a twisting of the back and non-symmetrical links, such as the 'reaching' and 'pushing' postures, were likely to be recorded less accurately than more symmetrical and uncomplicated postures, such as the 'crouching', 'lifting', and 'sitting' postures. The results also indicated that postures would be more accurately recorded in the frontal plane than in the transverse or sagittal planes. And finally, it was suggested that in general the arms would be the least accurately recorded, followed by the legs and feet, and that the neck and torso would usually be very accurately recorded.

The ANCOVAs revealed, however, that the magnitude of the errors often depended on an interaction of the posture and/or link the subjects were recording, the plane they were making the recordings in, and/or the viewing angle from which they were viewing the posture. For example, in all cases except for the 'sitting' and 'reaching' postures, the three-way interaction of Plane*Link*Viewing Angle was significant, indicating that the accuracy of the recordings depended on the link that was being recorded, the plane in which it was being recorded, and the viewing angle from which the posture was observed. The ANCOVA of the 'sitting' posture revealed that viewing angle did not have an effect on the accuracy of the recordings for that posture, but the Plane and Link conditions did.

The 'crouching' posture was the most accurately recorded posture averaging about 5 degrees of deviation, and the Plane main effect provides the best summary of the results. This effect demonstrated that almost all of the errors were made in the sagittal plane. A closer examination of the 'crouching' posture (See Figure 3.10 (a)-(c)) shows that in the frontal and transverse planes, the links are all in vertical or horizontal orientations. This strengthens the assumption that non-orthogonal links are recorded less accurately than orthogonal links (Malone, 1991). Apparently, it is easier for subjects to accurately record a link when it is in a vertical or horizontal orientation. Finally, the recordings were more accurate when this posture was viewed from the 'right' viewing angle which essentially presented the posture in the sagittal plane. This indicates that to record non-orthogonal links the most accurately, it is best to view the posture from the plane where the non-orthogonal orientations occur.

The next most accurately recorded posture was the 'lifting' posture which averaged about 7 degrees of angular deviation, and in this case, the Plane*Link interaction provided the best indication of the overall results (See Figure 4.12). This interaction also demonstrated that links in non-orthogonal orientations were recorded less accurately. In the frontal plane, all links except the upper legs were presented in orthogonal orientations, and were all recorded nearly perfectly, as were all the links in the transverse plane except the upper legs and the feet. In the sagittal plane, only the lower legs and feet were presented in orthogonal orientations and they were recorded almost perfectly, while the rest of the links were recorded with 5 to 18 degrees of angular deviation.

The 'sitting' posture was recorded with an average of about 12 degrees of angular deviation, and was the third best recorded posture. The Plane*Link interaction provided the best indication of the results which again demonstrated that links in non-orthogonal orientations are usually recorded less accurately than links in orthogonal orientations. In all three planes, the arms were in non-orthogonal orientations and were generally the least accurately recorded links. This was also the case for the lower legs, except for in the transverse plane where the errors were much greater, probably because in this plane the lower legs were pointing almost directly away from the observer. The other links were recorded very accurately in all planes except for the feet, which were bent severely in the sagittal plane.

The 'reaching' and 'pushing' postures were the least accurately recorded postures with average angular deviations of about 15 and 18 degrees, respectively. These two postures were not symmetrical, had very few orthogonally oriented links, and involved a twisting of the back which probably made it more difficult to record these postures (See Figures 3.9 (a)-(c) and 3.7 (a)-(c)). In both cases, the Link main effect provided the best summarization of the results (See Figures 4.21 and 4.27).

Because of their non-orthogonal orientations and the twisting of the back, the arms were the least accurately recorded links. If the subjects incorrectly twisted the back or forgot to twist it at all, they might have become disoriented and used the orientation of the torso instead of the hips to determine where each plane was oriented. This could have easily caused the arms and entire upper body to be recorded very inaccurately and might have been the reason that these postures were recorded less accurately than the other postures. Since the back was twisted more extremely in the 'pushing' posture than in the 'reaching' posture, it is possible that errors in twisting the torso were the reason for the 'pushing' posture being less accurately recorded than the 'reaching' posture. The only other major difference in accuracy between the two postures occurred with the feet, which were recorded much more accurately for the 'pushing' posture than for the 'reaching' posture. This was probably because the feet are in non-orthogonal orientations in the 'reaching' posture and orthogonal positions in the 'pushing' posture.

An additional analysis was performed to provide an overall view of the accuracy of the subjects responses. Since the subjects were only allowed to choose from a discrete number of positions for each link, averaging the angular deviations might not be appropriate. A histogram was generated to provide an overall view of the accuracy of the subjects' responses for each link in each plane of each posture (see Table 5.1 and Figure 5.1). The histogram shows that approximately 70 percent of the total responses ranged between 0 and 15 degrees of angular deviation, which indicates that most responses were only one position away from the correct position. Over 90 percent of the responses fell between 0 and 45 degrees of angular deviation, or a maximum of three positions away from the correct position.

