An Investigation of Factors that Affect Subjective Assessment of Wrist Posture and Applied Hand Force

by

Michael H. Lau

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Doctoral Committee:

Professor Thomas J. Armstrong, Chair
Professor Gary D. Herrin
Professor Richard E. Hughes
Professor W. Monroe Keyserling

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Chapter 1

Introduction

Problem Statement

A number of tools have been proposed for assessing the risk of developing work-related musculoskeletal disorders (WMSDs) (National Academy of Sciences, 1999). All of these tools require estimates of exposure to risk factors as inputs, e.g. force and posture. Estimates based on observations and subjective assessments are among the most widely used procedures for estimating worker exposures in actual work settings (Li & Buckle, 1999). Previous studies suggest that the accuracy of these methods is poor, but those studies were not performed under controlled conditions (Lau & Armstrong, 2010; Genaidy, Al-Shedi, & Karwowski, 1994). New knowledge is needed that can be used to determine the limitations of observational methods and guide users in analysis of jobs.

This work aims to test a two part thesis that 1) observer estimates of worker wrist posture are biased by viewing angle and 2) worker estimates of exertion force are biased by the direction of force. The first thesis is based on a biomechanical analysis of a link representation of the forearm and hand (Paul & Douwes, 1993) that can show that unless the wrist is viewed along its axis of rotation, parallax will distort the apparent wrist angle resulting in under- or overestimating the wrist angle. The second thesis is based on laboratory studies of manual hose insertion forces that show that the force required to join a hose to a flange is related to the inside diameter of the hose and the outside diameter of the flange, but that the effort required to join hoses are affected by subject and task factors such as insertion technique and hand clearance (Grieshaber & Armstrong, 2007; Lau, Drinkaus, Armstrong, & Grieshaber, 2006; Grieshaber & Lau, 2007; Grieshaber D. , Armstrong, Chaffin, Keyserling, & Ashton-Miller, 2009).

This dissertation supports the development of improved subjective assessment methods by examining i) the effect of viewing angle on wrist posture estimation in both static and dynamic situations, and ii) the effect of task orientation on measured and perceived insertion force characteristics in a manual hose installation task. To address these problems, this dissertation will test the theses that i) posture estimate errors can be predicted based on parallax errors for a link representation of the forearm and hand, and ii) the applied force and perceived effort used to join parts are solely determined by the resistance between the parts.

Rationale

Work-related musculoskeletal disorders of the upper extremity have been identified as an important national health problem, placing substantial economic burden on individuals, employers and society at large (NRC, 2001). In their review of existing evidence, the National Research Council identified a need to improve tools for exposure assessment of risk factors, which included “enhanced quantification of risk factors” (NRC, 2001). Force, posture, repetition, and vibration are some of the main factors that have been associated with increased risk of upper extremity musculoskeletal disorders. The multi-factorial nature of risks for these disorders means that it is difficult to establish direct causation between one risk factor and the disorder outcome. Some associations have been shown to be stronger than others. For instance, there is strong evidence of a positive association between exposure to high applied hand forces and awkward wrist posture and carpal tunnel syndrome, but insufficient evidence of a positive association between wrist posture alone and carpal tunnel syndrome (Bernard, 1997).

Many exposure assessment protocols exist, which often include ways to evaluate a wide variety of factors believed to affect WMSD risk for the upper limb. Table 1.1 lists a selection of the more influential assessment methods that have been developed since the 1970s. The methods have been created to study the relationship between exposure and epidemiological findings, to screen jobs and work tasks for abnormal ergonomic exposures, to prioritize the importance of particular risk factors, and/or to determine the dose-response relationship between the risk factor and musculoskeletal disorders. The choice of the method selected by researchers or practitioners is often driven by the level of detail required (Li and Buckle, 1999).

Subjective observations and/or worker ratings are widely used to identify and estimate exposures, including those for wrist postures and hand forces. Different methods to quantify wrist posture and hand force exposure have been developed for use within these frameworks. Exposure assessment methods range from a macro level of screening for the presence of a risk factor to a micro level of analyzing in detail the level of exposure at discrete intervals in time. A review of techniques for assessing physical exposure to WMSD risks by Li and Buckle (1999) identified an abundance of posture-based methods and a necessity to develop methods to investigate other risk factors such as force, frequency, and task duration.

Table 1.1 Selected subjective exposure assessment methods for upper-limb musculoskeletal disorders with an emphasis on posture- and force-based metrics; listed in chronological order

Authors	Method	Remarks
Priel (1974)	Numerical definition of posture	First pen and paper method to describe posture; used 'posturegrams'.
Karhu, et al. (1977)	OWAS (Ovako Working Posture Analysis System)	Analytical method to assess working posture based on work sampling. Analysts classify work postures according to a four point rating scale.
Corlett, et al. (1979)	Posture targetting [sic]	Technique for recording whole body postures by marking positions on target-like charts.
Armstrong, et al. (1979)	Time-based filming of manual work	Recording hand position and force at 4 frames per second.
Armstrong, et al. (1982)	MTM based recording of upper extremity postures	Description of posture of each joint in upper extremity according to pre-defined classification intervals for MTM based work elements.
Holzmann (1982)	ARBAN	Whole body assessment using time-sampled video and Borg scale.

Authors	Method	Remarks
Keyserling (1986)	Real-time video analysis	Computer-aided analysis using pre-defined postures, for non-seated jobs.
Kemmlert and Kilbom (1987)	PLIBEL	Screening tool, checklist based to identify ergonomic hazards.
Stetson, et al. (1991)	Observational analysis of hand and wrist	Classification of gross hand postures and wrist joint angles using multiple analysts.
McAtamney and Corlett (1993)	RULA (Rapid Upper Limb Assessment)	Investigate exposure of individual workers to risk factors associated with WMSDs using diagrams of body postures and scoring tables.
Christmansson (1994)	HAMA (Hand-Arm-Movement Analysis)	Linked data to specific work activity.
Fransson-Hall, et al. (1995)	PEO (Portable Ergonomic Observation)	Real-time in-person observations using portable hand-held computer.
Yen and Radwin (1995)	Synchronous video and objective measures	Analog data recording synchronized with video images to assess manual repetitive tasks.

Authors	Method	Remarks
Moore and Garg (1995)	Strain Index	Assessment of six task variables, assigning ordinal rating and multiplier to calculate a risk index for upper extremity MSDs.
Armstrong and Latko (1997)	Cycle time, force, posture and movement based approach	Characterizing posture, force and repetition; original basis for ACGIH TLV© for Hand Activity Level.
Wells, et al. (1997)	Common measurement metric	Reporting exposure estimates from self-report, expert observers, work sampling, video analysis, and EMG in a common metric.
Occhipinti (1998); Columbini (1998)	OCRA	Indexes exposure to repetitive movements of the upper limbs.
Hignett and McAtamney (2000)	REBA (Rapid Entire Body Assessment)	Developed for increased sensitivity to unpredictable work postures in health care. Scoring system for muscle activity; divides body into coded segments. Outputs an Action Level
Paquet, et al. (2001)	PATH (Posture, Activities, Tools, Handling)	Fixed-interval observations to characterize proportion of time spent in awkward postures, handling loads and performing manual materials handling.

Authors	Method	Remarks
Ketola, et al. (2001)	Semi-quantitative, time-based method to assess six upper extremities physical load factors	For cyclical work, measure duration and assess each cycle for presence of each load factor.
Winter, et al. (2006) as cited in Fritzsche (2010)	AAWS (Automotive Assembly Worksheet)	Checklist for estimating four categories of ergonomic risk factors; Fritzsche applied AAWS to digital human model simulations.
David, et al. (2008)	QEC (Quick Exposure Checklist)	Epidemiological and practitioner-tested method that assesses four main body areas and other factors and combines multiple risk factors in an additive scoring system.
Village, et al. (2009) (2010)	Back-EST and modified Back-EST	Original version was modified to include upper limb exposure and has 16 ergonomic variables sampled each minute

Subjective analysis methods are used often as a starting point in walkthrough surveys and often in lieu of direct measurement. These methods are used because compared to direct measures, they are often less complicated, interfere less with the work being analyzed, and can be used to integrate exposures to several risk factors into a single metric (e.g. Strain Index). They may be perceived as being more cost effective than instrumental methods. The cost difference cannot be disputed, but their effectiveness is still an open question and requires further study. Observations and worker ratings are sometimes the only feasible quantitative option to use in complex work environments with unconventional restrictions such as sterile environments, space-limited work areas, when large amounts of personal protective equipment are worn, and jobs that are highly mobile.

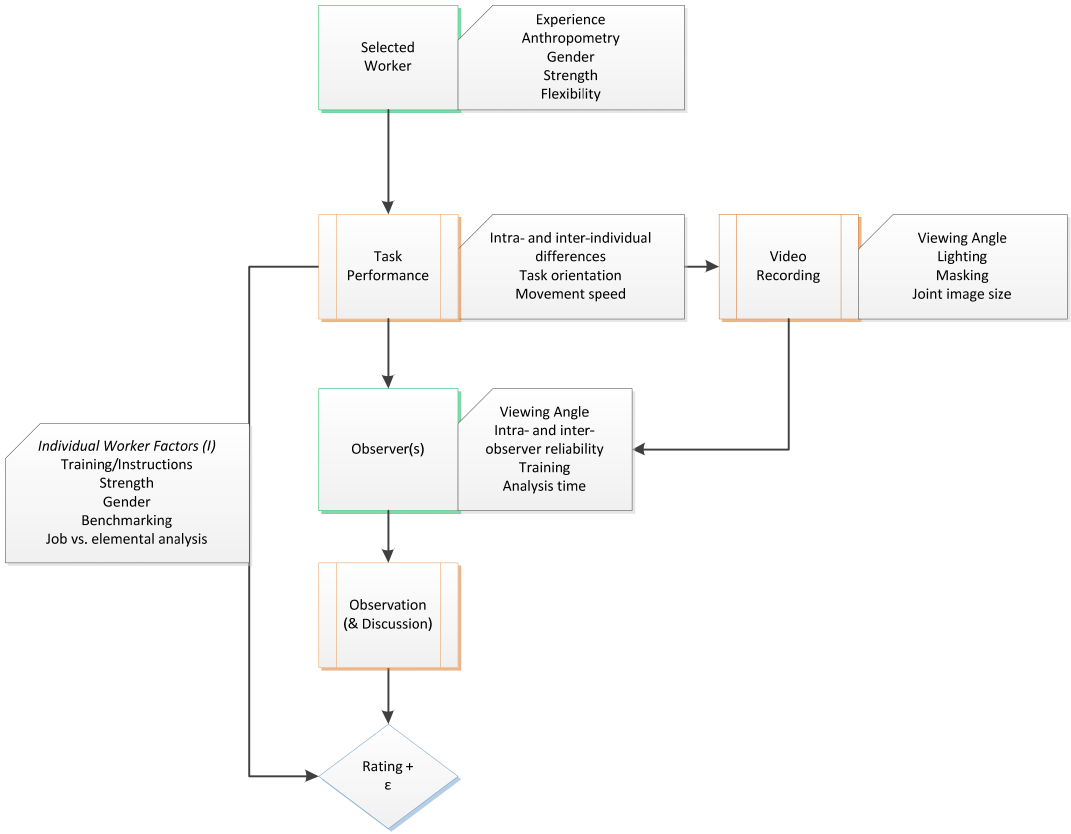
Figure 1.1 depicts a flowchart of the typical subjective rating process broken down into the basic components. A rating can be made by the subject worker or a rating can be given by an analyst. The analyst can either observe the worker directly or observe a video recording of the worker. The analyst can even be the subject worker or another worker familiar with the job (Kadefors & Forsman, 2000).

Several researchers have questioned the accuracy, validity, and reliability of subjective assessment methods. Genaidy, Al-Shedi, et al. (1994) reviewed postural stress analysis in the industry and one of their major findings was that there were no criteria reported to determine the sources and magnitudes of errors associated with postural classifications. They argue that such criteria were important to develop any structured method to train job analysts and only vague statements have been made by researchers as to the satisfactory use of their observational techniques. Researchers have attempted to overcome these limitations by modifying the rating schemes by increasing the interval size in classification-type methods, using reference pictures to aid estimation (Armstrong & Latko, 1997), and using computerized methods to facilitate the rating process (Yen & Radwin, 2000). These modifications do not address the fundamental factors that affect rating accuracy and validity.

Worker, task, and observation factors all can be sources of variance (see Figure 1.1). Worker factors include experience, gender, and anthropometry. Task factors include speed of work and task orientation. Observation factors include viewing angle, masking, and image size, for example. These sources of variance are believed to make rating more difficult.

Analysts need to identify and integrate relevant job and task information to rate exposures accurately. Training quality, experience (Sidhu, et al., 2004), assessment criteria (Lowe, 2004), and perceptual issues are believed to affect accuracy. Lastly, the subject worker's rating may be influenced by factors like strength, comprehension of the rating scale, and ratings of the entire job or of individual elements (Ebersole, 2005).

This study will help to determine to what extent the variance associated with posture and force ratings can be predicted and to what extent it is random. Subjective ratings of exposure can thus be expressed as a function of the actual exposure, observer variance, task variance, observation variance, and random error (see Figure 1.1). Until more is understood about the effects of these identified factors, researchers and practitioners can only assume that their effects are negligible.



$$Worker\ Rating = Actual\ Exposure + \varepsilon;\ \text{where } \varepsilon = f(Task, I_{1,}I_2, \ldots, I_n); I = factor$$

$$Analyst\ Rating = Actual\ Exposure + \varepsilon;\ \text{where } \varepsilon = f(Task, \varepsilon_{worker}, \varepsilon_{recording}, \varepsilon_{observation}, \ldots \varepsilon_{analyst})$$

Figure 1.1 Worker and analyst ratings of exposure expressed as a function of the actual exposure and error. Error itself can be expressed as a function of task, worker, recording and analyst factors that can affect the rating.

Wrist Posture

The posture of the wrist joint was selected for study for several reasons listed below.

- The National Institute of Occupational Safety and Health concluded from the literature that there was strong evidence to support that wrist posture in combination with high hand force is a risk factor for musculoskeletal disorders of the upper limb (Bernard, 1997). On its own however, there is "insufficient evidence" of a positive association with WMSDs, but it is unclear why (Bernard, 1997).
- The wrist joint is highly mobile and flexible. Its range of motion includes flexion and extension, radial and ulnar deviation, and works in combination with forearm pronation and supination.
- The wrist appears to be susceptible to several perceptual factors such as viewing angle, viewing distance, and lighting that could hamper rating efforts.
    - Parallax has been shown to affect measurement of postures from two-dimensional images (Paul & Douwes, 1993)

- The wrist is a small joint and when (video) recordings are made, researchers often capture the entire limb, reducing the wrist to a small image size.
- The wrist is often masked by external objects and personal protective equipment.

Several different observational and/or subjective assessment techniques are used by researchers and practitioners to assess wrist posture. Wrist posture is commonly divided based on the plane of movement of interest: flexion/extension and radial/ulnar deviation. These are typically assessed independently even though they often occur simultaneously. The following list includes the most common ways wrist posture is assessed in observational methods with selected examples:

- Assign value only if the wrist adopts a posture beyond a pre-determined threshold (e.g. Rapid Upper Limb Assessment (RULA) (McAtamney & Corlett, 1993))
- Categorize peak, average, or instantaneous observed wrist posture into pre-determined bins (verbal categories, defined intervals in degrees) (e.g. Strain Index (Moore & Garg, 1995); (Stetson, Keyserling, Silverstein, & Leonard, 1991))

- Assign observed wrist posture to a pre-determined scale (e.g. Armstrong & Latko, 1997)
- Estimate the observed wrist posture in degrees (e.g. Armstrong, Foulke, Joseph, & Goldstein, 1982)
- Estimate an aggregate statistic for average or peak posture observed over the period of interest/observation (Latko, 1997)

Several studies have been conducted to investigate the reliability and validity of observational estimates of wrist (Genaidy, Al-Shedi, et al. 1994). Researchers have determined that the assessment and classification of postures of smaller joints had lower reliability than larger joints (Baluyut, Genaidy, et al. 1995; Bao, Howard, et al., 2009; Jensen, Eenberg, et al. 2000). Lowe (2004) and Bao, Howard, et al. (2009) reported low inter-analyst agreement and significant misclassification of wrist in their studies. Observers exhibited moderate agreement when compared to experts in assessing wrist posture, but did not perform well when compared to wrist goniometry data (Ketola, Toivonen, et al., 2001).

Applied Hand Force Estimates

Subjective estimation of applied hand force was selected for study for the reasons listed below:

- Worker ratings are often used to estimate force demands because analysis by observation would require first-hand knowledge of the task, which is not always possible to obtain.
- The exposure is invisible; only the effects of the applied forces can be seen.
- The effects of task factors that might affect the subjective ratings have rarely been studied.
- Rating of peak or average applied hand force according to a predefined scale, usually 0-100% of a maximal voluntary contraction, may be subject to perceptual biases of individual workers and the quality of instruction in the rating task.

Studies have shown that benchmarking workers to maximal power grip exertions improves the rating accuracy (Marshall, Armstrong, & Ebersole, 2004; Marshall, 2002). Wurzelbacher, Burt, et al, (2010) as part of a study investigating the validity of the ACGIH® Hand Activity Level TLV® found only slight correlations and low percentages of exact agreement between worker and paired observer ratings of perceived exertion (RPE). Bao, Spielholz, et al, (2009) examined different force quantification methods and found that the sensitivity of each method varied in detecting exertion-level differences between different jobs. Also, for power grip forces they reported weak correlations between self-report values and observer estimates (r=0.45) and even weaker correlations with force matching methods (r=0.36).

In spite of their advantages, observational methods are far from perfect and research is required to understand the factors that cause assessment of wrist posture and hand forces to have low reported accuracy, validity, and/or reliability. These different and unknown sources of error are currently assumed to be negligible, but it is very evident that researchers will continue to have serious reservations about results from studies using these methods. It is these errors that need to be resolved in order for there to be more widespread acceptance of research methodologies that use these important observational methods.

This work begins to investigate several factors that are believed to affect the accuracy, reliability and/or validity of subjective assessments of wrist posture and applied hand force. It seeks to provide methods that can be used by ergonomists, epidemiologists, and researchers to adapt current methods to minimize the potential effects of these factors when conducting studies that use observations and worker estimations. It also seeks to communicate the necessity of improved rigor and control in study protocols.

Research Objectives

The following research objectives were established:

1. Investigate the effect that viewing angle has on wrist posture estimation from static photographic images and compare with predictions made by quantitative models of parallax.
    a. Develop an applicable tool correlating viewing angle and static wrist posture assessments to actual wrist postures for predictive purposes.
2. Investigate the effect that viewing angle has on wrist posture estimation from video of simulated, dynamic tasks.
3. Investigate the effect that task orientation has on perceived ratings of difficulty, comfort, and hand force, peak and average insertion force, strength, percent capacity used, and insertion time in a manual hose installation task.

Dissertation Organization

This dissertation is organized into five chapters. Chapter 1 serves as an introduction to the research problem and discusses the significance of the dissertation. Chapters 2 through 4 are presented as a series of self-contained manuscripts, each addressing one or more of the research objectives.

Chapter 2 examines the effect of viewing angle on observational ratings of wrist flexion and deviation postures in terms of accuracy and compared to a quantitative model of parallax error introduced by the viewing angle. Twenty-six novice raters participated and rated wrist postures from static images of the wrist in sixteen different postures and from ten different view angles.

Chapter 3 examines the effect of three static camera viewing angles and two task speeds on observational ratings of peak and average wrist flexion and extension postures from videos of ten simulated tasks. Twenty-two novice raters participated and rated wrist postures for all conditions.

Chapter 4 examines the effect of task orientation on fourteen subjects' psychophysical ratings (of applied hand force, difficulty, and comfort) and task demands (required force, strength, and percent capacity used) in the context of a manual hose installation task common in manufacturing environments.

Chapter 5 concludes the dissertation with a summary of the individual studies and a discussion of main findings. Included is an application on the results of Chapter 2 in the form of regression equations that allow the prediction of actual wrist angles given an estimated wrist posture from a static image and a known viewing angle. Recommendations of future research directions are provided.