5.3 Speed of Response

The average times for recording a posture ranged from 2.55 to 5.98 minutes indicating that the method is comparable to existing techniques (Malone, 1991). These results do not meet the objectives of 45-60 seconds, but since the method was designed to

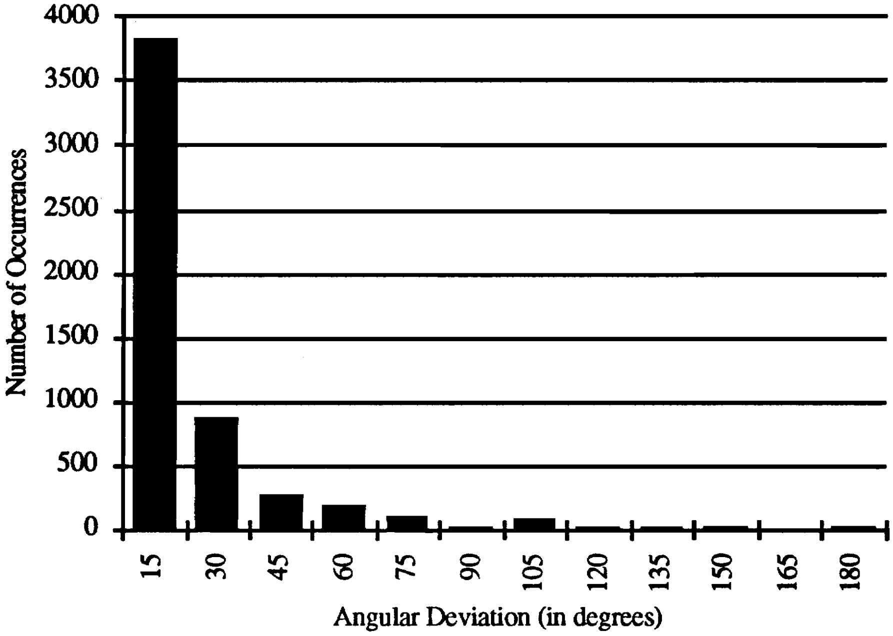


Figure 5.1 Histogram of the number of occurances of angular deviations for each link in each plane of each posture.

Table 5.1 Results of the Neuman-Keuls analysis of the Viewing Angle main effect - 'Pushing' posture.

Angular Deviation (degrees)	Total Number of Occurances	Percentage
15	3824	70.81
30	866	16.04
45	271	5.02
60	193	3.57
75	102	1.89
90	20	0.37
105	77	1.43
120	10	0.19
135	12	0.22
150	12	0.22
165	3	0.06
180	10	0.19

model postures from videotape or still photographs, it is really not that important that the postures be recorded quickly. The ANCOVA in Table 4.21 revealed no significant main effects or interactions indicating that none of the variables that were considered had an effect on the time necessary to record a posture. Most likely, with additional experience and training, the subjects would have produced faster recording times.

5.4 Spatial Ability

The results of the ANCOVAs indicate that spatial ability had no effect on the accuracy of the recordings or the time it took to record them. As stated before, this could again be due to the fact that the only one of the three components of spatial ability was tested, but it could also mean that spatial ability does not have an effect on the time it takes to record posture using this method.

6. CONCLUSIONS

Several conclusions can be drawn from the research based on the results of the inter-observer reliability, accuracy, speed of response, and spatial ability analyses.

1. In general, the results indicate that the method was usable by people with little training in ergonomics or anatomy.

2. The analyses also demonstrated that the data is readily stored in computerized format and can be easily retrieved.

3. The computer-based method was determined to be reliable among subjects, although the reliability appeared to be only moderate.

4. The recordings of the postures were accurate, but not to the level required to record posture for detailed ergonomic analyses.

5. Links in orthogonal orientations are generally more accurately recorded than links in non-orthogonal orientations.

6. Accuracy can be measured in two way, but neither provide a complete assessment of the recordings. The angular orientations of the limbs and the positions in space of the joints should both be considered when attempting to determine the accuracy of postural recordings.

7. The time taken to record the postures was longer than expected, but was adequate for the type of posture recording situations the method was designed.

8. Spatial ability had no effect on the accuracy of the recordings or the time required to record the postures.

The level of accuracy of the method and the speed with which postures were recorded may be less than adequate for some situations, but even in its present state the method should be very useful for providing moderately accurate posture recordings in relatively short periods of time.

7. SUGGESTIONS FOR FUTURE RESEARCH

Because of the success of this experiment, modifications should be made to the computer-based method in an attempt to increase the accuracy of the recordings and decrease the time needed to record a posture. To accomplish these goals, several modifications are suggested:

1. Create a more realistic postural representation by enfleshing the links,
2. Provide restricted ranges of movement for the links to reduce the complexity,
3. Increase the amount of training to allow the subjects to become more practiced at using the method.

Also, the area of spatial ability was not fully explored and could be tested in future experiments. The spatial relations and spatial transformation components should be tested to determine their relationship to both the accuracy and speed of posture recordings.

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APPENDIX A: Preliminary Instructions

A Computer-Based Method for Recording Three-Dimensional Body Postures

Thank you for participating in this research. This study is being conducted by the Industrial Ergonomics Laboratory of the Human Factors Engineering Center at Virginia Polytechnic Institute and State University. The experiment is being run by Greg Stewart as part of his Master of Science thesis work, and is being supervised by Dr. Jeffrey C. Woldstad, a professor in Industrial and Systems Engineering.

The effects of human posture on work place efficiency and safety are of great concern. To asses the ergonomic effects of a given posture on the human body it is first necessary to record the posture for future reference and analysis. A precise description of the posture a person adopts while performing an activity provides essential information for determining the effects that activity has on the person's musculo-skeletal system.

This study tests a computer-based method for recording three-dimensional posture that is intended to be accurate, fast, and easy to use. The program currently runs on a PC compatible computer system and has been designed to assist the analyst in recording postural information from a videotape or still picture record of the work posture. The testing procedure will attempt to determine if the method is an effective means of recording three-dimensional postures.

The method uses relatively simple two- and three-dimensional graphics to represent the position of the subject. A three-dimensional figure is provided so that it can be manipulated and directly compared to the observed image. Front, Back, Right, Left, and Top views of the figure are also provided, which can be adjusted to mimic the observed posture. A mouse is used to manipulate the links.

Prior to the actual experiment, subjects will be asked to complete two tests of spatial ability. The scores will be kept confidential, and only used to determine the effect of spatial ability on the task of posture recording. The tests should last a total of 20 minutes.

Also, prior to the experiment, each subject will undergo a training session designed to instruct the subjects on how to use the method. This period should last approximately 15 minutes.

Your part in the actual experiment will involve observing 5 postures captured on videotape, and recording them using the method. The experimenter will present the videotaped postures over a television monitor, which will be located next to the computer monitor used to present the posture recording program. This part of the experiment is expected to take 30 minutes.

The data collected by the computer will be analyzed by September 15th, 1992 to determine if the computer-based method is adequate for recording working postures captured on videotape. Your name will be removed from your data as soon as the experiment is completed. The results will be made available to you if you desire. The research team members for this experiment are:

Greg Stewart, Graduate Student
Dr. Jeff Woldstad, Professor, ISE

If you have any concerns about the way in which you have been treated, or the manner in which the experiment is conducted, and do not wish to express these concerns directly to the experimental team, you may contact the University's Institutional Review Board Chairperson, Dr. E. R. Stout, at (703) 231-9359.

Thank you again for agreeing to participate in the experiment. We hope you will find it interesting and educational.

APPENDIX B: Informed Consent Form

Informed Consent Form

This form constitutes informed consent by you to participate in this study. Please read it carefully, as well as the attached sheet, and then sign below.

Your rights as a subject are:

1. It is your right to withdraw from the study at any time for any reason.
2. Any of the research team members will answer any questions that you may have, and you should not sign this for until you have understood fully all of the terms involved.
3. You have the right to see your data and withdraw them from the study if you so desire. Please inform the experimenter immediately of this decision, as the data will be handled anonymously, and will not be possible to track after the experimental session is over.
4. You have the right to be informed of any risks or discomforts in this research. No risk or discomfort is anticipated, however.

If you wish to receive a synopsis of this study, please include your address under the signature line below and a copy will be sent to you. If after reading the synopsis you would like a more detailed report, please contact one of the team members and a full report will be made available to you.

Should any further question arise, please contact one of the team members. If you have any concerns about the way the experiment is being conducted or the way you are being treated, you may contact Dr. Stout, the Institutional Review Board Chairperson, at the number on the previous page.

Your participation is greatly appreciated, and we hope that you will find the study a pleasant and interesting experience. Your signature below indicates that you have read this document in its entirety, that your questions have been answered, and that you consent to participate in the study described.

I understand that in the case of physical injury, no medical treatment or compensation are offered by the research program, or by VPI & SU.

I understand that for my participation I will receive payment at a rate of $5.00 per hour, and it is estimated that the entire experiment will last approximately 1 hour for a total of $5.00.

I understand that the results of my efforts will be recorded. I consent to the use of this information for scientific purposes and understand that any records of my participation in this study may be disclosed only according to federal law, including the Federal Privacy Act, and its implementing regulations. This means that personal information will not be released to any third party without my explicit consent.

I, ______________________, am participating in this research on a completely voluntary basis. No one has coerced or intimidated me to participate.

Gregory Stewart has adequately answered any and all of my questions I have asked about this study, my participation, and the procedures involved, which are described in the instruction form, which I have signed.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE UNDER THE CONDITIONS DESCRIBED ABOVE.

Signature: ________________________________ Date: _______________
and SSN

Address:____

____

Signature: ____________________________ Date: _______________
of Witness

APPENDIX C: Instructions for Use

Computer-Based Posture Recording

Instructions for Use

The method you are about to use has been designed to enable the user to record three-dimensional postures from working postures captured on videotape. A computer and a mouse input device will be used to enter the postures and save the recorded postural information. A television monitor and VCR will also be used to present the postures to be recorded. In the actual experiment, the experimenter will operate the television monitor and VCR to present the postures. The posture recording program is presented on the computer screen, and both the mouse and the keyboard will be used to input the postural information.

There are seven boxes on the screen, six of which enclose the different views, and one which contains the enlarged version of whatever view is to be manipulated. The five of the six representative views (Front, Back, Left, Right, Top) can be enlarged for manipulation of the specific links. The Three-Dimensional view can be rotated around the x, y, and z axes, but the individual limbs cannot be manipulated. The postural representations can only be manipulated while in the enlarged box.

When a view is enlarged, each link can be manipulated by selecting the joint with a mouse click (left button) to activate a circle of 24 dots surrounding the joint. The associated link, and the links that will move with it will be highlighted as well. Then, using the right button on the mouse, any of the dots may be selected to rotate the link into that position around the joint. As each link is manipulated, the smaller representation incorporates the new position, and, when another view is selected, all views incorporate the changes.

If joints are overlapping in a particular view, a menu is provided, when one of the joints is selected, that lists the joints that can be manipulated. The user simply selects one of the joints from the list with a mouse click (right button) and the circle of dots for that particular joint will be activated, and the associated links will be highlighted.

When the Three-Dimensional view is selected, it can be rotated around an axis by clicking (left button) on the arrows located on either side of the letters indicating the axis to be rotated around.

To record a posture, it is first necessary to rotate the Three-Dimensional view into the same perspective as the posture being observed. This will provide a reference for the user to look at whenever there is a question about the accuracy of a particular manipulation. If a link is rotated in one view, but it is hard to determine if it has been rotated correctly, the Three-Dimensional view can be referred to, to determine the if the link matches the observed posture.

The next step is to determine the view that is closest to the perspective of the observed posture. This will provide the user with the best view to record the posture. The view is enlarged by a mouse click (left button) anywhere in the box enclosing that particular view. When the view is enlarged, every link that needs to be adjusted should be manipulated at this time, using the procedure mentioned above.

If the user decides to select a new view, but does not want to incorporate the new changes made, the escape button can be selected with a mouse click (left button) to leave the current view without incorporating any of the changes.