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Chapter 2

The effect of viewing angle on wrist posture estimation from photographic images using novice raters

Abstract

Observational assessment of wrist posture using photographic methods is theoretically affected by camera view angle. A study was conducted to investigate whether wrist flexion/extension and radial/ulnar deviation postures were estimated differently by raters depending on the viewing angle and compared to predictions using a quantitative 2D model of parallax. Novice raters (n=26) estimated joint angles from images of wrist postures photographed from ten different viewing angles. Results indicated that *ideal* views, orthogonal to the plane of motion, produced more accurate estimates of posture compared to non-ideal views. The neutral (0°) posture was estimated the most accurately even at different viewing angles. Raters were more accurate than model predictions. Findings demonstrate a need for more systematic methods for collecting and analyzing photographic data for observational studies of posture. Renewed

caution in interpreting existing studies of wrist posture where viewing angle was not controlled is advised.

Introduction

Observational methods are widely used by researchers and practitioners for ergonomic analysis of body postures. These methods provide valuable insight into understanding the causes of musculoskeletal disorders. The evaluation of worker posture by observational methods however, is believed to be prone to error from several sources.

Wrist posture has been recognized as a risk factor for work-related musculoskeletal disorders by the National Research Council (1999). Evidence indicates that awkward wrist posture *combined* with high hand forces or repetition is a risk factor for wrist disorders (Bernard 1997), but the role of awkward posture alone is not as well understood. Improving the accuracy of assessment methods may help to clarify these relationships.

Generally, researchers estimate working postures directly or from recordings and assign ratings from them where more extreme postures are associated with higher risk. Existing observational methods differ in many aspects, including the types of posture analyzed and the metrics used to scale the postures. Examples of these methods include those interested in whole body postures (Corlett, Madeley, et al. 1979; Hignett and McAtamney 2000; Karhu, Kansi, et al. 1977), those concerning the general upper limb (David, Woods, et al. 2008; McAtamney and Corlett 1993; Moore and Garg 1995), and those examining wrist posture in detail (Armstrong, Foulke, et al. 1982; Colombini 1998; Yen and Radwin 2002). These methods are often used in lieu of methods for objectively measuring posture in occupational settings.

A review of postural assessment methods by Li and Buckle (1999) described a general lack of precision and reliability. Assessment and classification of postures of larger body segments had higher reliability than smaller joints (Baluyut, Genaidy, et al. 1995; Bao, Howard, et al. 2009; Jensen, Eenberg et al. 2000). Low inter-analyst agreement and significant misclassification of wrist posture was observed by several researchers (Bao, Howard, et al. 2007; Lowe 2004). Observers exhibited moderate validity compared to experts in assessing wrist posture, but fared poorly when compared to wrist goniometry data (Ketola, Toivonen, et al. 2001). Despite these weaknesses being identified, what specifically caused the error in postural classifications had neither been identified nor reported (Genaidy, Al-Shedi, et al.

1994). Bao, Howard, et al. (2009) suggested that reliability depended on variability of the posture parameters, camera positions, video quality, and complicated work postures.

Parallax

Parallax is thought to be an important error source in posture analysis (Dartt, Rosecrance, et al. 2009; Stetson, Keyserling, et al. 1991). Parallax errors result when the viewing angle is not aligned with the axis of joint rotation (Paul and Douwes 1993). Parallax affects how objects appear to us. In this case, the wrist appears differently depending upon at which angle it is viewed at (Figure 2.1).

Parallax is a well-studied phenomenon with origins in astronomy. In the book *De revolutionibus orbium coelestium* (Copernicus 1543), Copernicus stated that the earth's motion around the sun caused the retrograde and apparent motion of the planets, not the planets revolving around the earth. Planetary parallax is many orders larger than postural evaluation, but the systematic alteration of the appearance of objects caused by changes in perspective is highly relevant.

Parallax is almost always present when observing worker posture; workers move frequently and constantly change the view angle, often without the observer realizing it. Viewing angles are often not reported in posture studies (Juul-Kristensen, Fallentin, et al. 2002; Mattila, Karwowski, et al. 1993; McAtamney and Corlett 1993; Spielholz, Silverstein, et al. 2001; Stetson, Keyserling, et al. 1991). Some researchers try to minimize any effect of parallax by observing workers from multiple angles (Baluyut, Genaidy, et al. 1995; Juul-Kristensen, Hansson, et al. 2001; Lowe 2004), sometimes simultaneously using video recordings (Yen and Radwin 2000).

Figure 2. 1 A single wrist flexion posture from four different viewing angles

Parallax Model

Paul and Douwes (1993) proposed a general model to quantify parallax introduced during photographic recording of posture. This model shows that as the angle between the line of sight and the axis of joint rotation increases in one direction, the observed joint angle appears to increase. As the view angle increases in an orthogonal direction, the observed joint angle appears to decrease.

The model can be applied to the analysis of wrist postures. For example, wrist angle (α) can be measured using a view with no parallax (Figure 2.2a). When the angle between the line of sight and the axis of joint rotation increases (β), the dimensions of the hand (a′ and c′) are altered (Figure 2.2b) and the apparent angle (α') is larger than the actual angle, ranging up to 180°. With an increase in the angle between the line of sight and the joint movement plane, the apparent angle decreases from the actual angle, down to a minimum of 0°.

This parallax model is based on two-dimensional line drawings and does not consider the effect of three-dimensional (3D) surfaces, shadows, etc. The wrist is not a simple stick figure and viewing images in 3D provides a richer experience, allowing one to integrate other visual cues. These visual cues, notwithstanding those from external objects, may include relative lengths of wrist segments, visibility of wrist creases, visible surfaces of fingertips, fingernails or sides of the hand, the prominence of finger tendons under the skin of the forearm, textural differences between the palm and back of the hand, depth cues (Nawrot and Joyce 2006), light/shade, and contrast. When parallax exists, it is believed that observers are able to overcome its effects somewhat by using this added information.

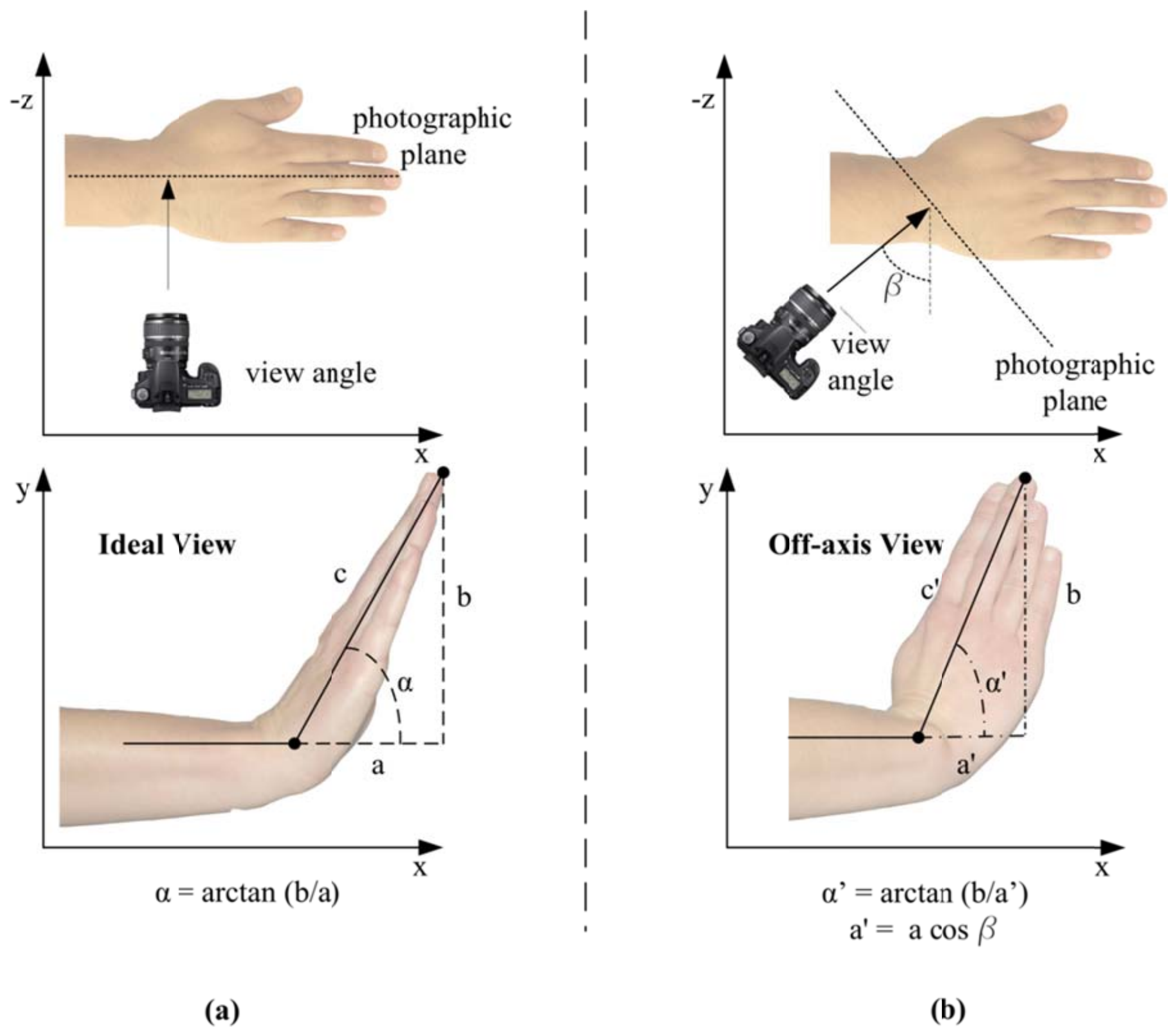

Figure 2. 2 2D model depiction of the wrist segment as seen from two different views

Viewing Angle Definitions

Here we identify three general categories of view angles that could be adopted by an observer of a particular joint posture. *Ideal* view angles produce no perspective distortion (i.e., no parallax) and presumably lead to the most accurate posture estimation. These ideal angles are defined here to be orthogonal to the plane of motion and in the axis of rotation. An *in-line view* is directly in the plane of joint motion and through the axis of rotation. It is believed to produce the largest distortion because the wrist appears as a straight line with no visible joint angle. An *off-axis view* is neither orthogonal to nor in-line with the plane of motion and causes the joint angle to appear larger or smaller than it actually is depending upon the view angle. The view angles selected for this study include ideal views, in-line views, and several off-axis views that might typically occur when observing or photographing a worker in person.

Study Objectives

This study was conducted to investigate whether wrist flexion/extension and radial/ulnar deviation postures were estimated differently by subjects for different viewing angles. The null hypothesis was that there was no difference between observer and predicted parallax error between different viewing angles.

We aimed to test this hypothesis and provide data about the accuracy and precision of posture estimates from different viewing angles.

The greatest effect of parallax was expected to be seen in the in-line views. From these views, the apparent wrist angles all appear as 90° or 0° because the joint angle is not visible. For off-axis views, the measured effect of parallax was expected to be more pronounced as the wrist angle increases or as the view angle moves away from the ideal view. These conditions were expected to produce a corresponding decrease in accuracy. Parallax was not expected to affect the ideal views.

Method

Image preparation

The right hand and wrist (hand length = 15.4 cm; breadth = 7.5 cm) of a 1st percentile Caucasian female research associate was photographed in sixteen postures from ten different view angles (Figure 2.3). The view angles were labeled according to the surface of the neutral wrist that is captured by that view. The wrist was positioned in nine flexion and extension (F/E) (F90°, F60°, F45°, F30°, 0°, E30°, E45°, E60°, E90°) and eight radial and ulnar (R/U) deviation (R30°, R20°, R10, 0°, U10°, U20°, U30°, U45°) postures. Wrist postures were obtained by aligning landmarks drawn on the model's hand, wrist, and forearm to clear Plexiglas marked with the desired angles. For F/E, markings were place on the medial side of the fifth metacarpophalangeal (MCP) joint, the ulnar styloid process, and the medial epicondyle. The joint angle for F/E was defined as the angle formed between the long axis of the forearm and the line formed between the fifth MCP and ulnar styloid. For R/U deviation, markings were place on the volar surface of third MCP joint, the midpoint of the distal wrist crease, and on a line connecting the midpoint of the cubital fossa. Wrist deviation angle was defined as the angle between the long axis of the forearm and the line formed by the third metacarpal. The view angles were selected to represent a range of typical view angles. A single associate was used to create the experimental images to isolate the effects of parallax as much as possible.

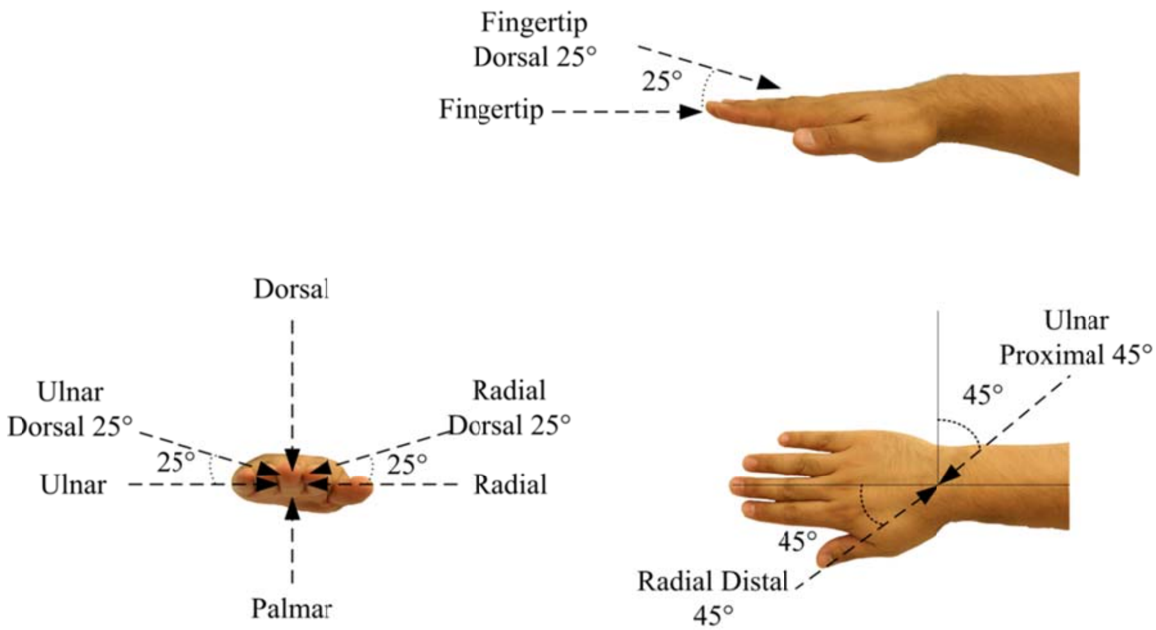

Figure 2.3 Camera view angles labeled by surface of hand captured in image

A digital SLR camera was used (Canon 6.0MP, focal length = 28mm). Each image contained the hand, wrist, forearm, and sometimes part of the torso. The camera-to-wrist distance was set at 117 cm (46"), which optimized image size and kept hand size constant in the images. The internal flash was used and ambient fluorescent lighting was controlled. Shadows were minimized, but could not be completely eliminated. Background objects were concealed using a patterned backdrop. This backdrop was selected to provide visual stimuli in the absence of recognizable objects.

Participants

Twenty-six university students with normal/corrected vision participated and received monetary compensation. Participants had little to no prior experience in ergonomic posture analysis.

Protocol

Participants were given a short training session. Simple diagrams of a wrist positioned in flexion, extension, and ulnar and radial deviation with lines drawn on the long axes of the forearm and hand were shown to the participants. The angle to be rated was indicated to them for each posture. Eight practice trials were given using exemplar images captured from ideal views and feedback was given after each trial. Participants verbally indicated that they understood how to perform the task prior to the start of the experimental conditions. The diagrams were made available throughout the study as reference if the participant needed them. Participant use of these materials was not recorded, but appeared to be minimal. The study was conducted using an 18” LCD monitor, where images were approximately one-half of the screen area.

Participants were instructed to estimate wrist posture in degrees for each presented image of wrist F/E or R/U deviation. Participants were not informed of the specific study objectives and were not given information of the view angles, nor were they informed of the purpose of the study. Feedback was not given during the experiment.

Trials were blocked by movement type (flexion/deviation) to eliminate the need to distinguish between posture types. Wrist images were presented randomly using experimental software (MediaLab v2006.1.29). To prevent estimation beyond the expected range of motion as a trained expert would do, maximum limits were set for each posture type (F: 90°, E: 120°, U: 45°, R: 30°). A full factorial design was used. Each participant performed 170 different observations.

Results

Observations were performed for all conditions by all subjects. The results are presented separately by F/E and R/U deviation. Three values were used for comparison: *actual* wrist angles, *apparent* angles (model predictions), and corresponding *observed* angles (subjects' estimations). The difference between the observed and actual angles and the absolute value of the error was used to calculate the mean error for all conditions.

Flexion and Extension

Actual, apparent, and observed wrist angles are shown for F/E postures in each chart in Figures 2.4 and 2.5 grouped by ideal views (Figure 2.4) and in-line and off-axis views (Figure 2.5). Flexion postures are negative angles and extension, positive.

In the ideal views, the model outputs (apparent angles) are equal to the measured wrist angles. Subjects rated flexion postures more accurately than extension postures. The E90° posture was underestimated by subjects by mean values ranging between 6°-30° across views.

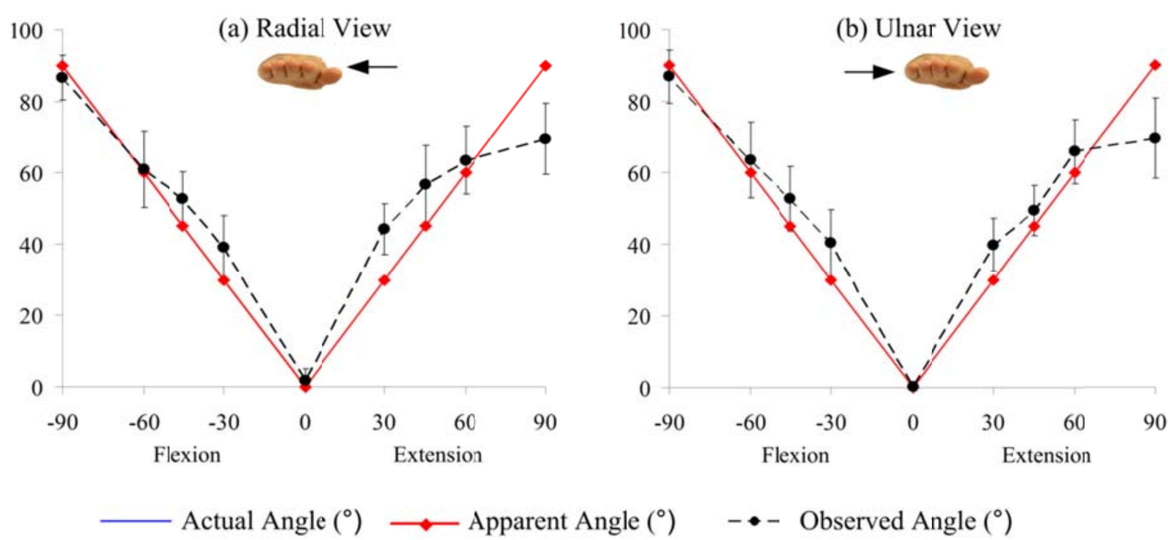

Figure 2.4 Ideal Views - Actual, apparent and mean estimated angles (± 1SD) are shown (in °) for F/E postures (actual angle = apparent angle)

The model predicts that all F/E angles seen from the in-line views (Figure 2.5a) would appear the same: as 0° for and all F/E angles and 90° from the Fingertip and Fingertip Dorsal 25° views (Figure 2.5b). The observed angles did not follow these predictions, but instead aligned more with the actual angles. Mean errors for these views ranged between 7°-14° and were comparable to those observed in other views. Interestingly, observed values from the Radial Distal 45° and Ulnar Proximal 45° (Figure 2.5c) views appeared to align more with the predicted values than with the actual angles. Observed values from the Radial Dorsal 25° and Ulnar Dorsal 25° views (Figure 2.5d) were similar to each other and to the ideal views.

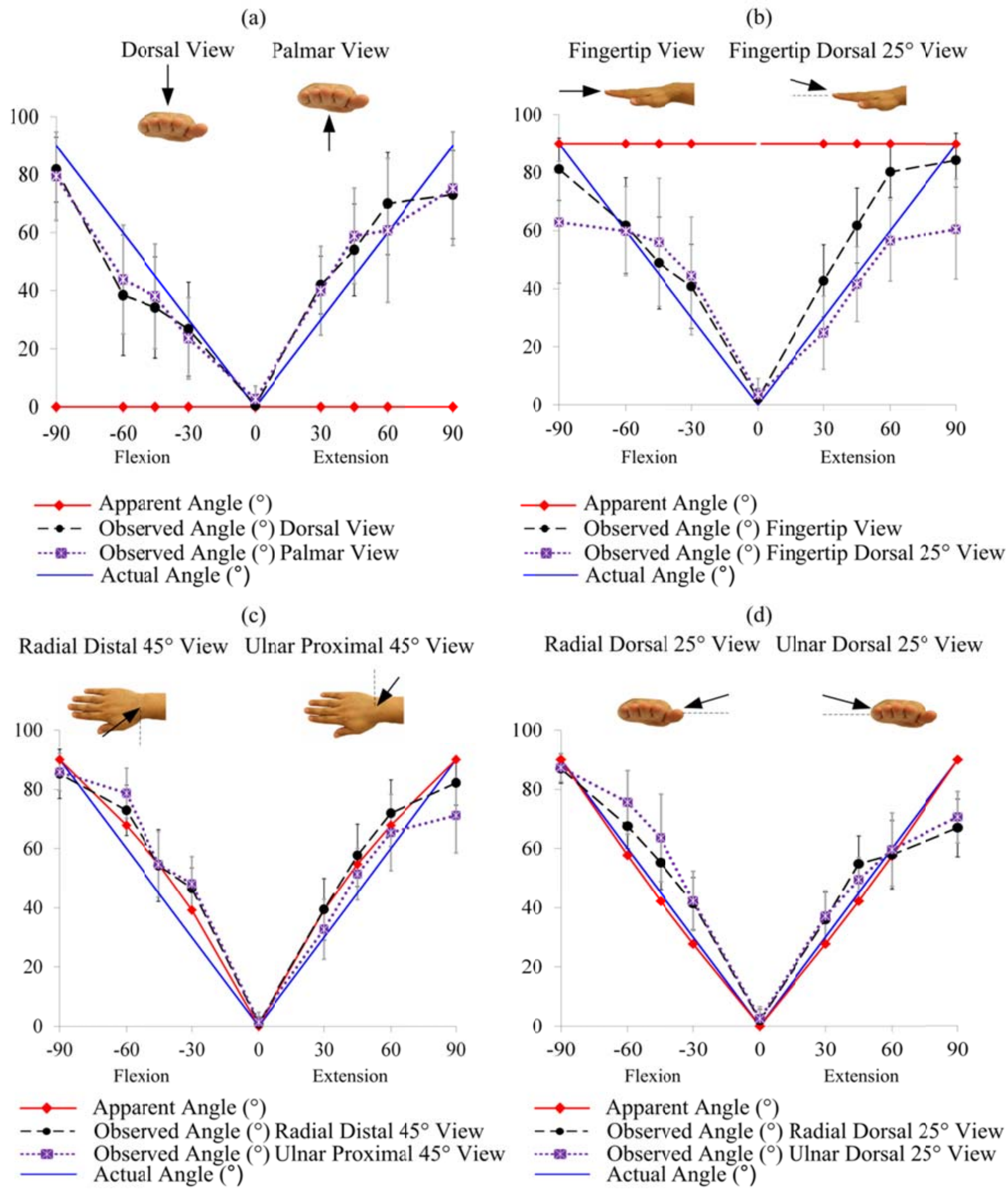

Figure 2.5 In-Line and Off-Axis Views - Actual, apparent, and mean estimated angles (±1 SD) are shown (in °) for F/E postures

Posture Underestimation and Overestimation

The estimates were evaluated for whether they were greater than, equal to, or less than the actual wrist angle. The biases, or proportion of overestimation, underestimation, and exact responses are shown separated by viewing angle in Table 2.1; the same is shown by posture in Table 2.2 along with the mean error. In total, 38% of the trials contained underestimates, 39% had overestimates, and 23% had no error. The range of mean error was largest for the Fingertip View (-25° to + 26°) and least for the Radial View (-12° to 14°). The F90° posture was never overestimated because participants were instructed that 90° was the limit of the range of motion. The F60° and E90° postures were underestimated 68% and 58% respectively. Note that the F60° posture underestimates were large; mean error was about 30°, or greater than 50% of the actual angle.

Table 2.1 Proportions of underestimation, overestimation, and exact observations for wrist flexion and extension postures by viewing angle

	Ulnar*	Radial*	Dorsal	Palmar	Finger-tip	Ulnar Distal 45°	Radial Proximal 45°	Radial Dorsal 25°	Finger-tip Dorsal 25°	Ulnar Dorsal 25°
Under-estimation	23%	43%	43%	44%	46%	14%	41%	23%	53%	32%
Over-estimation	44%	38%	28%	28%	41%	50%	39%	42%	33%	35%
Exact	33%	19%	29%	28%	13%	36%	20%	35%	14%	33%

*ideal view; n=234 for each viewing angle

Table 2.2 Proportions of underestimation and overestimation of observations and mean error for wrist extension and flexion by posture

	E90°	E60°	E45°	E30°	F30°	F45°	F60°	F90°
Underestimation	8%	7%	5%	45%	27%	37%	68%	42%
Mean (SD)	18 (5)	14 (9)	13 (3)	20 (14)	14 (3)	14 (7)	31 (17)	16 (8)
Overestimation	28%	64%	77%	42%	47%	39%	18%	0%
Mean (SD)	19 (5)	19 (7)	19 (6)	15 (3)	16 (4)	16 (7)	15 (3)	--

n=260 for each posture

Observed Error

Error, calculated as the absolute value of the difference between the actual and observed angles, is shown for each posture and view in Table 2.3. For extreme postures, mean error for extension (E90°) ranged between 6-30° and 2-27° for flexion (F90°) depending on the view angle. The mean error for mid-range postures (F/E: 30°, 45°, 60°) ranged from 5-20°. For the neutral posture, mean error was lower, ranging between 0.2-4°. The overall mean error for each view across all postures is shown on the right side of Table 2.3.

A 9 (Wrist Angle) x 10 (View) analysis of variance for repeated measures was conducted in SPSS. Significant main effects of Wrist Angle and View and an interaction effect all at $p<0.0001$ were found.

Table 2.3 Mean error (and SD) in degrees by Viewing Angle and Posture for wrist flexion/extension

Viewing Angle	E90°	E60°	E45°	E30°	N 0°	F30°	F45°	F60°	F90°	Mean
Ulnar*	20.4 (11.2)	7.5 (7.6)	5.2 (6.5)	10.2 (6.8)	0.2 (1.0)	11.9 (7.2)	8.1 (8.7)	9 (6.6)	3.1 (7.4)	8.4 (7.0)
Radial*	20.6 (9.9)	7.3 (7.0)	12.9 (9.4)	15.0 (5.3)	1.7 (3.4)	10.7 (6.6)	7.7 (7.5)	7.1 (7.9)	3.5 (6.3)	9.6 (7.0)
Dorsal	16.9 (15.2)	16.5 (11.4)	12.9 (12.7)	12.7 (8.8)	0.6 (2.1)	15.2 (5.7)	16.1 (12.3)	25.4 (15.5)	8.3 (11.2)	13.8 (10.6)
Palmar	14.8 (19.6)	18.8 (15.6)	17.7 (12.0)	13.8 (11.8)	2.7 (4.5)	12.9 (8.1)	14.6 (12.3)	20.8 (13.2)	10.6 (15.2)	14.1 (12.5)
Fingertip	6.3 (8.8)	20.2 (8.9)	16.7 (12.9)	13.8 (11.1)	2.1 (3.5)	13.8 (11.4)	9.2 (13.3)	13.3 (9.6)	8.8 (10.8)	11.6 (10.0)
Ulnar Distal 45°	7.9 (7.5)	13.1 (9.8)	12.7 (10.5)	10.2 (9.6)	0.9 (2.3)	16.5 (6.9)	9.6 (11.8)	12.9 (8.5)	4.8 (8.3)	9.8 (8.4)
Radial Proximal 45°	18.8 (12.6)	10.8 (8.7)	7.9 (7.2)	8.1 (6.5)	1.3 (3.3)	18.0 (9.2)	10.0 (10.8)	19.0 (7.5)	4.2 (6.3)	10.8 (8.0)
Radial Dorsal 25°	23.1 (9.7)	9.0 (7.3)	9.8 (9.4)	9.0 (6.2)	1.9 (3.8)	11.4 (8.8)	10.6 (8.6)	7.5 (7.5)	3.1 (4.9)	9.5 (7.4)
Fingertip Dorsal 25°	19.4 (8.6)	8.8 (8.5)	6.0 (6.3)	7.9 (7.8)	2.5 (4.0)	12.3 (10.0)	19.3 (13.7)	16.7 (8.7)	2.7 (4.7)	7.6 (5.7)
Ulnar Dorsal 25°	29.4 (17.3)	11.9 (7.7)	8.8 (9.8)	19.6 (8.4)	3.5 (5.6)	17.9 (17.1)	19.8 (14.2)	11.7 (9.6)	27.1 (21.0)	10.8 (7.2)

**ideal view*

The mean error ranged between 7°-14° across views or about 8% of the wrist range of motion, showing that participants understood task requirements. The main effect of View, $F(9,225) = 13.3$, $p<0.0001$, was significant; the ideal views (Radial, Ulnar) had significantly lower error than all in-line views, supporting the hypothesis that ideal views produce more accurate estimates. Off-axis views (Figure 2. 5a, 5b) also had lower mean error than the in-line views. Interestingly, accuracy in the Radial Dorsal 25° view was at a similar level as the ideal views. The main effect of Wrist Angle, $F(8,200) = 26.1$, $p<0.0001$, was attributed to the high accuracy of observations of the neutral posture. The interaction effect, $F(72, 1800) = 6.4$, $p<0.0001$, meant that some postures were rated more accurately in some views compared to others.

Ulnar and Radial Deviation

This section presents results for observations of wrist deviation. Actual, apparent, and observed wrist angles are shown in each chart in Figures 6 and 7. Radial deviation is shown as negative and ulnar deviation as positive.

In the ideal views, Dorsal and Palmar (Figure 2.6a), the actual angles were included within one standard deviation of the mean observed values. Overall, accuracy was highest for these views, with mean error being about 5° less than for the in-line views. There were large errors in the in-line views (Figure 2.6b); overall, the mean error was at least 11° for each of these views. It appeared that observations were more accurate for ulnar deviation when made from the Ulnar view than when made from the Radial view. The other in-line views also did not produce the same results as was predicted by the model, but were instead closer to the measured values (Figures 2.6c and 2.6d). Errors tended toward underestimation. These results supported the hypothesis that parallax decreases the accuracy of observer estimates, but not as much as predicted by the model.

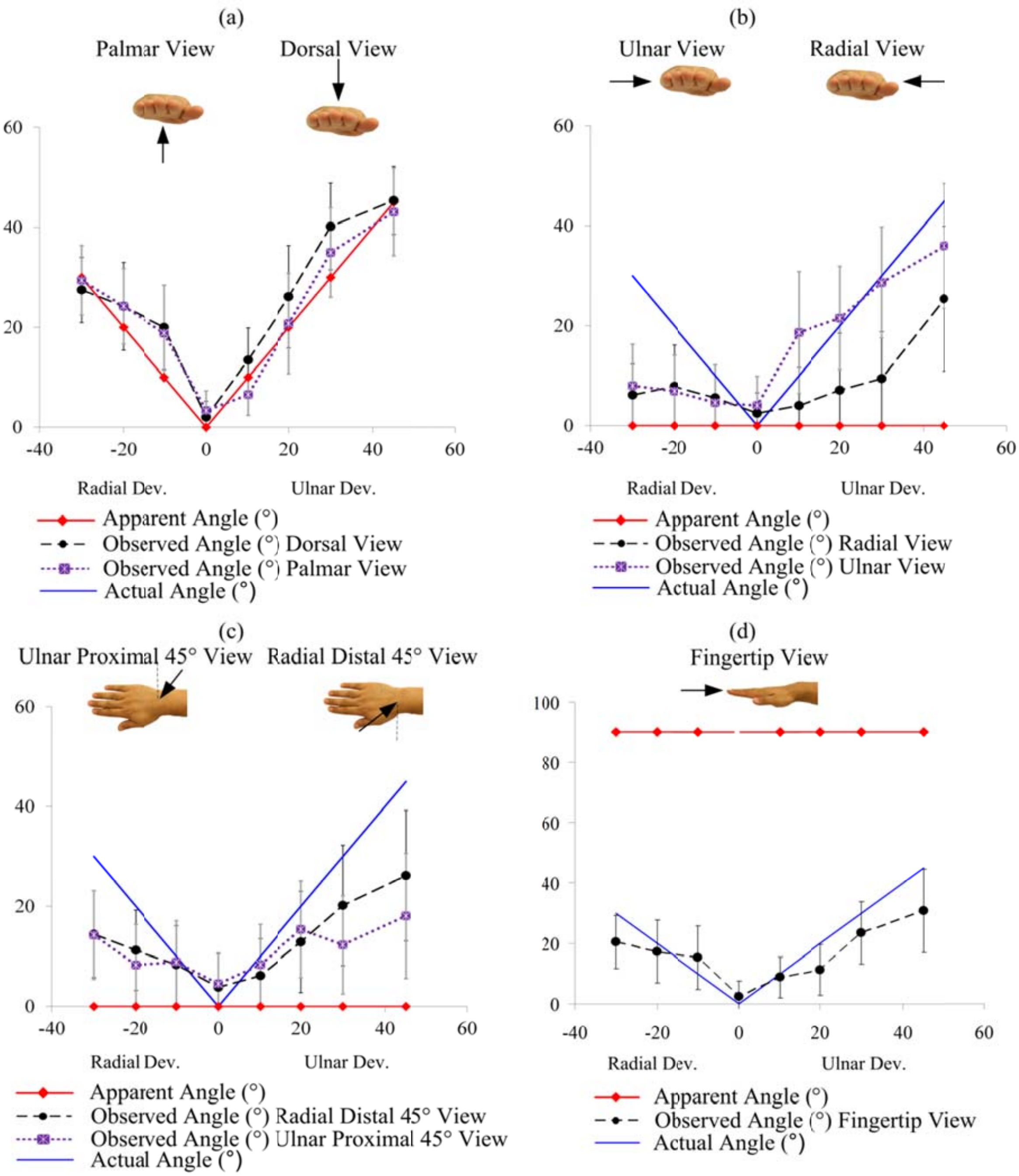

Figure 2. 6 Ideal and In-Line Views - Actual, apparent, and mean estimated angles (±1 SD) are shown (in °) for R/U deviation

In the off-axis views (Figure 2.7), there were remarkable underestimations of the angles seen across all postures in the Ulnar and Radial Dorsal 25° views (Figure 2.7a). As the posture became more deviated, the error also increased. These followed the values predicted by the model more than the actual angles. The Fingertip 25° view (Figure 2.7b) was more accurate that the predicted value, and, similar to the ideal views, the actual angles were encompassed within one standard deviation of the mean observed values.

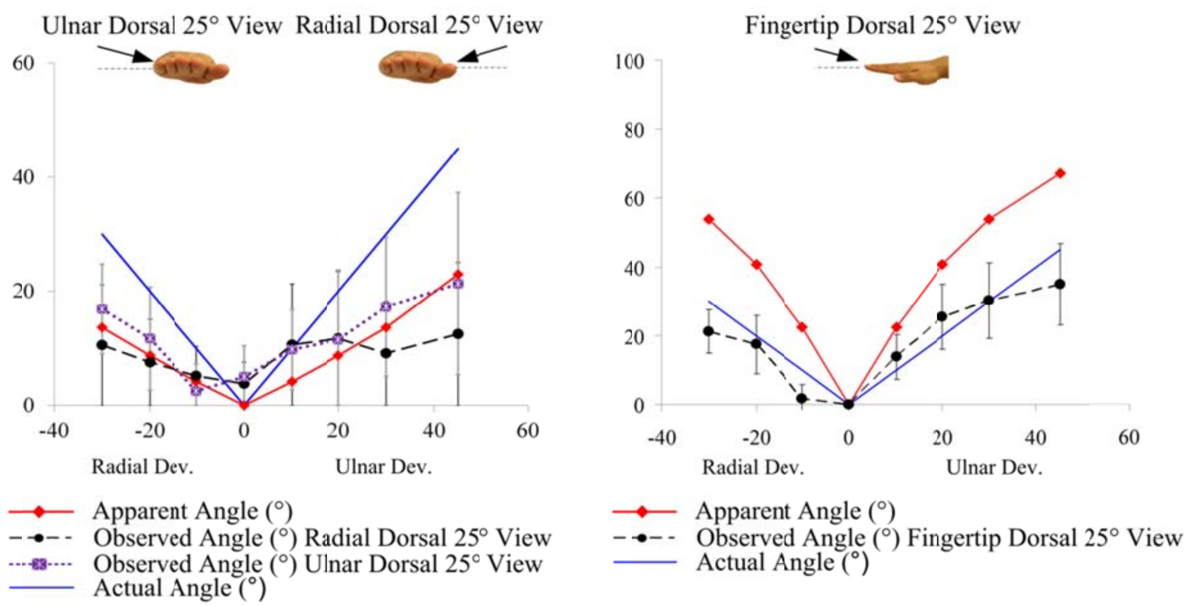

Figure 2.7 Off-Axis Views - Actual, apparent, and mean estimated angles (± 1 SD) are shown (in °) for radial and ulnar deviation

Underestimation and Overestimation

The proportion of overestimation, underestimation, and exact responses are shown by viewing angle in Table 2.4; the same is shown by posture in Table 2.5 along with the mean error. In total, 58% of the trials contained underestimates, 21% had overestimates, and 21% had no error. Seven views had >50% underestimation overall; this trend was also reflected when analyzed by Posture. The U45° posture was underestimated (67%) by a mean of 21°. The R30° posture was also underestimated (77%) by a mean of 16°. The overall underestimation seen in the most extreme radial deviation (R30°) posture was greater than half of the actual angle. These underestimation errors in the extreme postures were much less pronounced for the ideal views (<10°).

Table 2.4 Proportions of underestimation, overestimation, and exact observations for radial and ulnar deviation by viewing angle

	Ulnar	Radial	Dorsal*	Palmar*	Fingertip	Ulnar Distal 45°	Radial Proximal 45°	Radial Dorsal 25°	Fingertip Dorsal 25°	Ulnar Dorsal 25°
Underestimation	74%	54%	28%	18%	54%	66%	64%	67%	43%	62%
Overestimation	7%	24%	38%	50%	19%	14%	11%	12%	22%	14%
Exact	19%	22%	36%	32%	27%	20%	25%	21%	35%	24%

*ideal view; n = 182 for each viewing angle

Table 2.5 Proportions and means of underestimation and overestimation of observations and mean error for radial and ulnar deviation by posture

	R30°	R20°	R10°	U10°	U20°	U30°	U45°
Underestimation	77%	67%	49%	37%	55%	54%	67%
Mean (SD)	16 (5)	11 (3)	9 (1)	8 (12)	11(4)	15 (5)	21 (6)
Overestimation	3%	20%	29%	28%	30%	24%	16%
Mean (SD)	12 (2)	10 (2)	9 (4)	12 (6)	12 (3)	12 (4)	5 (1)

n=260 for each posture

Observed Error

Mean error for deviation postures is shown in Table 2.6. For extreme postures, mean error for radial deviation (R30°) ranged between 4-24° and 4-32° for ulnar deviation (U45°). Mean error for mid-range postures (R20°, R10°; U30°, U20°, U10°) extended from 3-21°. For the neutral posture, mean error ranged between 0-5°. The overall mean error for each view across all postures is shown on the right side of Table 2.6.

The mean error between all views ranged between 6.2° for the Dorsal view and 14.5° for the Ulnar view, a total difference of 8.3°. This range represented 7-18% of the range of motion. The mean absolute errors demonstrated that the participants were less accurate at estimating deviation than flexion/extension.

An 8 (Wrist Angle) x 10 (View) analysis of variance for repeated measures was conducted in SPSS. Significant main effects of Wrist Angle and View, and an interaction effect all at $p<0.0001$ were found. The main effect of View, $F(9,225) = 26.3$, $p<0.0001$ was significant. The ideal views (Palmar, Dorsal) had significantly lower mean errors than almost all other views. The in-line views (Radial and Ulnar) were observed to have the greatest error. The Fingertip and Fingertip Dorsal 25° views had lower mean errors relative to the other non-ideal views. The main effect of Wrist Angle, $F(7,175) = 47.6$, $p<0.0001$, was attributed to the accurate estimation of the neutral posture, similar to F/E postures. The interaction effect, $F(63, 1575) = 8.9$, $p<0.01$, also showed differences between specific postures and views.