Then another view must be selected, and every link that needs adjusting must be manipulated, to create a three-dimensional record of the posture. At any time, the user can select the three-dimensional view to compare the manipulated posture to the observed posture. Also, any other view may be selected, if, for example, the user feels that a particular link might be seen easiest from a third view.

After at least two views have been manipulated, and the three-dimensional representation looks as close as possible to the observed posture, the user will press the done button to save the postural information.

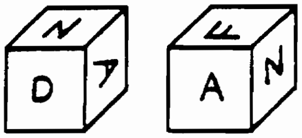
Then the experimenter will present the next posture and the procedure will be repeated. Nine postures will be recorded in the actual experiment, and it is suggested that the subjects attempt to record each posture as quickly as possible, without sacrificing accuracy.

APPENDIX D: Spatial Ability Tests

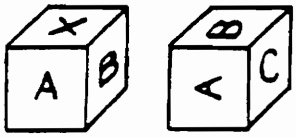
Name ____

CUBE COMPARISONS TEST -- S-2 (Rev.)

Wooden blocks such as children play with are often cubical with a different letter, number, or symbol on each of the six faces (top, bottom, four sides). Each problem in this test consists of drawings of pairs of cubes or blocks of this kind. Remember, there is a different design, number, or letter on each face of a given cube or block. Compare the two cubes in each pair below.



S ☐ D ■



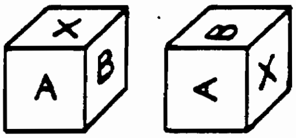
S ■ D ☐

The first pair is marked D because they must be drawings of <u>different</u> cubes. If the left cube is turned so that the A is upright and facing you, the N would be to the left of the A and hidden, not to the right of the A as is shown on the right hand member of the pair. Thus, the drawings must be of different cubes.

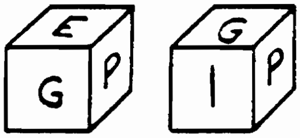
The second pair is marked S because they could be drawings of the same cube. That is, if the A is turned on its side the X becomes hidden, the B is now on top, and the C (which was hidden) now appears. Thus the two drawings could be of the same cube.

<u>Note</u>: No letters, numbers, or symbols appear on more than one face of a given cube. Except for that, <u>any</u> letter, number or symbol can be on the hidden faces of a cube.

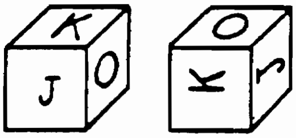
Work the three examples below.



S ☐ D ☐



S ☐ D ☐



S ☐ D ☐

The first pair immediately above should be marked D because the X cannot be at the peak of the A on the left hand drawing and at the base of the A on the right hand drawing. The second pair is "different" because P has its side next to G on the left hand cube but its top next to G on the right hand cube. The blocks in the third pair are the same, the J and K are just turned on their side, moving the O to the top.

Your score on this test will be the number marked correctly minus the number marked incorrectly. Therefore, it will <u>not</u> be to your advantage to guess unless you have some idea which choice is correct. Work as quickly as you can without sacrificing accuracy.

You will have <u>3 minutes</u> for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP.

DO NOT TURN THE PAGE UNTIL YOU ARE ASKED TO DO SO.

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Page 2

Part 1 (3 minutes)

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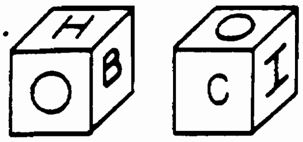

S ☐ D ☐

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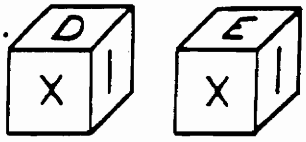

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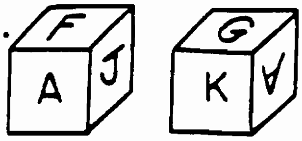

S ☐ D ☐

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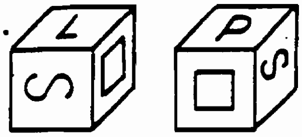

S ☐ D ☐

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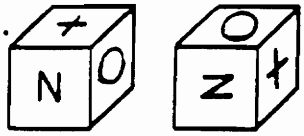

S ☐ D ☐

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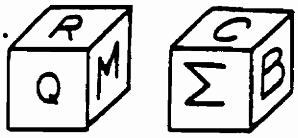

S ☐ D ☐

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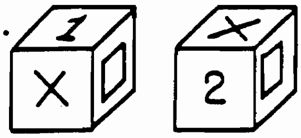

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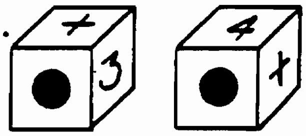

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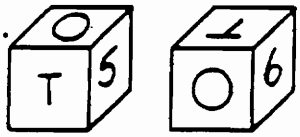

S ☐ D ☐

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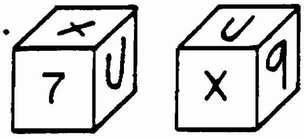

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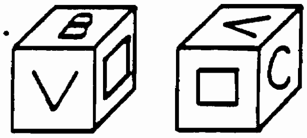

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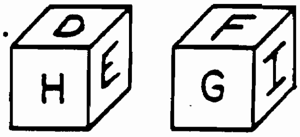

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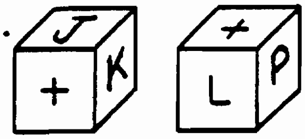

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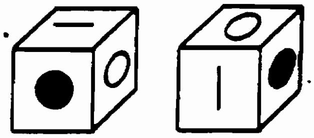

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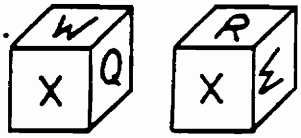

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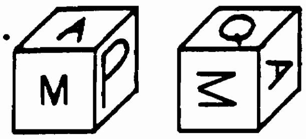