Table 2.6 Mean Error (and SD) in degrees by Viewing Angle and Posture for wrist radial/ulnar deviation

Viewing Angle	R30°	R20°	R10°	N 0°	U10°	U20°	U30°	U45°	Mean
Ulnar	22.0 (8.3)	13.5 (6.3)	8.1 (4.5)	4.0 (5.8)	11.0 (10.1)	8.5 (6.0)	8.3 (7.3)	14.0 (12.5)	14.5 6.9)
Radial	23.8 (6.2)	12.9 (7.0)	6.7 (4.2)	2.5 (4.1)	8.6 (4.1)	16.0 (6.2)	20.6 (9.4)	24.6 (14.5)	11.2 (7.6)
Dorsal*	4.4 (5.3)	6.9 (5.1)	8.8 (9.6)	3.3 (3.9)	3.8 (3.7)	7.7 (6.4)	8.1 (6.2)	6.9 (8.7)	6.2 (6.1)
Palmar*	4.4 (5.3)	8.5 (4.6)	10.0 (8.5)	2.0 (3.2)	4.6 (5.6)	9.2 (7.4)	11.3 (7.0)	4.6 (6.8)	6.8 (6.1)
Fingertip	10.7 (7.3)	8.8 (5.9)	8.3 (8.2)	2.3 (5.1)	5.5 (4.0)	10.0 (6.9)	8.8 (8.4)	19.2 (13.7)	9.2 (7.4)
Ulnar Distal 45°	15.7 (8.8)	12.5 (6.8)	6.9 (4.5)	4.5 (6.1)	6.3 (5.2)	8.5 (6.4)	18.1 (9.1)	31.9 (12.5)	13.0 (7.4)
Radial Proximal 45°	15.6 (8.6)	10.3 (5.7)	5.9 (5.2)	3.8 (6.7)	5.7 (5.9)	10.2 (6.8)	13.3 (7.9)	23.8 (13.1)	11.1 (7.5)
Radial Dorsal 25°	13.1 (7.9)	10.2 (6.7)	8.3 (3.1)	5.0 (5.5)	4.8 (5.0)	13.5 (6.0)	14.2 (10.3)	28.6 (16.0)	12.2 (7.5)
Fingertip Dorsal 25°	8.6 (6.2)	7.1 (5.1)	8.6 (3.0)	0.0 (0.0)	5.0 (5.6)	7.9 (7.5)	8.6 (6.4)	15.0 (11.8)	7.6 (5.7)
Ulnar Dorsal 25°	16.7 (9.3)	10.3 (6.4)	6.3 (4.1)	2.9 (3.8)	6.5 (8.4)	10.2 (5.6)	8.5 (7.3)	24.8 (12.5)	10.8 (7.2)

*ideal view

Discussion

The Effect of Parallax

Viewing angle was observed to affect the accuracy of wrist posture estimation from static images. Based on the data obtained in this study, the hypothesis that there was no difference between observer and predicted parallax error was rejected. In fact, observers performed better than the model predictions. These findings have implications for observational analysis of wrist posture.

Parallax effects were shown to be non-uniform between views, as predicted by the model. As expected, the ideal views produced the most accurate observations for both flexion and deviation type postures. Observations from the in-line views were the least accurate, but interestingly were still better than the predicted values. Bao, Howard, et al. (2009) described large between-rater variations when "dorsal" views were used for F/E and "side" views were used for R/U deviation. Because the parallax model is limited to 2D and did not provide insight into how people estimate postures in 3D, we construe that the raters were using other visual information, such as the relative length of the hand segment or the visibility of the fingers.

The parallax model appeared to be effective at explaining the observations from some of the off-axis lateral views (Radial Distal 45° and Ulnar Proximal 45° for F/E, and Ulnar Dorsal 25° and Radial Dorsal 25° for R/U). For F/E, there may not have been a large enough change in view angle in the two Dorsal 25° views to alter the images significantly from the ideal views, which supports the idea that greater observation error is associated with viewing angles with larger perspective error. The neutral posture was estimated the most accurately and did not appear to be affected by parallax. The neutral wrist appeared as a straight line or a "point" regardless of view, which may be more easily recognized by raters.

Relative Accuracy

In absolute terms, observer accuracy was similar between posture types in that the range of mean error between views was similar for wrist flexion/extension and deviation. However, deviation has a much smaller range of motion (ROM). This error expressed as a percentage of ROM for F/E is approximately 12%. For deviation, this error is about 23% of ulnar deviation ROM and 34% for radial deviation ROM. By view, the mean error ranged between 21% (Dorsal) to 48% (Ulnar) of the ROM for radial deviation. If similar errors are present in existing studies using observational methods, the prevalence of the more extreme deviation postures may be largely underestimated.

Underestimation and Overestimation

Disparity was also seen in the bias, or tendencies to underestimate or overestimate postures. In F/E, wrist angles were overestimated 39% and underestimated 38% of the time. Mean overestimation error was consistently near 15°, but underestimation error varied more (10-25°) depending on the view angle. Certain postures were more affected than others; E45° was overestimated 77% of the time ($\overline{X} = 19°$) while F60° was underestimated 68% ($\overline{X} = 15°$). Note the proximity of these poorly estimated mid-range postures to cut points used for previously mentioned observational methods.

In wrist deviation there was a much greater tendency to underestimate (58%). Underestimation varied by view and by posture, with mean error increasing for more extreme wrist angles. The largest mean underestimation error occurred in the Radial view ($\overline{X} = 17°$). Underestimation was lowest for the two ideal views (Dorsal and Palmar) ($\overline{X} = 8°$). Overestimation (22%) was very consistent across views and postures ($\overline{X} = 10°$).

Wrist Deviation

The results of wrist deviation estimation show errors being exacerbated by non-ideal view angles and degree of posture. This suggests that at least novice raters are unable to estimate wrist deviation with accuracy needed for either practical or research purposes (~10%) without knowledge of the view angle.

These results confirm existing research reported by Lowe (2004), who analyzed the accuracy of estimates of peak and mode wrist postures from video using a 3-category scale (20° F/E and 10° R/U deviation cut points) and a 6-category scale (20° and 45° F/E and 10° and 20° R/U deviation cut points) and found significant misclassification. Error was primarily underestimation, especially for the extreme postures. Ketola, Toivonen, et al. (2001) also noted that their observers underestimated the prevalence of non-neutral postures according to a 20° cut point; poor validity in comparison to wrist goniometry data was also reported.

Use of Other Visual Cues

From the data, it appears that the parallax model does not explain the variation seen in the in-line views where raters did not estimate all the postures as the same. Participants likely integrated other visual cues into their judgments because unlike the model, the wrist is not a simple stick figure. For example, in observations from the Ulnar view, ulnar deviation was more accurate than radial deviation, but this was not seen using the Radial view. Further investigation into which cues are being used is warranted.

An alternative explanation is that the camera angle may not have been perfectly in line with the axis of rotation, in which case the model predicts small, but different apparent angles for each posture.

Research Implications

A collective underestimation of exposure to extreme postures would weaken or mask relationships between wrist posture and musculoskeletal disorders. These results converge with the lack of evidence of a strong relationship between epidemiological findings and exposure estimations. Observational studies should be examined for parallax effects by analyzing viewing angles used in data collection methods.

Based upon these results, the use of cut-points in observational methods may i) be ineffective and/or ii) less meaningful due to their susceptibility to parallax. For example, the Rapid Upper Limb Assessment by McAtamney and Corlett (1993) uses a 15° cut point for wrist deviation. It could be estimated that from a non-ideal viewing angle (e.g. Ulnar view), deviation postures up to 33° could be misclassified as not increasing risk, i.e. 83% of an assumed 45° ROM. The Strain Index (Moore and Garg 1995) moved away from cut-points to a scale with verbal anchors loosely based on cut points proposed by Stetson, Keyserling, et al. (1991) and Armstrong, Foulke, et al. (1982), which may be more appropriate.

New cut-points can be recommended based upon the observed error levels. For wrist flexion/extension, analysts might be expected to categorize using 5 cut-points [-65°; -30°; 0°; +30°; +65°], which may produce better inter-rater reliability. These intervals correspond approximately in size to those recommended by Bao, Howard, et al. (2009). For ulnar and radial deviation, analysts may only be able to categorize acceptably at verbal anchors of neutral (0°), non-neutral (>0°), and maximum (end-range).

Limitations and Further Study

The simulated conditions in this study do not reflect field conditions for visual recording of workers. This study included a finite number of well-defined postures, close-up views, constant image size, consistent background, and adequate lighting. These conditions may not be readily attainable where camera positioning depends upon the task, environment, and worker movement, or is often complicated by limited space, obstructions, and/or a need to avoid work interference. Wrist posture estimation errors may be larger under real life conditions.

Work objects may affect the ability to estimate posture. The relative size of a part may provide additional depth cues. Objects that change the hand posture (e.g. gripping) may increase the probability of certain hand postures (e.g. extension), which could be useful for the analyst. They could also mask view of the hand, making it more difficult. There may also be a need to study additional hand sizes, aspect ratios, and skin colors.

The wrist is a relatively small joint. Obtaining large wrist images may conflict with a desire to capture whole body images. Accuracy is expected to be even more affected by parallax in this case. The effect of parallax of postural evaluation of larger joints merits further study.

The study was designed to eliminate the need for experienced participants, but analyst experience may still have an effect. Lowe (2004) found no clear effect of analyst experience on the accuracy of posture estimates. A study of surgeons and trainees showed that experienced surgeons were more adept at perceiving elaborate 3-D structures from 2-D images than were trainees

(Sidhu, Tompa, et al. 2004), but the effect was smaller after trainees received training. Experience may influence posture estimation if a viewing angle is known; experienced analysts may be more adept at accounting for parallax and obtaining meaningful cues from movement and/or task knowledge. Still, it is difficult to know the exact viewing angle without measuring it, even with direct observation. Without knowledge of the view angle "experts" likely are as susceptible to parallax effects as the naïve observer, possibly explaining the similarities Ketola et al. (2001) observed between experts and non-experts.

In this study observers did not differentiate between flexion and extension or between radial and ulnar deviation. The two posture types were also considered independently, even though they often occur at the same time. Furthermore, forearm rotation was not considered in this study. In actuality, analysts do need to integrate these factors and decide how to categorize postures. Viewing angle may affect this task and the resulting accuracy may be worse in real wrist posture estimation situations.

A single viewing angle cannot capture all the ideal angles when more than one posture type is being evaluated simultaneously. Even when multiple views are being used in synchrony, care must be taken to obtain as much footage from ideal angles as possible. Techniques to control for parallax effects when recording in occupational environments are needed and, based upon our results, include i) recording from the ideal view for the posture type, ii) measuring view angles, and iii) providing (simultaneous) views from multiple angles to maximize the opportunity to capture the ideal view.

Conclusion

Novice raters are able to estimate wrist flexion/extension angles remarkably well given good image capture conditions, but are nevertheless susceptible to the effect of different viewing angles. Researchers and practitioners need to control systematically for parallax when collecting and using photographic data for posture analysis. Capturing from ideal views for the posture in question is recommended, in-line views should be minimized, and using multiple cameras is preferred even if not synchronized. Documentation of methods for image capture should be detailed sufficiently that others may interpret possible effects of parallax. Future investigation of the effect of off-axis views is recommended. Training analysts on minimizing parallax effects in image recording may improve the accuracy of observational estimates of wrist posture both from ideal and non-ideal viewing angles.

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Chapter 3

The effect of viewing angle on observational estimates of wrist flexion and extension from video recordings of simulated tasks

Abstract

The accuracy of observational assessment of wrist postures is affected by camera viewing angle when static images are used, but this may be different when using video recordings. The effects of viewing angle and task speed on estimation of wrist flexion postures were investigated in a laboratory study. Twenty-two university students viewed videos of a person performing ten short tasks from three different viewing angles (0°, 45°, 90° relative to the sagittal plane) and at two different working speeds (fast/slow). Subjects estimated the 95^{th} percentile peak wrist extension and flexion angles, and average angle in degrees. Estimates were compared to measurements of wrist angle using an Optotrak Certus infrared motion capture system. Error was calculated as the difference between the measured and estimated values. Main effects for task, subject, viewing angle, and speed were observed. Faster speeds were associated with approximately 4° more error. Viewing angle effects were much smaller than subject and task

effects. Mean errors ranged from 6-10°, but standard deviations ranged from 17-31°. Significant interaction effects were observed between viewing angle and task; viewing angle appeared to affect estimates more in tasks with high or low levels of wrist movement.

Introduction

Wrist posture is recognized as an important risk factor in the development of upper extremity work-related musculoskeletal disorders (National Academy of Sciences, 1999; Bernard, 1997). Exposure to awkward wrist posture is often assessed using observational methods, often as one part of a larger analysis method that assesses exposure to multiple risk factors (Li & Buckle, 1999; Occhipinti, 1998, Armstrong & Latko, 1997; Moore & Garg, 1995; McAtamney & Corlett, 1993;). The convenience and unobtrusiveness of observational methods to analyze upper limb working postures are reasons why researchers and practitioners select them instead of direct, instrumented measurement methods (Lowe, 2004).

Observational methods to evaluate wrist posture

Many observational methods to estimate upper limb ergonomic exposures have been developed. Of those with aspects specific to evaluating wrist posture exposure, several different analysis techniques are used. For example, Stetson, Keyserling, et al. (1991) and McAtamney and Corlett (1993) both use threshold values of wrist angles which, if exceeded, give rise to positive findings; Latko (1997) and Ebersole and Armstrong (2006) used ratings of peak and average (wrist) posture along a 10-point continuous scale based on the worker's range of motion where 0 is the neutral posture and 10 is the end range of motion in either wrist flexion or extension; Moore and Garg (1995) developed the Strain Index in which wrist posture is assessed according to a 5-point scale with verbal anchors of "very good" and "very bad" relative to the neutral posture; and Bao, Howard, et al. (2009) had raters estimate wrist flexion/extension angles in degrees from videos of task.

Studies of validity and reliability of observational methods

Various aspects of validity and reliability of observational methods used to analyze wrist postures have been evaluated. The reported inter rater reliability between different types of observational methods for estimating wrist posture exposure assessment generally has been weak. Latko (1997) examined the inter rater reliability of ratings of peak and average wrist posture on a 10-cm scale and reported intraclass correlation coefficients (ICC) of 0.18 and 0.10 respectively based on 12 jobs and 17 raters. Burt & Punnett (1999) found high percent agreement between two raters using the method described by Stetston, Keyserling, et al. (1991) for identifying wrist flexion and extension postures, but the associated kappa statistics were very low because positive findings were rare in the sample of tasks. Stevens, Vos, Stephens, & Moore (2004) investigated the inter-rater reliability of the Strain Index and reported intraclass correlation coefficients for hand/wrist posture ratings ranging between 0.68-0.84 for individual raters. Ebersole and Armstrong (2006) observed that a single pair of analysts rating 848 jobs had low ICCs for initial ratings of peak and average wrist flexion/extension (ICC = .43 and .36 respectively), which increased after discussion between the raters (ICC = .8 and .54).

Lowe (2004) reported significant misclassification and underestimation of wrist postures when compared to direct measurement methods. In his study, Lowe (2004) reported that ergonomists underestimated peak and average wrist extension with mean errors of 29% and 10% of joint ROM respectively and that variability in observer error was large for all wrist postures. Ketola, Toivonen, et al (2001) reported low validity when observations of non-neutral wrist postures made by an expert and by two trained analysts were compared to wrist goniometer measurements. Spielholz, Silverstein, et al. (2001) conducted an "inter-method reliability study" and observed only weak correlations ($r \leq .33$) between observed wrist movement variables and goniometry measurements. Juul-Kristensen, Hansson, Fallentin, Andersen, & Ekdahl (2001) compared wrist angles measured by goniometry and those registered by analysts and while they found similarities between them for wrist flexion, the observations were made using three large intervals over the entire range of motion.

There is a need to understand and improve observational methods to estimate wrist posture exposure more accurately and with better reliability (Balyut, Genaidy, Davis, Shell, & Simmons, 1995). Without improved methods, researchers will only be able to speculate about the relationship between wrist posture and WMSDs. Genaidy, Al-Shedi, et al. (1994) reported a paucity of reasons why existing research had provided so little insight into why observational methods had such weak accuracy and reliability. Bao, Howard, et al. (2009) suggested that reliability depended on variability of the posture parameters, camera positions, video quality, and complicated work postures. To date, only limited research has been conducted to investigate systematically the effects of these specific factors on observers' abilities to estimate exposure not only for wrist postures, but other ergonomic risk factors.

Parallax affects accuracy of estimation of static wrist posture

Viewing angle is one factor that has been shown to affect observational estimates of wrist posture (Lau & Armstrong, 2010). According to theories of parallax, changes in the viewing angle will produce images of joint angles that can appear larger or smaller than they actually are (Paul and Douwes, 1993). Lau and Armstrong (2010) determined that analysts were for the most part more accurate when angles orthogonal to the plane of motion, termed *ideal* angles, were used compared to *off-axis* and *in-line* viewing angles.

The results of Lau and Armstrong's (2010) study were only applicable to the estimation of wrist posture in static situations and not for dynamic ones, such as from a video recording or in person. In dynamic situations, motion parallax needs to be considered; as the worker moves to perform the task, the viewing angle of the wrist often changes relative to a stationary observer or camera. Changes in viewing angle may be brought about by changes in wrist, forearm, shoulder, torso, and lower body postures. Where direct observations are being made, the observer can also introduce motion parallax by moving him/herself.

Motion parallax created by the observer is one method that has been identified by researchers whereby humans can obtain visual depth cues (Rogers & Graham, 1979). This may be one avenue by which observers can overcome the static effects of parallax.

In dynamic situations, observers are often required to provide a point estimate, such as the peak or the average postural angle, for an entire task. This is different from estimates of posture from static images because it either involves the observer identifying a particular point in the task where the peak postural angle occurs, or it involves integrating all the observed postural angles and their respective durations over the observation period into an average value.

Lau and Armstrong (2010) demonstrated that observers are able to account for the effect of unknown viewing angles to some degree presumably because other visual cues were available. Observation of dynamic tasks have richer visual environments than static ones and here the observer may be able to use visual cues such as movement, predicted movement based on task, motion parallax, and relative distances to external objects to aid estimation.

Task speed

The speed of motion may also affect estimation if changes in posture occur too rapidly for an observer to detect. Faster motions may impede one's ability to identify peak and average postures over the task cycle. A few observational methods attempt to record the speed of work either directly (e.g. Strain Index) or indirectly through recording percentages of the cycle time spent in a given posture, however, how the speed affects the exposure assessment of posture has historically not been specified.

Study objectives

The primary objective of this study was to investigate whether viewing angle and task speed affected observers' estimates of peak and average wrist flexion and extension joint angles in degrees from video recordings of simulated tasks. This rating method is the similar to that proposed by Latko (1997), but instead of using a 10-cm visual analog scale, raters estimate wrist joint angles in degrees. The secondary objective was to compare these estimates to angles measured by a motion capture system to determine the accuracy of the estimates. A tertiary objective was to determine whether task speed affected the accuracy of the estimates as well.

The null hypothesis was that estimates of wrist flexion and extension postures should be the same regardless of what viewing angle the task was viewed at or what speed the task was performed at. It was expected that when the viewing angle was predominantly an ideal angle for the duration of the task, estimates would be more accurate for that view. As the viewing angle moved away from the ideal angle, it was expected that the error would increase as parallax increased. Regarding task speed, it was expected that when it was faster, estimates of said wrist joint angles would be less accurate because visual cues from motion parallax not be as easily observed.

Method

Experimental preparation of task videos

Thirteen short tasks were simulated by a research associate in a laboratory environment and these were recorded simultaneously from three different viewing angles. Table 3.1 provides a brief description of each task. Similar to Lowe (2004), tasks were treated as repetitive mono-task activities. The tasks were designed to incorporate a variety of working postures of the wrist and were limited to a maximum 30-second cycle time. The associate wore a short-sleeved shirt to minimize the risk of clothing masking wrist postures. All tasks were performed on a workbench positioned at a height of 92 cm.

Table 3.1 Names and descriptions of the simulated tasks

Task Name	Task Description
Bolts	Three bolts were screwed into a plank of wood with a powered drill
Box	A taped cardboard box was cut open using a box cutter
Candy	A box was packed with 48 chocolate bars
Caps	Caps were placed and tightened onto eight bottles of a sports drink
Clock	The battery of a wall clock was inserted into the back of the back
Glue	Small wooden cutouts were glued onto a board with a glue gun
Hammer*	Three nails were hammered into a plank of wood
Pegs	Pegs were inserted into a piece of Styrofoam
Pipette*	Liquid was transferred from a beaker into test tubes using a pipette
Scoop	Ice cream was scooped from a gallon tub and put into plastic cups
Vice	Two vices were used to fasten a plank of wood to the worktable
Wipe*	Repeated scrubbing back and forth over a small area with a sponge
Wires	A wire was stripped using wire strippers to expose individual wires

* indicates the task was excluded from the results due to measurement error

The associate performed each task at two different speeds (fast/slow). Task speed was not measured objectively; in the fast condition the associate performed the task as fast as possible without making any mistakes and in the slow condition, the associate performed the task at a slower speed bounded by the 30-second cycle time limit.

Three similar digital video cameras were used to record the tasks from different viewing angles. The cameras were stationed 1.8m away from the right limb of the associate: Camera 1 was situated 0° in front and captured a sagittal view, Camera 2 was placed 45° to the right of the associate, and Camera 3 was placed further right at 90° and captured the right lateral view (Figure 3.1). Camera placement was selected to capture an ideal view and an in-line view for each task.

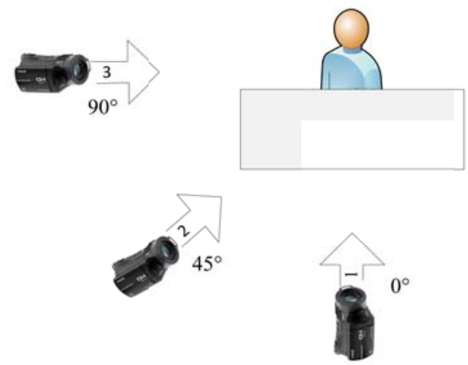


Figure 3.1 Overhead view showing the three camera locations with respect to the task simulation

A black backdrop was used to control for background objects and shadows. Image size was held constant by keeping approximately the same proportion of the associate visible in the display window of each camera. A six-inch scale printed on yellow card stock was situated in each video to provide the viewer with a constant reference in case the image size was different between videos. The right wrist of the associate was always visible in each video.

Each video was analyzed and the view of the wrist joint predominantly captured throughout was rated and documented and these are shown in Table 3.2. Where possible, the view naming convention described by Lau and Armstrong (2010) was used, but it is likely that the actual viewing angle was not purely orthogonal to the plane of movement of interest.

Table 3.2 Predominant views of the wrist angle in each task by viewing angle

Task	Speed	Viewing Angle (0°)	Viewing Angle (45°)	Viewing Angle (90°)
Bolts	Fast	Lateral	Off-axis	In-line
	Slow	Anterior/lateral	Off-axis/bottom/lateral	Bottom/lateral
Box	Fast	Anterior/lateral	Off-axis	Lateral
	Slow	Anterior	Off-axis	Lateral
Candy	Fast	Anterior	Off-axis	Lateral
	Slow	Anterior	Off-axis	Lateral
Caps	Fast	Anterior/lateral	Lateral/off-axis	Off-axis/bottom
	Slow	Off-axis/lateral	Lateral/off-axis	Off-axis/bottom
Clock	Fast	Top/lateral/off-axis	Lateral/top	Lateral/off-axis/top
	Slow	Top/lateral/off-axis	Top	Lateral/off-axis/top
Glue	Fast	Top/off-axis/anterior	Top	Top/off-axis
	Slow	Top/off-axis/anterior	Top	Top/off-axis
Pegs	Fast	Anterior/top	Off-axis/lateral	Off-axis/lateral
	Slow	Anterior/top/off-axis	Lateral/up/off-axis	Lateral/up/off-axis
Scoop	Fast	Lateral/top	Bottom/lateral/top	Bottom/lateral/top
	Slow	Lateral/top	Bottom/lateral/top	Bottom/lateral/top
Vice	Fast	Lateral/bottom/top	Lateral/bottom	Bottom
	Slow	Lateral/bottom	Lateral/bottom	Bottom
Wires	Fast	Anterior/top/off-axis	Top	Top
	Slow	Anterior/top/off-axis	Top/lateral	Top/lateral

Direct measurement

An Optotrak Certus motion capture system with two position sensors was used to record the wrist position throughout the task. Seven strobers were placed on the right upper limb of the model: on the upper arm, three on a rigid washer on the forearm located at the distal one-third of the forearm, the lateral epicondyle, the wrist joint center on the posterior wrist, and on the third metacarpophalangeal (MCP) joint on the dorsal hand. The strobers were 4mm in diameter and were faintly visible in the video recordings, but were not expected to influence the posture estimation task. Small strober wires were secured using a flesh-colored elastic bandage. Co-ordinate locations (x,y,z) were recorded for each strobe at 100 Hz. Video and motion capture data were synchronized using a tone emitted at the end each trial.

Motion-capture data were used to determine the 95^{th} percentile and average angles of wrist flexion and extension, calculated as the angle between the plane formed by the three markers on the forearm and the plane formed by the three markers on the hand. Occasional strober dropout occurred and missing data were interpolated from surrounding data. Consecutive data losses for greater than one second were not interpolated and these tasks were excluded from the results. This occurred for three of the thirteen tasks.

Participants

Twenty-two engineering graduate and undergraduate students participated in this study. Participants were inexperienced in posture analysis. Subjects were monetarily compensated a fixed amount for their participation.

Equipment

Experimental video presentation and data collection were coordinated on a computer using MediaLab (v2006.1.29). The study was conducted using an 18" LCD monitor, where videos were sized approximately one-half of the screen area.

Protocol

Participants were first given a short training session similar to that described in Chapter Two in which they were shown simple diagrams of a wrist positioned in flexion and extension with lines drawn on the long axes of the forearm and hand. The angle to be rated was indicated to them for each posture. Practice trials were given using exemplar images captured from ideal views and feedback was given after each trial. Participants were then shown several videos of a person performing a simulated task and asked to estimate the 95th percentile peak wrist extension, 95th percentile wrist flexion postures, and the average wrist posture. Feedback was given in degrees. Participants verbally indicated that they understood how to perform the task prior to the start of the experimental conditions. The diagrams were made available throughout the study as reference if the participant needed them. Participant use of these materials during the study was not recorded, but appeared to be limited under informal observation.

Participants were instructed to estimate the 95th percentile wrist extension, the 95th percentile flexion, and the average wrist posture, in that order, for each condition. They were instructed not to estimate the absolute peak posture that they observed, but to use this as the upper limit from which to estimate a 95th percentile from. The 95th percentile was chosen instead of an absolute peak to attempt to exclude random extreme postures that occurred less than 5% of the time. This rating method was adapted from Ebersole and Armstrong (2006). The 95th percentile postures will heretofore be referred to as the "peak" postures. Participants were allowed to pause and or replay each video as many times as necessary to replicate typical analysis conditions. This may have negated some effect of speed, but participants were qualitatively not observed to use this feature excessively.

Due to the unique nature of some of the tasks, participants may have been able to remember a task viewed previously from a different viewing angle. To control for order and history effects the videos of each task were assigned to three groups, group order was randomized among subjects, and task order within groups was randomized among subjects.

Data analysis

'Actual' wrist angles were calculated from the motion capture data. The three strobers on the rigid plate were used to calculate the approximate plane of the forearm and wrist. The vector calculated by the wrist and MCP joint marker was projected onto the plane and the resulting angle was obtained, where extension and flexion were noted by positive and negative values respectively. Missing values were interpolated using piecewise cubic Hermite interpolation for sequential data losses that were less than one second. Data loss greater than one second resulted in the task being eliminated from the results. The 5^{th} and 95^{th} percentiles and the average postures were calculated for each task and speed condition.

Estimates of posture were compiled across subjects for each variable and condition. Analyses of variance were conducted in PASW 18 (SPSS) to determine statistically significant differences between the experimental conditions. Univariate analyses of variance Task x Speed x Viewing Angle (10 X 2 X 3) were conducted in SPSS for estimated angle, error, and absolute error. Subject was included in the ANOVA models as a random effect and two-way interactions were analyzed. Here, total variance is equal to the variance due to viewing angle, speed, subject, and error.

Results

Participants completed estimates for 13 tasks, at two movement task speeds, and three viewing angles. Marker occlusion resulted in excessive motion capture data loss for three tasks (Hammer, Pipette, and Wipe). All three tasks were removed from the data set and results for the remaining ten tasks are presented (N=1320 total observations).

Estimates for peak extension, peak flexion, and average wrist posture were obtained. These were compared to the actual values as measured by the motion capture system to obtain *error* calculated as the difference between the actual angle and the estimated angle.

Table 3.3 and Figure 3.2 present the mean results and standard deviation for the peak estimates of extension (a.) and flexion (b.), and the average posture estimates (c.) by task for each viewing angle condition. The variability was quite large; standard deviations were often greater than the means themselves, which demonstrated large inter-subject variability.

Table 3.3 Mean absolute errors by viewing angle

	0		45		90			
	Mean(°)	**SD**	**Mean (°)**	**SD**	**Mean**	**SD**	**Overall Mean**	**Overall SD**
Average	9.0	17.2	11.2	17.3	9.3	19.1	9.8	17.9
Extension	8.0	20.1	10.0	18.3	7.9	21.0	8.6	19.8
Flexion	7.2	29.5	6.3	30.9	6.2	32.1	6.5	30.9
Total	**8.1**	**22.3**	**9.1**	**22.2**	**7.8**	**24.1**	**8.3**	**8.1**

Figure 3.3 shows the mean estimated peak wrist extension and flexion angles, and the actual angles (a and b), and the mean error by viewing angle (c and d) for each task, combined on speed. For two tasks, Candy and Pegs, error in estimated peak flexion was observed to be significantly larger than for other tasks. Further investigation revealed that the measured peak values in these two tasks were transient and most likely were excluded by the subjects as per experimental instructions. Overall, peak extension estimates tended to be underestimated compared to the actual values; peak flexion estimates were observed to have both been underestimated and overestimated.

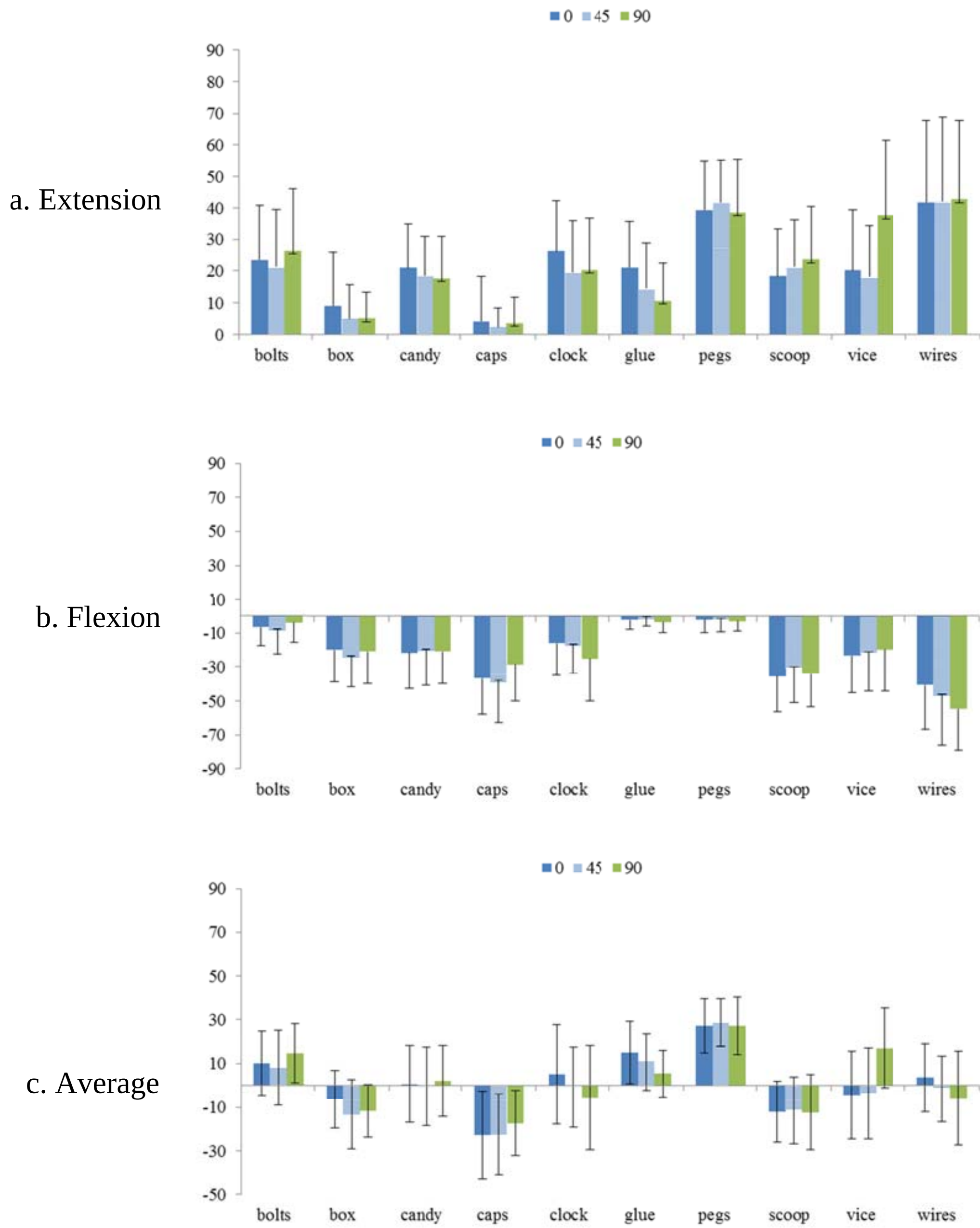


Figure 3.2 Mean estimates (°) +/- 1 SD by task for a. Extension, b. Flexion, and c. Average wrist posture by viewing angle

A Task(10) x Speed(2) x Viewing Angle(3) analyses of variance of Error was conducted in SPSS for estimated peak wrist extension, peak wrist flexion, and average wrist posture with Subjects included as a random effect to test between means for significance. Significant findings are listed in Table 3.4 ($\alpha < .05$). An analysis of variance with all three posture variables combined was also conducted and results are also shown in Table 3.4.

Participants estimated posture variables with differing accuracy between tasks. A main effect of task was observed for Error for the posture variables, meaning different tasks were associated with different levels of error. This was especially apparent in the large effect size seen for mean estimates of peak flexion, largely attributable to the two tasks, Candy and Pegs. When these two tasks were removed from the model, the F-value dropped significantly to $F_{(7, 147)}=45.620$, $p=0.000$. Tasks were designed to elicit different peak and average postures.

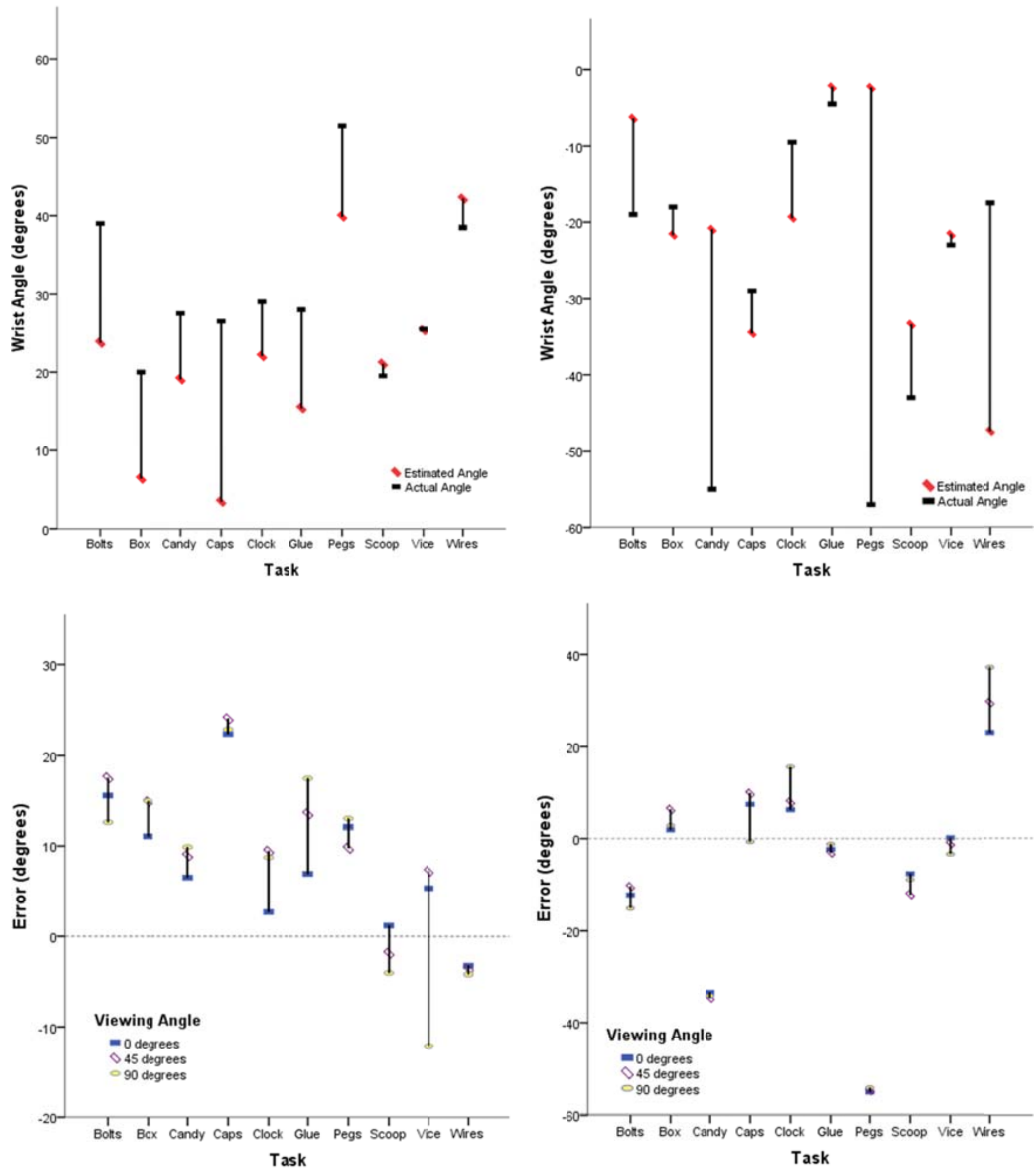


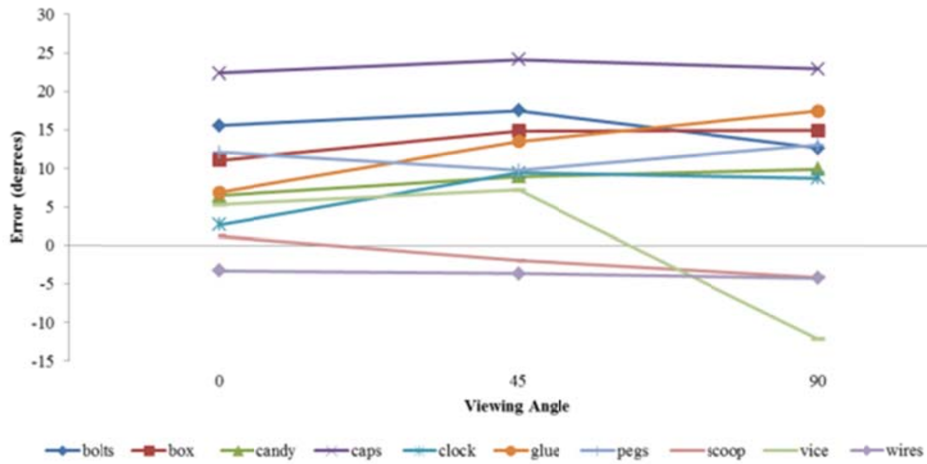
Figure 3. 3 Mean estimates of peak wrist extension and flexion (a and b) and respective error (c and d) by task

Table 3.4 Significant effects of four Task (10) x Speed (2) x Viewing Angle (3) analyses of variance on Error for estimates of peak wrist extension, flexion, average, and overall postures