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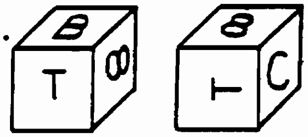

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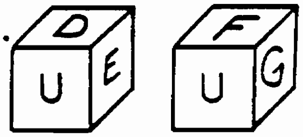

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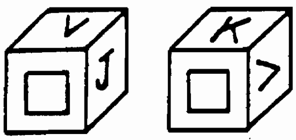

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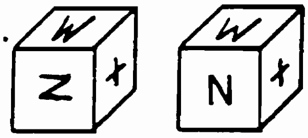

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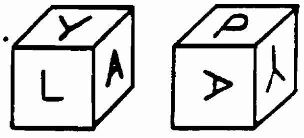

S ☐ D ☐

DO NOT GO ON TO THE NEXT PAGE UNTIL ASKED TO DO SO.

STOP.

Part 2 (3 minutes)

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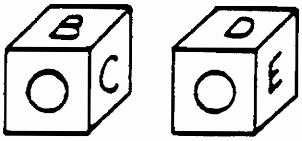

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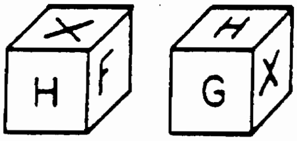

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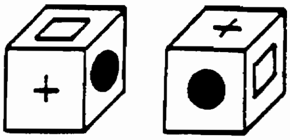

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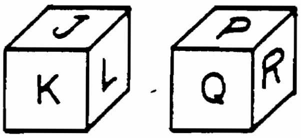

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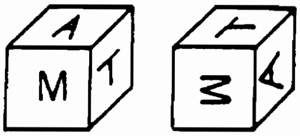

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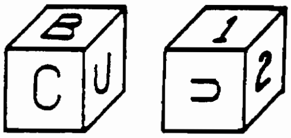

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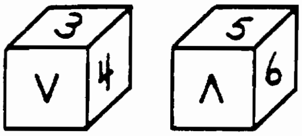

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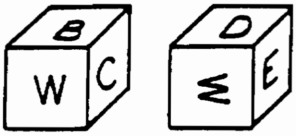

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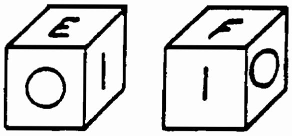

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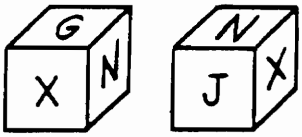

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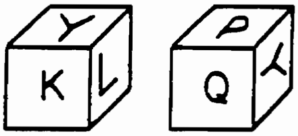

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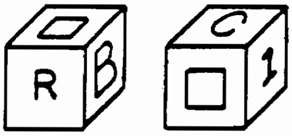

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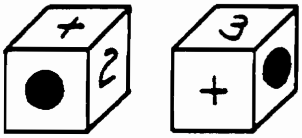

S ☐ D ☐

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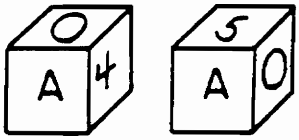

S ☐ D ☐

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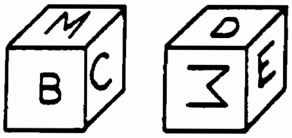

S ☐ D ☐

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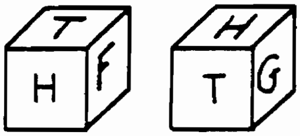

S ☐ D ☐

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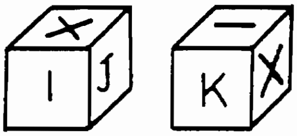

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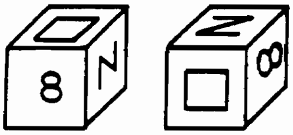

S ☐ D ☐

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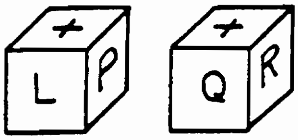

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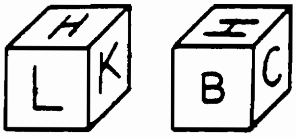

S ☐ D ☐

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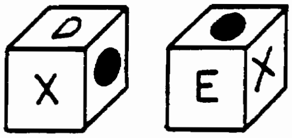


S ☐ D ☐

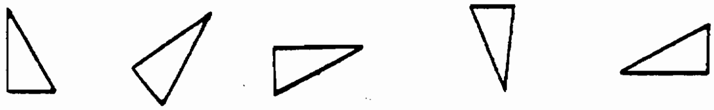
DO NOT GO BACK TO PART 1 AND
DO NOT GO ON TO ANY OTHER TEST UNTIL ASKED TO DO SO.

STOP.

Name ______________________________

CARD ROTATIONS TEST — S-1 (Rev.)

This is a test of your ability to see differences in figures. Look at the 5 triangle-shaped cards drawn below.



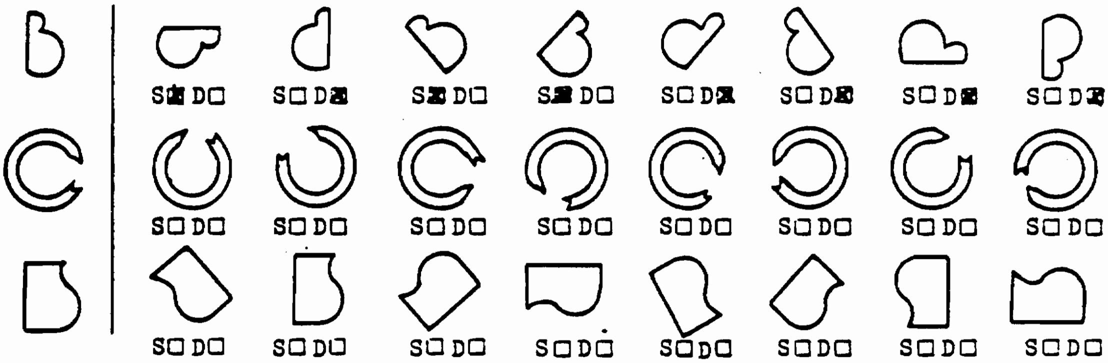
All of these drawings are of the same card, which has been slid around into different positions on the page.