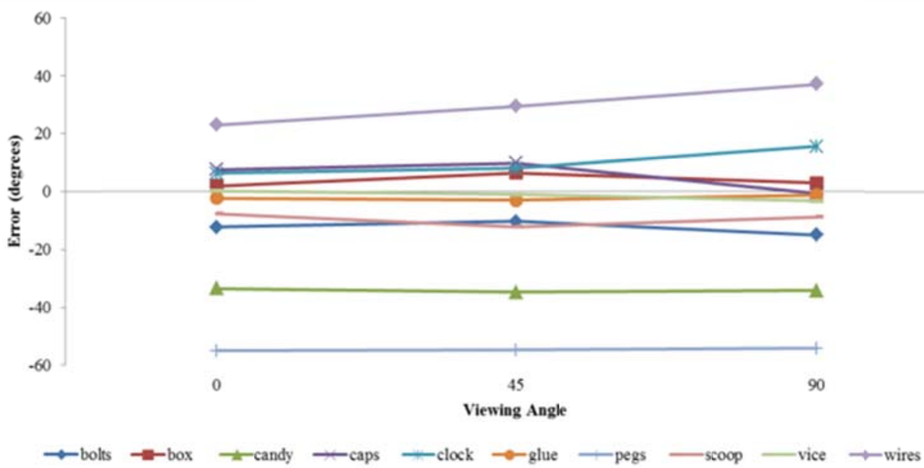
		Peak Extension		Peak Flexion		Average Posture		Overall	
	df	**F**	**p**	**F**	**p**	**F**	**p**	**F**	**p**
Task	(9, 189)	19.024	0.000	142.68	0.000	13.409	0.000	44.011	0.000
Speed	(1, 21)	35.978	0.000	31.364	0.000	0.178	0.677	0.101	0.754
Viewing Angle	(2, 42)	2.888	0.067	0.576	0.567	5.496	0.008	5.085	0.011
Subject	(21, 49)	11.290	0.000	13.646	0.000	4.919	0.000	19.114	0.017
Viewing Angle x Task	(18, 1005)	5.743	0.000	3.489	0.000	6.246	0.000	3.867	0.000
Speed x Task	(9, 1005)	55.821	0.000	96.558	0.000	3.334	0.000	14.901	0.000
Subject x Task	(189, 1005)	2.976	0.000	2.974	0.000	2.632	0.000	1.516	0.000

A main effect of Viewing Angle was observed for the error of estimates of average posture and also across all ratings (overall). Main effects were not observed for peak estimates. Interaction effects were observed for Viewing Angle x Task for all types of estimates (Figure 3.4). There were cases in each posture type where error increased systematically from the 0° view to the 90° or vice versa. This was not a pattern across all posture variables, but seemed to be more relevant for the Average posture estimates. In a few instances, error associated with one view was observed to be greater than the other two views (e.g. Candy, Glue). The peak flexion estimates were observed to have smaller differences in error between viewing angles by task.

a.
Extension



b.
Flexion



c.
Average

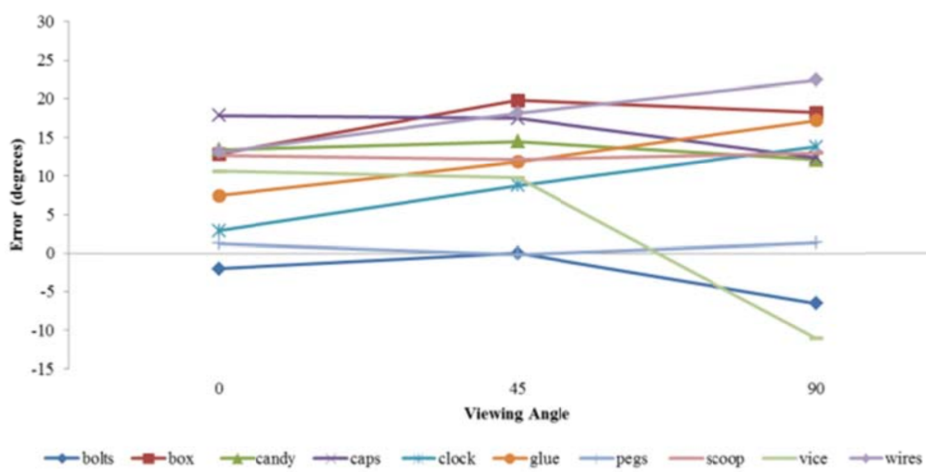


Figure 3.4 Mean error by task for each estimated posture condition: a. Extension by Viewing Angle and Task; b. Flexion by Viewing Angle and Task; and c. Average Posture by Viewing Angle and Task

Speed was observed to have an effect on peak posture estimates. Faster speeds were associated with an increased error (~4°) for peak extension and peak flexion estimates. Figure 3.5 shows the differences in mean error of the estimates by speed and wrist posture variable. Speed was observed to have a neither a significant main effect on estimated average wrist angle nor overall.

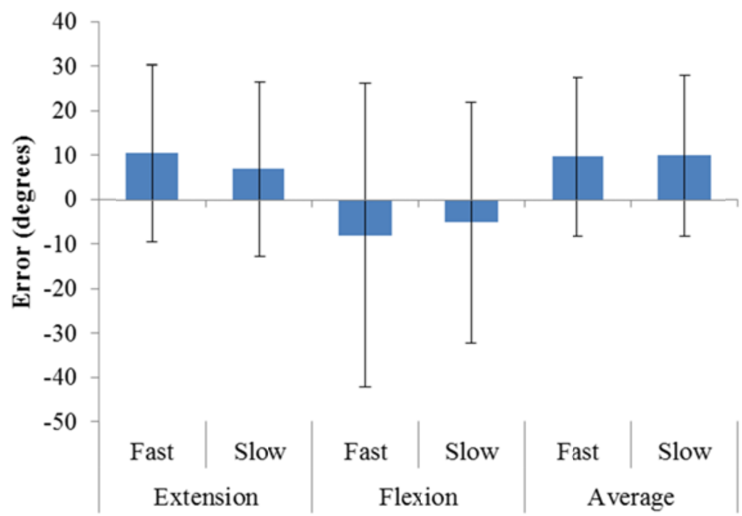


Figure 3.5 Overall mean error of estimated wrist angle by speed and evaluated posture (±1 SD)

Figure 3.6 shows the effect of speed by task. For the majority of the tasks, the error was lower for the slow speed compared to the fast. Fast speeds had on average a 4° greater error than the slow speeds.

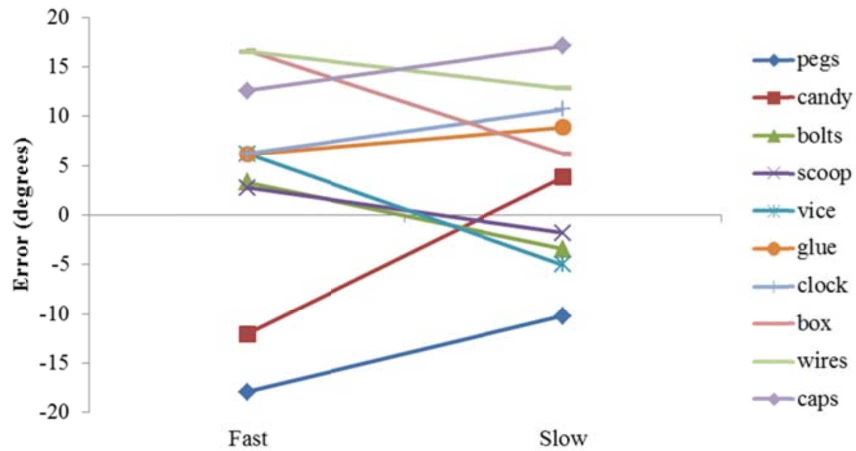


Figure 3.6 Mean error of combined estimates for peak extension and flexion, and average wrist posture by speed of task

Discussion

Overall task performance

The variance in the estimates was most largely explained by differences between tasks and between subjects. The subject effect showed that subjects differed greatly in their ability to rate peak and average wrist flexion and extension postures of short tasks. The large variation is consistent with low inter-rater reliability reported by Latko (1997), from which the ratings methods were adapted from. Lowe (2004) reported very large classification errors by ergonomists using categorical rating scales for wrist flexion. Lowe (2004) also observed that ergonomists' ratings of peak and average wrist flexion/extension using a continuous visual analog scale had low correlations with corresponding measurements using electrogoniometry. Together, these findings strongly suggest that raters cannot be expected to rate with high levels of precision.

Mean error ranged between 15°-24° for the different types of estimates across subjects and tasks. This amount of error was approximately 10° larger than the mean errors reported by Lau and Armstrong (2010) for ratings of wrist posture from static images. Providing peak or average point estimates of wrist angle from observations of tasks appear to be more difficult than simple static images.

The poor precision and inter-subject reliability of the estimates suggests that more training is needed, better techniques for this type of rating task need to be developed, or this task could be beyond the capabilities of observers. For example, training videos could provide feedback using directly measured postures or have the worker demonstrate full range of motions the rater can use as benchmarks.

The effects of viewing angle

Estimates of wrist posture from static images are known to be affected by viewing angle, but the effect was expected to be tempered dynamic situations.

Parallax is still present when estimating wrist posture in dynamic situations, but its effect is most likely not constant. The variance explained by viewing angle was less than that due to subject and task differences.

For the three posture estimates, a main effect of viewing angle was observed for estimates of average wrist posture, but not the peaks. The constantly changing viewing angle may have assisted in identifying the peaks across the three camera angles. The visual cues that observers receive from movement and movement trajectory can be used to compensate for changes in viewing angle. For less mobile tasks such as using a powered drill to fasten bolts, viewing angle changes would occur less or less dramatically than for tasks with more wrist movement such as fastening a vice. The wrist may change viewing angle more frequently than many other body joints of interest because it is subject to rotation from the shoulder, elbow, and forearm, making it difficult to plan video recording for observational analysis.

Important interaction effects were observed in error between viewing angle and task. It appeared that this interaction could be divided into three categories: i) no differences, ii) linear increase in error , and iii) one viewing angle error was different than the other two. The third case, evidenced by the Vice task, showed that 90° view, which was an in-line view, had greater error than the other two views. When using only one camera, it might be a beneficial strategy to use the 45° view to hedge against selecting the least accurate viewing angle in the third case. This would be different than the recommendation by Lau and Armstrong (2010) to capture from the ideal angle in the static case.

The type of wrist movement may explain viewing angle differences for the two cases with the largest difference between viewing angles, Vice and Glue. The Vice task involved repeated supination and pronation of the forearm, causing large and frequent changes to the viewing angle in any one recording. The most salient postures would be when the movement switches direction. The Glue task involved very little movement of the wrist because the model was holding a glue gun and working in a small space, similar to parallax effects in static situations. These two types of movement characteristics may cause the larger differences as seen in viewing angle.

Effect of speed

Speed of task performance had a large effect on the accuracy of peak estimates and faster speeds were associated with greater error (~4°) than slower ones. This confirms our hypothesis that faster movement speed affects rating accuracy; however, the magnitude of effect is small when compared to the inter-subject variability and may not be influential at a risk level. Faster, more ballistic movements may be responsible for higher peaks that are transient and less noticeable to observers. The difference between task speeds was not controlled beyond instructing the associate to work as fast as possible in the Fast condition.

Limitations

Subjects were obtained from a university engineering student population, but they did not have any prior experience with estimating posture angles or other video analysis. This was not expected to have an effect on the results because the task was simplified to a level that was easy to understand by participants. Ketola et al. (2001) observed similarities between experts and novices but differences between observations and objective measures. Lowe's (2004) sample of 28 ergonomists from academia and industry had considerable accuracy concerns as well. It appears that experienced raters fare similarly compared to novice raters. These findings suggest that either i) experienced raters are as limited in their ability to rate wrist postures as novices or ii) a more thorough and comprehensive training regimen needs to be developed before we can rely on human observations to estimate exposure to awkward postures.

Subjects were not familiar with the task; they rated based on what they were seeing from the video only. They were not given any task information such as object weights, sizes, and were not given the opportunity to view the tasks firsthand. It is possible that experienced raters may be able to predict movement trajectories more compared to inexperienced raters. Further study comparing results to direct observations may be useful.

Subjects could pause the video in the experiment. This was intended to be reflective of expected video reviewing capabilities. This may have confounded the movement speed effect by turning the dynamic estimating task into a static one. Qualitatively, subjects were not observed to pause the video excessively. Subjects were paid a flat fee for their participation, which did not incentivize longer experiment-taking. They were instructed to work at a reasonable pace, without feeling a need to be perfect. They could also still see the frames leading up to and after the point of the pause, enabling them to see the visual cues that were found to be important from the static analysis. If pausing did have an effect, then we might see an even greater effect of speed.

The ability for subjects to integrate mentally the posture over time to come up with an overall estimate may have been compromised by the ability to pause the video. Pausing the video may have led to an exaggeration of the effect of a particular posture that the video was paused at. However, given the nature of the task and the short duration of the videos, this was not expected to be large distractor.

Another limitation of this study is the assumption that the motion capture method used to measure the actual wrist angle is as accurate as it purports to be. The data collected was analyzed in the same manner for each task and there were no changes to the equipment during the task simulation phase, therefore any inaccuracies would be consistent throughout the tasks and results would be similarly biased across all subjects.

Acknowledgements

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Chapter 4

Task orientation and its effects on subjective ratings and insertion characteristics in manual rubber hose installation

Abstract

Manual hose installation is performed in many ways in many different industries and requires high hand forces. It has been shown that the direction and orientation of force affects both strength and perceived exertion. Psychophysical approaches have been used extensively to determine acceptable task design limits (Snook & Ciriello, 1991). A laboratory study was conducted to investigate how perceived hand force, overall difficulty, and postural comfort, and other insertion dynamics are affected by task orientation. Fourteen subjects (7F, 7M) performed a simulated hose insertion task on a tri-axial strain gauge for ten different orientations. Subjects rated each orientation on 10-point visual analog scales. Insertion forces were measured in three dimensions and maximal efforts for each orientation were obtained. Results indicated that orientation affected perceived difficulty and postural comfort, but not applied hand force. Orientation also affected peak resultant insertion force, insertion strength, and

grip posture adopted, but neither percent capacity used, nor insertion time. Insertion strength was affected by orientation, as was the peak axial insertion force, such that the percent capacity (%MVE) and relative perceived hand forces were constant. This finding is important as most tools for assessing risk of musculoskeletal disorders and fatigue are based on relative force. Findings have implications for the design of manufacturing tasks; the orientations that will minimize peak axial insertion forces are Push Down, Push Medial Down 45°, Push Medial, and Push Medial Up 45°.

Introduction

Flexible hoses are widely used and installed by hand in many industries, e.g., automobiles, aircraft, and appliances and have been studied in mainly in automotive contexts (Grieshaber, et al. (2009), Andrews, Potvin et al. (2008), Robinson (2005), Lau, Drinkaus et al. (2006)). Sufficient grip or pinch force must be applied to the hose to keep it from slipping out of the hand as it is pushed onto a flange. Hose installation jobs are often repetitive and require high hand forces that may be exerted in different directions at different locations in space. Physical studies of automotive workers by Ebersole et al., (2005) found hose installation to be among the most demanding tasks. The National Academy of

Sciences (1999, 2001) concluded that repetitive, forceful exertions, especially in extreme or awkward postures, were associated with fatigue and musculoskeletal disorders (WMSDs). Understanding of how perceived hose insertion forces are affected by force direction is needed to study the contribution of hose insertion forces to work-related musculoskeletal disorders. The findings can provide insight into the accuracy of subjective force requirements for other manual tasks.

Lau, Drinkaus, et al., (2006), Grieshaber & Armstrong, (2007), and Grieshaber, Armstrong, et al., (2009) conducted studies on manual hose installation in which hoses were only pushed forward onto the flange, but hoses may be inserted in many directions. Hose insertions often are constrained by the flange orientation and local obstructions, such that workers have limited hand and body access to the flange. One of the few studies in which hose installation was studied for multiple directions was by Andrews, Potvin, et al., (2008) who found that subjects exerted a consistent level of maximal voluntary exertion (MVE) of 63% at a rate of one exertion per minute across insertions.

Magnitude estimation of force has been used in many studies where force data was too difficult to collect. The power function relationship between estimated and actual characteristics using the psychophysical approach has been demonstrated to be robust for many different types of variables (Stevens S. S., 1964). Psychophysical approaches have been used extensively to determine acceptable task design limits (Snook & Ciriello, 1991).

Hose insertion direction and location affect worker posture, which are believed to affect insertion capacity. Different orientations may place the worker at a biomechanical advantage or disadvantage (Chaffin, Andersson, & Martin, 2006; University of Michigan 3DSSPP™). We hypothesize that workers exert lower levels of effort as measured by a strain gauge and have lower levels of perceived effort for insertion orientations that are biomechanically advantageous.

Hypotheses

The basic hose-flange interference properties that affect the force required to install a hose are the same regardless of insertion direction; the minimum force required to put the hose on is constant. The null hypothesis is no difference in peak and average insertion forces between orientations.

Grip strength is maximized when the upper extremity is in a neutral posture (O'Driscoll, Horii, Cahalan, Richards, & An, 1992; Pryce, 1980). Differences in strength between orientations are hypothesized because of posture differences, as some postures will be closer to neutral than in others. Orientations that rely on upper limb strength and cannot utilize lower body musculature will also have lower capacities and ratings.

With identical required insertion forces, but different strengths or capacities between orientations, it was hypothesized that subjects would not insert hoses at the same percentages of their capacity between orientations. Insertion orientations with higher strengths were expected to be completed at lower percentages of capacity than the other orientations.

Perceived hand force ratings were hypothesized to be similar between orientations because the required force is the same. However, when a posture affords a greater ability to generate thrust force to insert the hose, the perceived demand or difficulty is expected to be lower. Awkward or extreme postures were hypothesized to contribute adversely to perceived ratings of difficulty and comfort, however, some research has shown that workers sometimes preferred working in postures that would be classified as 'awkward' (Imrhan & Farahmand, 1999). Men were hypothesized to perceive the insertions as less difficult than women, because of greater strength.

Insertion time was hypothesized to change with orientation; orientations with lower perceived ratings of difficulty were expected to take less time and more difficult insertions were expected to take longer.

Method

Study Design

A laboratory study was conducted where participants inserted a hose onto a flange that was positioned in 10 different orientations (Figure 4.1). A factorial design was used and each subject performed two insertions, two maximal exertions, and gave ratings of perceived hand force, task difficulty, and comfort for each orientation. Orientation order was randomized. Insertion forces and hose position along the flange were recorded. Flange tip height was normalized to subject elbow height.

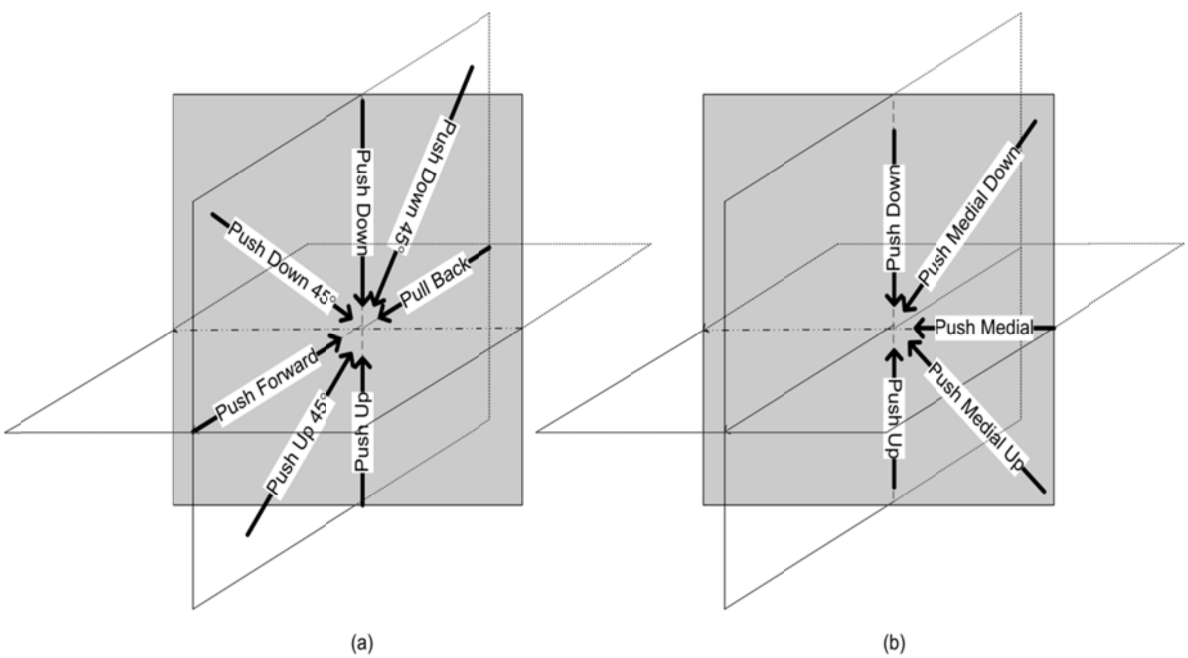


Figure 4.1 Arrows point in the direction that the hose is inserted onto the flange for each of the orientation conditions; frontal plane is shown in shaded region.