Now look at the 2 cards below:

These two cards are not alike. The first cannot be made to look like the second by sliding it around on the page. It would have to be flipped over or made differently.

Each problem in this test consists of one card on the left of a vertical line and eight cards on the right. You are to decide whether each of the eight cards on the right is the same as or different from the card at the left. Mark the box beside the S if it is the same as the one at the beginning of the row. Mark the box beside the D if it is different from the one at the beginning of the row.

Practice on the following rows. The first row has been correctly marked for you.



Your score on this test will be the number of items answered correctly minus the number answered incorrectly. Therefore, it will not be to your advantage to guess, unless you have some idea whether the card is the same or different. Work as quickly as you can without sacrificing accuracy.

You will have 3 minutes for each of the two parts of this test. Each part has 1 page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

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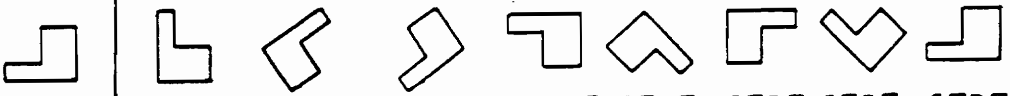
Part 1 (3 minutes)

1.

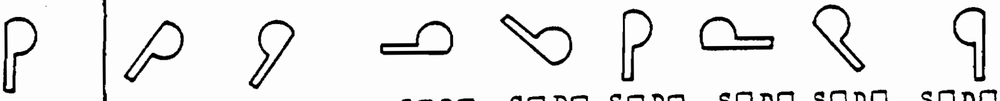
S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐

2.



S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐

3.



S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐ S ☐ D ☐

4.

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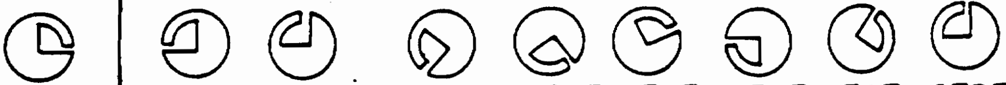
5.



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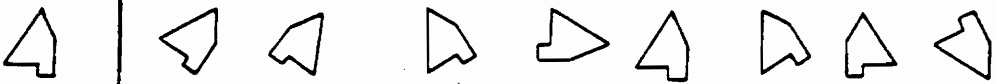
6.



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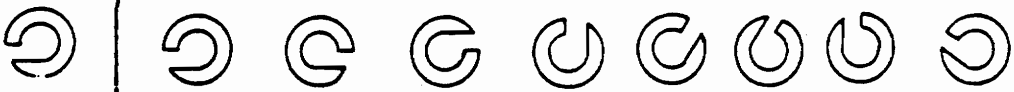

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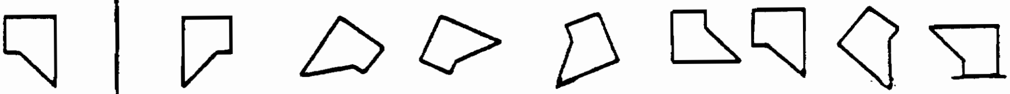

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DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

STOP.

Part 2 (3 minutes)

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DO NOT GO BACK TO PART 1 AND
DO NOT GO ON TO ANY OTHER TEST UNTIL ASKED TO DO SO.

APPENDIX E: Training Sheet

Computerized Posture Recording

Training Sheet

Introduction:

Only two planes are needed to completely record a three-dimensional posture (two orthogonal views).
Each plane goes through the center of the body at the hips.
The three-dimensional view is only a reference.
Make quick but accurate recordings.

Screen Controls:

How to select an orthogonal view
How to incorporate changes
How to not incorporate changes ('ESCAPE')
How to end program

Sample Target:

How to select a joint
Overlapping links menu
Rotating a link
Links that cannot be rotated in a particular view

Procedures for Use (using sample posture 1):

Rotate the three-dimensional view into the same perspective as the observed posture.

Determine which orthogonal view most closely matches the position of the observed posture.

Adjust all of the links in that view to their appropriate positions.

Check any questionable changes with by referring to the three-dimensional view.

Select another orthogonal view.

Adjust all of the links in that view to their appropriate positions.

Check any questionable changes with by referring to the three-dimensional view.

You can also check your manipulations by observing one of the other orthogonal views.

If any of the links would be easier to adjust in a different view, do it.

The torso can only be rotated in the Top view.
****Note:** Recordings should be made as quickly as possible, without sacrificing accuracy.**