Subjects

Fifteen, right-handed volunteers (8 female, 7 male), with no reported history of upper extremity musculoskeletal disorders participated in the study. Mean subject age for the females was 21 years (SD=2.2) and for males, 23 years (SD=4.5). Subjects were drawn from a healthy university student population without prior experience in hose installation tasks. Data from one female subject were removed from the study because the subject was consistently unable to complete the insertion task within an allotted time of 10 seconds. Table 1 shows the demographic data of the subjects. Such an individual would likely self-select out of employment in this area if the jobs demands were not being met.

Table 4.1 Subject demographics (Mean and SD)

	Female	Male	Pooled
N	7	7	14
Age (years)	20.9 ± 3.7	22.9 ± 4.0	21.9 ± 3.8
Height (cm)	156.8 ± 13.8	176.3 ± 12.4	166.5 ± 13.1
Weight (kg)	58.2 ± 6.6	76.0 ± 13.1	67.1 ± 9.8
Grip Strength (N)	278.9 ± 50.9	509.4 ± 107.6	394.1 ± 79.2

Instrumentation

A custom-built hose insertion device was employed for this study. A flange (dimensions in Figure 4.2) was mounted on a tri-axial strain gauge (AMTI,

#SRMC3A-6-1000), as described in Grieshaber and Armstrong (2007). The strain gauge was mounted on a fixture that could be adjusted in the frontal (xy) and sagittal (zy) planes. The entire device was mounted onto a height adjustable arm (Figure 4.3).

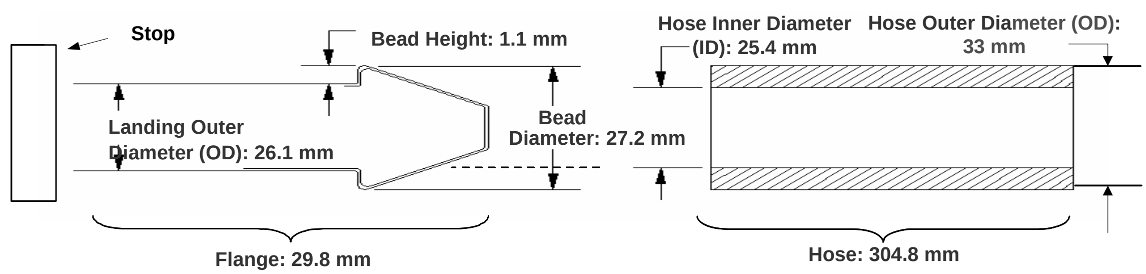


Figure 4.2 Hose-flange system with relevant flange dimensions

A basic rubber heater hose, diameter = 33mm, was inserted onto the flange (Figure 4.2). This hose was selected because its diameter fit into the 30-50 mm range expected to facilitate a maximal axial thrust force (Pheasant and Haslegrave, 2006), reported to be in the range of most comfortable cylinder diameters for maximal grip force exertions (Kong and Lowe, 2005) and was commercially available.

An Optotrak Certus™ motion capture system was used to track hose and wrist location. A strober was placed on the inserted end of the hose. Eight strobers were affixed to a rigid octagon-shaped cylinder on top of the flange mount, at least three of which were visible to the sensors at all times. The co-ordinate location of the flange tip was calculated from these strobers. One marker was affixed to the end of the hose. Strain gauge data and motion capture data were synchronized by the Optotrak system. Data were collected at a frequency of 30Hz.

Figure 4.3 Hose insertion apparatus

A device was custom-made to facilitate the collection of participant ratings using a digital vernier caliper affixed to a wooden board labeled with a 10-cm line. Subjects adjusted the calipers to a desired point on the line according to three pre-defined scales and the reading was recorded as the participant's rating as described by Grieshaber and Lau (2007). The verbal anchors on the scales were (0-10): No Force and Greatest Force Imaginable; Not Difficult and Very Difficult; and Very Uncomfortable and Very Comfortable.

Protocol

Subjects came to the experiment rested. Soap was used to wash the hands to control for friction characteristics of the hand. Optotrak™ markers were attached using a layer of medical tape to protect the skin and then double-sided tape.

To calibrate subjects to the hand force rating scale, subjects performed two right-handed grip strength exertions using a Takei grip dynamometer according to the protocol developed by (Marshall, 2002). The grip exertions were used to benchmark the participants to a rating of 10 on a scale of 0-10 where 10 was the 'greatest force imaginable' and 0 was 'least force imaginable'. The first exertion was done at the beginning of the trials. The second insertion was completed at the midpoint of the trials. The power grip posture was what was needed to insert a hose of this diameter onto the flange.

Subjects practiced the basic insertion task on the apparatus pushing forward. Subjects were instructed to insert the hose onto the flange using whatever grip posture they preferred and to insert the hose quickly. Participants were allowed to adopt any desired whole body posture with the following exceptions; 1) they could not use their left hand to stabilize or support the body;

and 2) they could not step beyond a line marked on the floor, a horizontal distance of 24 inches from the tip of the flange.

Subjects alternated between hose installations and maximum thrust strength trials for each of the ten different orientations. Two trials of each were performed. Subjects were asked to select their most comfortable grip posture before they performed the insertion. Grip strength research has shown that individuals are capable of selecting handgrip positions that afford highest mean maximal grip strength (Boadella, Kuijer, Sluiter, & Frings-Dresen, 2005). They could either adopt a “radial” power grip, where the thumb led the hand in the direction of insertion or an “ulnar” power grip, where the fifth digit led the insertion. Subjects were instructed to try to keep the hose strober in view of the position sensor unless it affected their insertion technique. Subjects were instructed to insert the hose “quickly” onto the flange, but “not as fast as possible”. Subjects were told to simulate that they were working on an assembly line where they had other tasks to do in addition to the hose task in a one-minute cycle. To eliminate any confounding effect of insertion height, the bottom of the flange tip was set at subject elbow height for each orientation. Orientation order was randomized for each subject.

After each hose installation, a maximum thrust strength trial was conducted with the hose still on the flange. Here, the subjects gripped the hose and built up force gradually to their maximum for a total of 4-5 seconds (Chaffin, Ergonomics guide for the assessment of human static strength, 1975) using the same hand posture and push direction as they had for the insertion. Subjects were given two minutes of rest after each trial. To help pass the time, participants were allowed to play 2-minute online word games in these rest periods. Only two maximum strength trials were collected for each insertion to reduce fatigue effects.

The hose was always removed from the flange by the experimenter as this appeared to required significantly more effort than the insertion. Upon completion of the second insertion trial for each orientation angle, the participant was asked to perform three ratings for the insertion that they had just performed. The hose did not appear to deform over time, but as a precaution, a new hose was used midway between the trials.

Subjects rated perceptions on three continuous scales of 0-10 with two verbal anchors. Subjects were asked to rate i) the hand force required to insert the hose (0-No Force, 10-Greatest Force Imaginable) and were reminded to benchmark this rating against a maximal power grip; ii) how difficult was it to perform the task (0-Not Difficult, 10-Difficult); and iii) how comfortable was it to perform the task (0-Not Comfortable, 10-Comfortable).

Data Analysis

Data were recorded from the time that the hose first touched the flange to the time at which the hose completed moving 29.8mm along the length of the flange. Peak and average forces in three dimensions were recorded for this period and resultant forces were calculated from these values. The 'axial' force represents the force exerted in the insertion direction. The data were filtered using a one-second moving average. The "overpush" as defined by Grieshaber and Armstrong (2007) was not analyzed here because it was not considered to affect the ability of the subjects to insert the hose.

Ratings of perceived difficulty, postural comfort and required hand force were collected using 0-10 linear scales with verbal endpoints. The power grip postures (radial or ulnar) selected by the participants were recorded.

ANOVA models for repeated measures and post-hoc pairwise comparisons were used to determine if significant differences between orientations existed for insertion forces, strengths, perceived ratings, percent capacity used, and insertion time using SPSS statistical software. Gender effects were also determined, but any findings are limited to the sample population.

Results

All participants completed the two insertion trials, the two maximum push strength trials, and three psychophysical ratings for each of the ten orientation conditions. Mean psychophysical ratings, peak and average insertion forces, insertion times, insertion strengths and percent capacities used are shown in Table 4.2, divided by gender, and in Table 4.3, pooled.

Insertion Forces

Peak axial insertion force was obtained from each condition between the point the hose first touched the flange and when it had traveled the length of the flange. This force did not include any data that occurred after the hose had traveled the distance to the back end of the flange and could go no further.

A main effect of orientation was observed for peak axial insertion force ($F_{9,108}$=3.86, $p<0.01$), but not for peak resultant insertion force. The Push Down condition had the lowest peak axial insertion force $(\overline{X} = 135N)$ compared to the Push Forward condition $(\overline{X} = 155N)$. There were no gender or interaction effects.

There was a much larger variability in the peak resultant insertion forces for the three Push Medial types of conditions compared to the peak axial force.

Main effects of orientation were observed for the average resultant insertion force ($F_{9,108}$=4.4, p<0.001), but were not observed for the average axial insertion force. The conditions with the lowest average axial forces were the Push Up 45°, Push Up, and Pull Back orientations. The conditions with the highest average axial forces were the Push Down 45° and Push Medial Down 45°. Gender and interaction effects were not observed.

Insertion Strength and Percent Capacity Used

The insertion strength was obtained using the peak resultant values recorded for each maximum exertion condition. A main effect of orientation was observed ($F_{1,12}$=3.37, p<0.05). The Push Up and Pull Down 45° conditions had the lowest mean strengths recorded and the Push Down 45° condition had the highest. Figure 4.4 shows examples of the different whole body postures that subjects assumed to perform the maximal exertion trials.

The mean strength values for the male subjects trended as greater than for the female subjects however, statistical significance was not achieved due to the large variability in both sets of strengths and the small sample size for each gender. It is expected that with a greater sample size, statistical significance would be reached because the mean grip strengths of the subjects were similar to industrial populations.

Percent capacity used was calculated by dividing the peak resultant insertion force by the peak resultant strength. The overall mean percent capacity was 66%. The mean percent capacities ranged from 53-83% of their maximum thrust force when grouped by gender across the different orientations. Interestingly, neither main effects of orientation nor gender effects were observed. Subjects performed the task at similar levels of their capacities despite having different strengths for each of the conditions.

Perceived Ratings

Hand force ratings were not affected by orientation. Pairwise comparisons indicated that the Push Up orientation may be rated higher than some orientations, but this was not significant.

A main effect of orientation was observed for ratings of overall difficulty ($F_{9,108}$=3.317, $p<0.01$). The Push Up orientation was given the highest difficulty ratings and the Push Forward orientation, the lowest. No gender effect was found. Interaction between orientation and gender was observed ($F_{9,108}$=3.57, p<0.001) and was attributed to the Push Up orientation. Female subjects had a mean rating of 7.6, which was twice that which the male subjects rated this orientation.

Figure 4. 4 Examples of different whole body postures assumed for maximal exertions (strength)

Table 4. 2 Mean psychophysical ratings, measured insertion forces, insertion strength, percent capacity used, and insertion time by insertion direction, and grouped on gender

Insertion Direction	Difficulty Rating (0-10)	Comfort Rating (0-10)	Hand Force Rating (0-10)	Peak Axial Force (N)	Peak Resultant (N)	Average Resultant Force (N)	Insertion Strength (N)	% Capacity Used	Insertion Time (s)
Female									
Push Forward	3.2 ± 1.7	3.8 ± 1.4	6.6 ± 1.5	156 ± 35	151 ± 35	91 ± 26	205 ± 43	79 ±19	2.4 ± 1.6
Push Up 45°	4.6 ± 2.4	3.3 ± 1.4	5.3 ± 2.5	149 ± 18	137 ± 15	71 ± 7	220 ± 45	68 ± 17	2.9 ± 2.1
Push Up	7.6 ± 1.2*	5.0 ± 0.9*	4.7 ± 2.0	145 ± 31	131 ± 26	68 ± 25*	197 ± 68	79 ± 37	2.6 ± 1.5
Pull Back	5.2 ± 2.0*	4.6 ± 1.6*	4.6 ± 2.2	163 ± 39	151 ± 37	71 ± 10*	223 ± 39*	70 ± 22	3.8 ± 1.6
Pull Down 45°	4.0 ± 2.3*	5.2 ± 1.8*	4.6 ± 2.5	153 ± 33	150 ± 34	81 ± 27	196 ± 20*	78 ± 24	3.3 ± 0.6
Push Down	4.2 ± 2.5	4.5 ± 2.2*	3.9 ± 2.4	115 ± 29*	116 ± 33	77 ± 17	185 ± 89	73 ± 34	3.1 ± 2.3
Push Down 45°	4.2 ± 1.4	3.8 ± 1.1	3.4 ± 2.4	151 ± 28	151 ± 28	90 ± 17	228 ± 45*	68 ± 13	2.5 ± 0.9
Push Medial Down 45°	3.4 ± 1.0	4.5 ± 0.8*	3.3 ± 1.9	143 ± 32*	162 ± 48	102 ± 33	262 ± 88	66 ±10	3.2 ± 2.1
Push Medial	4.4 ± 1.9*	5.1 ± 1.7*	3.8 ± 2.1	124 ± 28*	143 ± 66	87 ± 34	232 ± 87	62 ±11	2.7 ± 1.7
Push Medial up 45°	3.9 ± 1.1	4.5 ± 1.8	4.6 ± 2.0	137 ± 29*	160 ± 82	91 ± 44	219 ±103	77 ± 31	2.3 ± 1.2
Male									
Push Forward	3.2 ± 1.8	5.7 ± 3.8	6.9 ± 1.6	155 ± 23	151 ± 20	79 ± 17	261 ± 40	65 ± 18	2.4 ± 2.3
Push Up 45°	2.5 ± 1.5	5.0 ± 3.3	3.1 ± 2.1	155 ± 31	146 ± 24	78 ± 21	260 ± 57	60 ± 9	2.7 ± 2.9
Push Up	3.8 ± 1.7*	6.9 ± 5.0*	3.3 ± 1.4	142 ± 34	126 ± 22	65 ± 16*	219 ± 35	66 ± 14	2.5 ± 1.3
Pull Back	4.5 ± 0.9*	7.1 ± 4.6*	3.2 ± 2.6	144 ± 57	133 ± 48	59 ± 23*	297 ± 38*	53 ± 18	3.7 ± 2.6
Pull Down 45°	4.8 ± 1.8*	7.4 ± 5.2*	3.4 ± 1.1	156 ± 35	157 ± 28	84 ± 28	220 ± 41*	82 ±33	2.0 ± 2.0
Push Down	3.2 ± 1.6	6.8 ± 4.5*	5.6 ± 2.3	134 ± 40*	153 ± 40	90 ± 20	269 ± 102	62 ± 16	1.6 ± 1.4
Push Down 45°	3.3 ± 1.6	5.0 ± 3.8	2.9 ± 2.0	149 ± 40	157 ± 35	86 ± 21	315 ± 67*	55 ± 16	2.2 ± 1.7
Push Medial Down 45°	4.8 ± 1.6	5.8 ± 4.5*	3.4 ± 1.4	128 ± 42*	173 ± 87	107 ± 51	285 ± 118	65 ± 32	2.2 ±1.6
Push Medial	4.5 ± 1.9*	8.6 ± 5.1*	3.5 ± 1.1	128 ± 25*	199 ± 124	128 ± 25	269 ±111	76 ± 49	2.6 ± 1.5
Push Medial up 45°	4.2 ± 1.5	7.4 ± 4.5	4.6 ± 3.0	140 ± 43*	203 ± 116	104 ± 47	264 ± 117	83 ± 45	2.2 ± 0.8

Note. Values that differ significantly from the Push Forward condition in each grouping are noted with an asterisk (p<.05)

Table 4.3 Mean psychophysical ratings, measured insertion forces, insertion strength, percent capacity used, and insertion time by insertion direction

Insertion Direction	Rating Difficulty (0-10)	Rating Comfort (0-10)	Rating Hand Force (0-10)	Peak Axial Force (N)	Peak Resultant Force (N)	Average Resultant Force (N)	Insertion Strength (N)	% Capacity Used	Insertion Time (s)
Push Forward	3.2 ± 1.8	4.8 ± 2.6	6.8 ± 1.6	156 ± 29	151 ± 28	85 ± 22	233 ± 42	72.0 ± 19	2.4 ± 2.0
Push Up 45°	3.6 ± 2.0	4.2 ± 2.4	4.2 ± 2.3	152 ± 25	142 ± 20	75 ± 14	240 ± 51	64.0 ± 13	2.8 ± 2.5
Push Up	5.7 ± 1.5	6.0 ± 3.0	4.0 ± 1.7	144 ± 33	129 ± 24	67 ± 21	208 ± 52	72.5 ± 26	2.6 ± 1.4
Pull Back	4.9 ± 3.1	5.9 ± 3.1	3.9 ± 2.4	154 ± 48	142 ± 43	65 ± 17	260 ± 39	61.5 ± 20	3.8 ± 2.1
Pull Down 45°	4.4 ± 2.1	6.3 ± 3.5	4.0 ± 1.8	155 ± 34	154 ± 31	83 ± 28	208 ± 31	80.0 ± 29	2.7 ± 1.3
Push Down	3.7 ± 2.1	5.7 ± 3.4	4.8 ± 2.4	125 ± 35	135 ± 37	84 ± 19	227 ± 96	67.5 ± 25	2.4 ± 1.9
Push Down 45^{c}	3.8 ± 1.5	4.4 ± 2.5	3.2 ± 2.2	150 ± 34	154 ± 32	88 ± 19	272 ± 56	61.5 ± 15	2.4 ± 1.3
Push Medial Down 45°	4.1 ± 1.3	5.2 ± 2.7	3.4 ± 1.7	136 ± 37	168 ± 68	105 ± 42	274 ± 103	65.5 ± 21	2.7 ± 1.9
Push Medial	4.5 ± 1.9	6.9 ± 3.4	3.7 ± 1.6	126 ± 27	171 ± 95	108 ± 30	251 ± 99	69.0 ± 30	2.7 ± 1.6
Push Medial Up 45°	4.1 ± 1.3	6.0 ± 3.2	4.6 ± 2.5	139 ± 36	182 ± 99	98 ± 46	242 ± 110	80.0 ± 38	2.3 ± 1.0

A main effect of orientation was observed for ratings of comfort ($F_{9,108}$=5.14, p<0.01). The Push Forward condition was rated as being more comfortable than most of the other orientations. The Push Up condition was rated as being less comfortable than several of the other orientations. A gender effect was seen ($F_{9,108}$=8.24, p<0.05). Overall, the male subjects on average rated their perceived comfort approximately 29% higher than females did. No interaction effect was observed.

Insertion Time and Other Variables

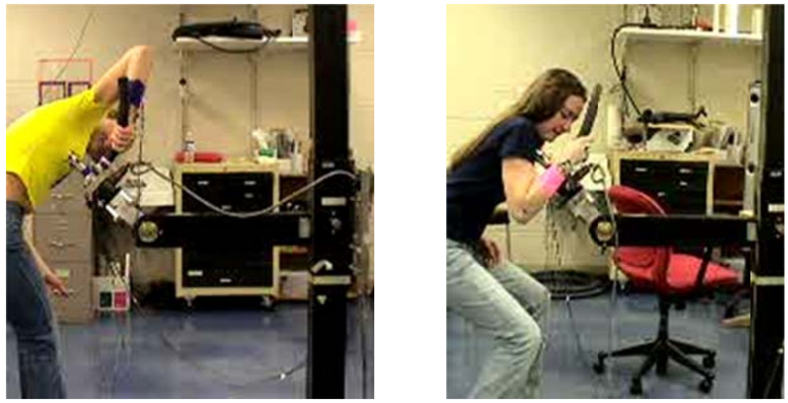
Insertion time was defined from the instant the hose made contact with the flange to the point where the hose had traveled the length of the flange (29.8mm). This was considered the point where a participant could not push the hose on any further and any force recording after this point was considered beyond that which was required.

No main effect of orientation was observed on insertion time. Mean insertion times ranged between 1.6-3.8 seconds across all conditions. No gender effect was observed. No interaction effect was present. It is likely that the level of demand was not high enough to elicit differences. The data that were eliminated from one subject were done so because the subject failed to complete the exertion within a maximum allotted time of 10 seconds. In this case, the demands were too great for the subject. No effects of orientation were seen on maximum instantaneous velocity or average insertion velocity.