APPENDIX F: Program Used to Determine Angular Deviation

```
Program DetermineCategoriesAngles;

Type
 IType = Array[1..21, 1..3] Of Integer;
 RType = Array[1..12,1..3] Of Real;

Var
 dm: IType;
 theta,cat,costheta,radtheta: RType;
 TempIn,TempOut,ListOfAngPosts: Text;
 Subj,Gend,ViewAng,Post: String;
 tab: Char;
 i,j,bw,bh,ew,eh: Integer;
 a,b,c,arccost: Real;

Procedure ReadData;

 Begin
  Readln(ListOfAngPosts,Subj);
  Readln(ListOfAngPosts,Gend);
  Readln(ListOfAngPosts,ViewAng);
  Readln(ListOfAngPosts,Post);
{   Writeln('Categorizing data for Subject ',Subj,' Angle ',ViewAng,' Posture ',Post);}
  Assign(TempIn,'C:\GREG\DATA\'+Subj+ViewAng+Post+'.DAT');
  Reset(TempIn);
  For i := 1 To 21 Do
   Begin
    For j := 1 To 3 Do
     Begin
      Read(TempIn,dm[i,j]);
     End;
   End;
  Close(TempIn);
 End; {ReadData}

Procedure GetTheta;
 Begin
  a:=sqrt(sqr(bw-ew)+sqr(bh-10-eh));
  b:=10;
  c:=sqrt(sqr(bw-ew)+sqr(bh-eh));
  If (a=0) or (c=0) Then
  Begin
   If a=0 Then theta[i,j]:=0;
   If c=0 Then theta[i,j]:=999;
  End
  Else
  Begin
   costheta[i,j]:=(sqr(a)+sqr(b)-sqr(c))/(2*a*b);
   If (costheta[i,j]=1) or (costheta[i,j]=-1) Then
   Begin
    If costheta[i,j] = 1 Then theta[i,j]:=90;
    If costheta[i,j] = -1 Then theta[i,j]:=180;
   End
   Else
    radtheta[i,j]:=(pi/2)-arctan(costheta[i,j]/sqrt(1-sqr(costheta[i,j])));
    theta[i,j]:=radtheta[i,j]*(180/pi); {Convert radians to degrees}
```

```
    If (bw-ew<0) and (bh-eh>0) Then
    theta[i,j]:=theta[i,j];
    If (bw-ew<0) and (bh-eh<0) Then
    theta[i,j]:=theta[i,j]+90;
    If (bw-ew>0) and (bh-eh<0) Then
    theta[i,j]:=theta[i,j]+180;
    If (bw-ew>0) and (bh-eh>0) Then
    theta[i,j]:=theta[i,j]+270;
    If (bw-ew=0) and (bh-eh>0) Then
    theta[i,j]:=0;
    If (bw-ew=0) and (bh-eh<0) Then
    theta[i,j]:=180;
    If (bw-ew<0) and (bh-eh=0) Then
    theta[i,j]:=90;
    If (bw-ew>0) and (bh-eh=0) Then
    theta[i,j]:=270;
{     If (dm[4,1]<>dm[5,1]) and (bw-ew<0) and (bh-eh>0) Then
    theta[i,j]:=theta[i,j];
    If (bw-ew<0) and (bh-eh<0) Then
    theta[i,j]:=theta[i,j]+90;
    If (bw-ew>0) and (bh-eh<0) Then
    theta[i,j]:=theta[i,j]+180;
    If (bw-ew>0) and (bh-eh>0) Then
    theta[i,j]:=theta[i,j]+270;}
   End;
  End;

Procedure Angles;
  Begin
  {TRANSVERSE PLANE}
   {neck}
    i:=1; j:=1;
    bw:=dm[3,1]; bh:=dm[3,2]; ew:=dm[2,1]; eh:=dm[2,2];
    GetTheta;
   {torso}
    i:=2; j:=1;
    bw:=dm[7,1]; bh:=dm[7,2]; ew:=dm[3,1]; eh:=dm[3,2];
    GetTheta;
   {right upper arm}
    i:=4; j:=1;
    bw:=dm[4,1]; bh:=dm[4,2]; ew:=dm[16,1]; eh:=dm[16,2];
    GetTheta;
   {left upper arm}
    i:=3; j:=1;
    bw:=dm[5,1]; bh:=dm[5,2]; ew:=dm[17,1]; eh:=dm[17,2];
    GetTheta;
   {right lower arm}
    i:=6; j:=1;
    bw:=dm[16,1]; bh:=dm[16,2]; ew:=dm[18,1]; eh:=dm[18,2];
    GetTheta;
   {left lower arm}
    i:=5; j:=1;
    bw:=dm[17,1]; bh:=dm[17,2]; ew:=dm[19,1]; eh:=dm[19,2];
    GetTheta;
   {right upper leg}
    i:=8; j:=1;
```

```
  bw:=dm[8,1]; bh:=dm[8,2]; ew:=dm[10,1]; eh:=dm[10,2];
  GetTheta;
 {left upper leg}
  i:=7; j:=1;
  bw:=dm[9,1]; bh:=dm[9,2]; ew:=dm[11,1]; eh:=dm[11,2];
  GetTheta;
 {right lower leg}
  i:=10; j:=1;
  bw:=dm[10,1]; bh:=dm[10,2]; ew:=dm[12,1]; eh:=dm[12,2];
  GetTheta;
 {left lower leg}
  i:=9; j:=1;
  bw:=dm[11,1]; bh:=dm[11,2]; ew:=dm[13,1]; eh:=dm[13,2];
  GetTheta;
 {right foot}
  i:=12; j:=1;
  bw:=dm[12,1]; bh:=dm[12,2]; ew:=dm[14,1]; eh:=dm[14,2];
  GetTheta;
 {left foot}
  i:=11; j:=1;
  bw:=dm[13,1]; bh:=dm[13,2]; ew:=dm[15,1]; eh:=dm[15,2];
  GetTheta;
{FRONTAL PLANE}
 {neck}
  i:=1; j:=2;
  bw:=dm[3,2]; bh:=dm[3,3]; ew:=dm[2,2]; eh:=dm[2,3];
  GetTheta;
 {torso}
  i:=2; j:=2;
  bw:=dm[7,2]; bh:=dm[7,3]; ew:=dm[3,2]; eh:=dm[3,3];
  GetTheta;
 {right upper arm}
  i:=3; j:=2;
  bw:=dm[4,2]; bh:=dm[4,3]; ew:=dm[16,2]; eh:=dm[16,3];
  GetTheta;
 {left upper arm}
  i:=4; j:=2;
  bw:=dm[5,2]; bh:=dm[5,3]; ew:=dm[17,2]; eh:=dm[17,3];
  GetTheta;
 {right lower arm}
  i:=5; j:=2;
  bw:=dm[16,2]; bh:=dm[16,3]; ew:=dm[18,2]; eh:=dm[18,3];
  GetTheta;
 {left lower arm}
  i:=6; j:=2;
  bw:=dm[17,2]; bh:=dm[17,3]; ew:=dm[19,2]; eh:=dm[19,3];
  GetTheta;
 {right upper leg}
  i:=7; j:=2;
  bw:=dm[8,2]; bh:=dm[8,3]; ew:=dm[10,2]; eh:=dm[10,3];
  GetTheta;
 {left upper leg}
  i:=8; j:=2;
  bw:=dm[9,2]; bh:=dm[9,3]; ew:=dm[11,2]; eh:=dm[11,3];
  GetTheta;
 {right lower leg}
```

```
  i:=9; j:=2;
  bw:=dm[10,2]; bh:=dm[10,3]; ew:=dm[12,2]; eh:=dm[12,3];
  GetTheta;
 {left lower leg}
  i:=10; j:=2;
  bw:=dm[11,2]; bh:=dm[11,3]; ew:=dm[13,2]; eh:=dm[13,3];
  GetTheta;
 {right foot}
  i:=11; j:=2;
  bw:=dm[12,2]; bh:=dm[12,3]; ew:=dm[14,2]; eh:=dm[14,3];
  GetTheta;
 {left foot}
  i:=12; j:=2;
  bw:=dm[13,2]; bh:=dm[13,3]; ew:=dm[15,2]; eh:=dm[15,3];
  GetTheta;
{SAGGITAL PLANE}
 {neck}
  i:=1; j:=3;
  bw:=dm[3,1]; bh:=dm[3,3]; ew:=dm[2,1]; eh:=dm[2,3];
  GetTheta;
 {torso}
  i:=2; j:=3;
  bw:=dm[7,1]; bh:=dm[7,3]; ew:=dm[3,1]; eh:=dm[3,3];
  GetTheta;
 {right upper arm}
  i:=3; j:=3;
  bw:=dm[4,1]; bh:=dm[4,3]; ew:=dm[16,1]; eh:=dm[16,3];
  GetTheta;
 {left upper arm}
  i:=4; j:=3;
  bw:=dm[5,1]; bh:=dm[5,3]; ew:=dm[17,1]; eh:=dm[17,3];
  GetTheta;
 {right lower arm}
  i:=5; j:=3;
  bw:=dm[16,1]; bh:=dm[16,3]; ew:=dm[18,1]; eh:=dm[18,3];
  GetTheta;
 {left lower arm}
  i:=6; j:=3;
  bw:=dm[17,1]; bh:=dm[17,3]; ew:=dm[19,1]; eh:=dm[19,3];
  GetTheta;
 {right upper leg}
  i:=7; j:=3;
  bw:=dm[8,1]; bh:=dm[8,3]; ew:=dm[10,1]; eh:=dm[10,3];
  GetTheta;
 {left upper leg}
  i:=8; j:=3;
  bw:=dm[9,1]; bh:=dm[9,3]; ew:=dm[11,1]; eh:=dm[11,3];
  GetTheta;
 {right lower leg}
  i:=9; j:=3;
  bw:=dm[10,1]; bh:=dm[10,3]; ew:=dm[12,1]; eh:=dm[12,3];
  GetTheta;
 {left lower leg}
  i:=10; j:=3;
  bw:=dm[11,1]; bh:=dm[11,3]; ew:=dm[13,1]; eh:=dm[13,3];
  GetTheta;
```

```
  {right foot}
   i:=11; j:=3;
   bw:=dm[12,1]; bh:=dm[12,3]; ew:=dm[14,1]; eh:=dm[14,3];
   GetTheta;
  {left foot}
   i:=12; j:=3;
   bw:=dm[13,1]; bh:=dm[13,3]; ew:=dm[15,1]; eh:=dm[15,3];
   GetTheta;
 End;
Procedure WritetoFiles;

Begin
 If j = 1 Then Writeln(TempOut,'TRANSVERSE PLANE');
 If j = 2 Then Writeln(TempOut,'FRONTAL PLANE');
 If j = 3 Then Writeln(TempOut,'SAGGITAL PLANE');
End;

Begin {Main Program}
 Tab:=chr(9);
 Assign(ListOfAngPosts,'C:\GREG\ANALYZE\ANGPOST.LST');
 Reset(ListOfAngPosts);
{ Readln(subj);}
 Assign(TempOut,'C:\GREG\ANALYZE\ANGLES\ANGLES.ANG'); Rewrite(TempOut);
 Repeat
  ReadData;
  Angles;
{   WriteToFiles;}
  For j:= 1 to 3 Do
   Begin
    For i := 1 to 12 Do
     Begin
      Writeln(TempOut,Subj,tab,Gend,tab,ViewAng,tab,Post,tab,i,tab,Theta[i,j]:4:2);
     End;
   End;
 Until Eof(ListOfAngPosts);
 Close(ListOfAngPosts);
 Close(TempOut);
End. {Main Program}
```

VITA

Gregory Bruce Stewart was born on June 4, 1968 in Rochester, New York. He received a Bachelor of Arts degree in Psychology from Allegheny College in Meadville, Pennsylvania in June, 1990. He began his graduate education in human factors engineering in the fall of 1990 at Virginia Polytechnic Institute and State University. During the summer of 1991, he interned at General Motors, where he was a member of the human factors engineering staff. Currently, he is working at Ford Motor Company as a human factors engineer in the IVHS group of the Electronics Division.

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