Grip Posture

All subjects did not use the same grip posture for each insertion condition. Subjects selected their preferred of two grip postures for each orientation angle. 'Radial' is used to describe the grip where the thumb leads the insertion. 'Ulnar' refers to the grip where the fifth digit leads the insertion. The distribution of grip postures by orientation is shown in Figure 4.4 together with two examples of the different grips used in the Pull Down 45° condition.

It is possible, but highly unlikely that subjects used a pinch grip to insert the hose. The use of pinch grip was not directly observed in this study because the hose diameter facilitated what appeared to be power grip postures and it was impossible to determine by inspection whether subjects were using a pinch grasp.



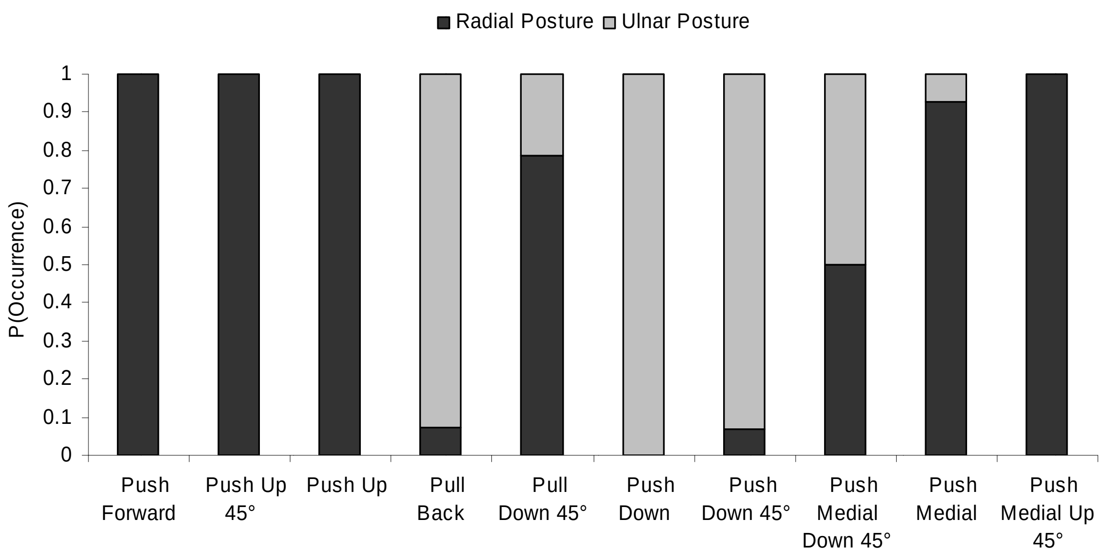


Figure 4.5 Distribution of grip posture selected by participants by orientation

Discussion/Conclusion

By measuring various psychophysical and physical insertion dynamics of hose installation, this study showed that insertion orientation affects, in different manners, the perceived difficulty and comfort, peak axial and average resultant insertion forces, insertion strength and grip posture adopted. This study also showed that orientation does not necessarily affect average axial insertion force, percent capacity used, insertion time, or hand force ratings. These results indicate that the orientation of the hose insertion in an assembly environment with respect to the worker can influence how much effort is used to exert to install the hose and how difficult the task is perceived.

The Percent Capacity Used data from Table 4.2 show that the subjects found the inserting of this particular hose-flange combination to be well within their capabilities. Hand force ratings suggest that subjects perceived these insertions to be equivalent, which might be due to participants knowing that aside from the orientation, the basic insertion demand was the same. Percent capacity data show that subjects neither worked at nor near their maximum capabilities when inserting the hose.

Presumably, the force differences among different orientations for the same hose and flange should be very small. The postures required to position the hand on the hose for different flange orientations may vary greatly—as will the resulting strength capacity. The relative exertion force (%MVE) and the relative perceived hand force exertion can be expected to change with flange orientation.

The Push Up condition appears to be the least comfortable and most difficult of the insertions, even though the perceived hand force exertion is not different than other conditions. Subjects do not have a good visibility of the end of the flange, and may rely on tactile information to know when the insertion is completed. This tactile information may be related to the perceived hand force because the subject could rely on the similarity of the feeling to other conditions when then hose was inserted successfully. Also, the subjects are unable to use their body weight to aid in this insertion and must rely on smaller muscles in the elbow and shoulder to generate the required thrust force.

The Push Forward condition was perceived as being less difficult and more comfortable than most of the other conditions. Subjects were capable of applying inward torque to the hose, and were able to use their body weight to assist the insertion, possibly require less effort from the shoulder flexor muscles.

Insertion Forces

Push-on forces of coolant hoses measured by Robinson (2005) were significantly lower than that measured in this experiment. Even though the hose diameters were almost 5mm larger, the hoses were inserted at a constant rate of 127mm/min, which was much slower than the speed used by the participants in this study. The effect of higher insertion velocity and individual factors most likely acted to increase the peak forces seen here compared to the controlled measurements made by Robinson (2005).

The peak axial insertion force was affected by orientation whereas the peak resultant insertion force was not. This may be interpreted as the subjects exerting a similar overall effort across orientations, but with some conditions resulting in a more effective translation of the effort into axial force.

Large differences up to 35% (115-163N) were observed between the peak axial insertion forces of different orientations. The required insertion forces are essentially the same across all orientations, yet subjects were able to push harder in the axial direction in some cases. The Push Down condition had the lowest peak axial insertion force. This position also was the only position in which all participants utilized the same ulnar power grip. Strength-wise, it was toward the lower end and the limiting factor was mostly likely the ability to generate force in this condition and not the ability of the hand to transmit the force. Subjects relied upon body weight and passive tissue properties to perform this exertion. Further, this direction was rated less difficult and more comfortable than several other conditions.

Strength and Percent Capacity Used

The highest insertion strength was generally observed in the Push Up 45° condition. Several possible factors could be contributing to this: i) subjects were able to utilize the lower body to assist in generating axial force; ii) subjects could push in the relative y-direction (perpendicular to the the long-axis of the flange), which enabled them to generate moments to counteract the internal moments at the wrist and maintain static equilibrium, as shown by Seo & Armstrong (2009).

The lowest insertion strengths were recorded for the Push Up and the Pull Down 45° conditions. In both of these conditions, pronounced ulnar deviation was observed in several participants and the elbow posture was not conducive to transmitting forces being generated at the shoulder or from gravitational forces acting on the body. The wrist may be better able (than the elbow/shoulder) to compensate for the demands of the task by approaching its end range of motion and using passive properties of the joint (ligaments) to transmit the necessary axial force. In these two orientations, it is difficult for the wrist to adopt such an extreme posture that would induce the passive properties of the tissue to act.

Subjects had different strengths for different insertion orientations. One would expect similar strength across conditions, but subjects were able to exert more force maximally in the Pull Back, Push Down 45° directions. The hand-hose coupling limits the ability to transmit force for some insertions, and the ability to generate force in the direction of interest may be the limiting factor in other insertions. Similar muscles are used to grip the hose and generate friction for different orientations, but the orientation has a much greater influence in determining which other body musculature is needed to generate the thrust force. Orientations in which the subject can create easily generate inward torque use the larger muscles of the upper arm, and/or apply body weight appear to be the orientations with the highest thrust strength values.

Subjects worked at similar levels of their capacity, in spite of having different strengths between insertion orientations. This was unexpected because the force demand from the hose and flange alone are the same across conditions. It would make more sense if subjects operated at lower levels of their capacity for insertions where they had higher strength in. The simplest explanation for these results is that the insertion task was not challenging enough to elicit true differences in the percent capacity used. This, coupled with the small sample size could explain the lack of statistically significant differences. An alternate explanation is that the subjects were able to regulate what level of capacity they performed at and chose to operate at a near constant level.

Men and women utilized similar levels of capacity (F: 62-79%; M: 53-83%). We expected females, who were more likely to possess lower thrust strength, to work at a higher percentage capacity, but this was not evident. This may have been due to the selected hose-flange combination, which may not have been difficult enough to produce effect. The results obtained by Andrews et al. (2008) are similar to these levels. It is almost as if subjects exert a predetermined %MVE regardless of the condition. Future studies should examine different hose force requirements for these orientations to see how the exerted force and perceived hand force change with demand. In studies of keyboards, subjects appeared to exert a certain minimum force regardless of the key force requirements and did not respond to key force requirements until they were quite high (Rempel, Dennerlein, Mote, & Armstrong, 1994).

Grip Strength

Grip strength measurements provide a basis for comparison between different populations. The mean values recorded for the female and male participants were consistent to those obtained by Bystrom & Fransson-Hall (1994) and of Boadella, Kuijer, et al. (2005). The differences in mean values between the recorded grip strengths in all studies were less than 11N. These other studies had larger sample sizes. Thus it may be possible to generalize results obtained in this study to a slightly broader population.

Even though each condition was normalized to subject elbow height, the whole body postures that subjects adopted for maximum push insertions were quite different between orientations as can be seen in Figure 4.4, often with the elbow not being at elbow height. The orientations that involved pushing down at some angle were able to use the weight of the upper body to assist. The orientations that involved pushing forward to some degree allowed use of the legs to assist.

Grip posture may have had an effect on insertion strength. It was assumed that participants selected the posture that would allow maximum strength production based upon research that people are able to self-select grip spans that maximize their grip strength (Boadella, Kuijer et al. 2005). For eight of the ten orientations there was a clear trend towards one posture over the other. Future research could determine the strength differences between ulnar and radial postures.

Limitations

The effect of insertion height needs to be investigated further. Push strength capacities for a given orientation may change depending upon the height in relation to the worker height. Subjects were told not to brace with the left hand and were required to keep their feet in front of the flange. This may affect the ability to assume the most ideal posture to maximize any biomechanical advantage. An analysis of joint by joint force demand or capacity comparisons could be performed for varying forces for each condition. A detailed analysis of hand and wrist postures and hose coupling would help understand the limiting factors of the task.

Hand posture was not controlled because it was more desirable to simulate realistic task conditions than it was to force participants to adopt a certain hand posture. The assumption is that the participants would select the hand posture that would produce the maximum force that they were capable.

The hose and flange diameters were not manipulated in this study. The diameter of the hose was chosen to elicit larger power grip forces. Different diameters would produce different grip strengths and subsequently different thrust forces.

Each subject typically performed twenty maximum thrust exertions over the course of the experimental session. Two-minute rest breaks were always given after each maximum exertion according to standard protocols however, the cumulative effects may have caused fatigue in a participant pool unaccustomed to such exertion. Trial order was randomized for each participant and this was expected to reduce any bias caused by fatigue. A larger sample size would also improve the power of the strength results.

Future work needs to look at the effect of height and whether there is any evidence of interaction with insertion orientation. The size of the hose may also play an important role in determining worker capacity for a given insertion because of modifications to the grip posture.

Significance of this work

The most interesting finding is that subjects appeared to scale perceived hand forces similarly, even though they were exerting more force in some conditions than others. From this, it can be seen that the actual force applied cannot be predicted from the ratings of hand force. Hand force ratings should not be used as a basis for determining the effect of task orientation and by extension, determining ergonomically ideal task orientations in the field. Other ratings, such as that of perceived difficulty, may include consideration of other important factors such as visibility and motor control.

This study established a set of values for functional push strengths in different orientations which manufacturers could consider when initially setting up insertion tasks. The consistency of grip strength findings with other published studies suggest that the population sampled could be representative of a larger working population. Training and conditioning may offset age effects in working populations and it is likely that gender differences would carry over to them as well. Results of this study show that there are different perceptions of the same task put in different orientations at elbow height. There are also significant strength differences within individuals between orientations.

In a reconfigurable manufacturing environment such as in automotive assembly operations, there may be opportunity to move a hose installation task from one part of the assembly to another. Changing task location does not alter the basic insertion task, at these force levels, but it does change the orientation by which the worker approaches the task, the height of the task, and the physical access to the part of interest. The results of this study suggest that the orientation can affect the task demands, whether actual or perceived. Orientations that encourage workers to exert higher forces than are 'necessary' could put a worker at increased risk of injury.

This study illustrates several points concerning the use of perceived exertions to assess task force levels for the study of WMSDs. First, they provide a consistent indicator of the %MVE irrespective of orientation (at these force levels). Second, the relative perceived hand force exertions consistently underestimated the %MVE at this force level by about 20%. Based on previous research by Frederick and Armstrong (1995), the perceived hand force may approach the %MVE at the highest force levels. Third, instructions to subjects must be clear regarding the rating of hand force and not that of other body parts.

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Chapter 5

Conclusions

The overall purpose of this work was to investigate factors that affect subjective assessments used in ergonomic analysis by studying the effect of viewing angle on the subjective assessment of wrist posture in static and dynamic situations, and the effect of orientation in a manual task on subject assessments of hand force. This research is needed because i) there is widespread use of observational assessment methods for both epidemiologic and practical purposes, ii) the accuracy, validity, and reliability of these methods has been found to be lacking, and iii) understanding the assessment capabilities and limitations of observers and workers can improve these methodologies.

Major Conclusions

1) **Viewing angle affected the accuracy of wrist posture estimations from static images; mean estimates were more accurate when the viewing angles were orthogonal to the plane of motion (ideal) than when the viewing angle was directly in the plane of motion (in-line) (Chapter 2).**

This is an important finding that has neither been previously studied nor reported in the literature. Twenty-six subjects estimated wrist flexion and extension joint angles and radial and ulnar deviation joint angles systematically captured from ten different viewing angles. The mean error for flexion and extension postures were approximately 9° for the two ideal views and 14° for in-line views. The mean error for deviation postures were approximately 6° for ideal views and 13° for in-line views. Other off-axis viewing angles had mean errors nearly all which ranged between that of the ideal and in-line viewing angles. Mean errors differed between viewing angle for individual postures, but meaningful interactions were not found. Large variability was observed throughout the results. These results increase the understanding of one factor of why researchers have historically observed such low inter-rater reliability and accuracy in both field-based and laboratory-based studies. Ideal viewing angles change depending on what type of wrist posture is being analyzed. Wrist deviation appears to be much more susceptible to viewing angle effects, must likely because of the smaller range of motion compared to flexion-type postures. These findings apply only to situations where analysts are rating static postures. Researchers and epidemiologists are strongly recommended to adjust existing protocols to include controls for viewing angle effects when these types of methods are used. Recommendations for controls based on the findings include recording the viewing angle the posture was captured at, and developing improved training methods so that analysts understand when they are at increased risk of introducing error because of the viewing angle. Ratings may be improved by filming subjects from different views. Because subjects appear to utilize visual cues, it is likely that large image size and good lighting can improve results. Training that emphasizes how surface features change with orientation might improve performance.

2) **Raters do not rate solely according to a model of parallax based on viewing angle and observed posture. Instead, raters are able to use other visual cues to adjust in part for the effects of parallax (Chapter 2).**

The parallax model used as a theoretical basis for Chapters 2 and 3 was based on work done by Paul & Douwes (1993). Paul and Douwes' study examined the bias introduced by viewing angle in photographic recording of body postures on a 2D basis and they did not attempt to determine its effects on human raters. The effect of viewing angle on the appearance of joint angles in a two-dimensional photographic recording can be predicted mathematically using stick-figure models, but these models do not account entirely for other visual cues available in three-dimensions that may also affect one's ability to estimate wrist posture. Human limbs are highly detailed and this likely gives rise to additional information to the observer in the form of visible surfaces of the hand, unique characteristics of surface anatomy associated with particular postures (e.g. wrist creases), motion parallax, depth perception cues, and shadows. This observation was most clear in the in-line viewing conditions in which the model predicted that all joint angles would appear the same, but raters estimated relative differences between joint angles in accordance with the actual postures. Also, raters appeared to be very adept at estimating the neutral (0°) posture regardless of the viewing angle. These other visual cues need to be identified and studied so that their information-giving properties can be exploited in analysis methods and recording techniques.

3) **The effect of viewing angle on estimates of wrist flexion and extension angles is different for dynamic situations than they are for static**

situations. The effects of fixed camera positions on estimation of wrist flexion and extension postures are task dependent (Chapter 3).

The major difference observed regarding stationary viewing angles in the dynamic situations in Chapter 3 was that the viewing angle of the wrist flexion/extension posture changed with any movement of the wrist by the worker. The proportion of the variance observed in the wrist posture estimates made by twenty-two subjects for ten different tasks explained by viewing angle (alone or by interaction), while significant, was observed to be much less than that explained by task or subject alone. Tasks with very high levels or very low levels of wrist movement may be more susceptible to viewing angle effects than those without. Aside from differences between static and dynamic rating, the effect of work speed appears to be small ($<4°$) and not significant at a risk level. Improved filming protocols can increase rating accuracy and so that ratings can be performed on frozen frames, as well as an emphasis on improved training methods.

4) **Task orientation did not affect ratings of applied hand force (at these force levels (54-83% MVE), but it did affect measured insertion forces, push strengths, and ratings of overall difficulty in a manual hose installation task (Chapter 4).**

Self-ratings of applied hand force scaled to maximal exertions are widely used to estimate force demands of jobs. When applied to the joining of two parts, such as in manual hose installation, differing locations in space did not affect the perceived hand force, which suggested initially that the rating was determined solely by the resistance between the hose and flange. Further examination revealed that differences were measured in axial insertion forces and strengths between orientations, but that the percent capacity used was similar across conditions. The rating of hand force should therefore be attributed to the percent capacity used and not directly to the absolute force applied. Ratings of hand force in previous studies of the joining of parts thus may not be representative of the absolute forces applied to the task of interest, but rather the percent capacity used in that particular orientation of that task.

Discussion and Application of the Findings

Viewing angle effects on wrist posture estimation

Knowing the effects that various viewing angles have on estimation of wrist postures from static images is well and good, but this is still relatively abstract for field research. For studies that use similar analysis methods to Chapter 2 (e.g. Armstrong, Foulke, Joseph, & Goldstein, (1982)), correction factors for estimates from known viewing angles can be applied to adjust for the effect of viewing angle.

The findings from Chapter 2 were further analyzed to develop regression equations that would allow an analyst to apply a correction factor to a rating of wrist posture for a static image from a known viewing angle. Table 5.1 shows the results of linear regressions completed for each viewing angle of the relationship between actual and estimated wrist flexion and extension angles. Use of these tables is cautioned because of the controlled circumstances under which the images used were captured; they should only be used for similar situations with large image size, good lighting, and controlled viewing angles.

The findings from Chapter 2 and Chapter 3 can be applied to:

- Selecting viewing angles of the task for recording that will produce the most accurate results (i.e. minimize parallax).

- Developing training protocols that provide examples of parallax distortion for raters to inform them of the potential effects.
- In studies where static wrist postures are estimated and the viewing angles are known, the results can be calibrated to adjust for the effect of viewing angle and reanalyzed (possibly using the provided tables). In studies where the posture was measured, we can see if raters became more or less accurate when viewing angle is factored into the rating.
- To obtain the best results: Use video recordings from multiple views in which at least one on-axis image is captured for the posture of interest; use adequate lighting and zoom in to obtain the best surface detail possible; use freeze frames and perform ratings on static images whenever possible; provide training that emphasis the effect of posture and viewing angle surface detail.

Accuracy and reliability of observational estimates of wrist posture

Accuracy is undoubtedly difficult to assess because even the measured comparisons can be subject to errors. When the results were combined across subjects, accuracy rose to acceptable levels in Chapters 2 and 3 (within 10% of measured values). However, the variability in estimates between subjects was so large that it often overshadowed any effect of viewing angle. This large variability, in agreement with several other previous studies (Juul-Kristensen, Hansson, Fallentin, Andersen, & Ekdahl, 2001; Lowe, 2004; Ketola, Toivonen, & Viikari-Juntara, 2001), confirms that observational assessment of wrist posture is not performed at acceptably reliable levels to draw inferences of its independent relationship to WMSDs of the upper limb (Bernard, 1997, National Academy of Sciences, 1999). An acceptable level of precision of wrist posture estimates (e.g. 10% ROM) is something that needs to be demonstrated for each observational method before it can be relied upon for meaningful analysis. Continued investigation into the basic task, assessment, and observer factors, and developments in training methods are needed to improve accuracy and precision of these methods.

Table 5.1 Linear regression equations for estimated angle of wrist flexion and extension postures as a function of actual wrist angle for each viewing angle, based on either flexion or extension data.

View	Regression Model			Coefficients: Actual Angle				Regression Model			Coefficients: Actual Angle			
	r^2	r^2-adj	Std Err	Flexion	β	t	Sig.	r^2	r^2-adj	Std Err	Extension	β	t	Sig.
Dorsal	0.73	0.72	16.01	Constant	2.68	1.06	0.29	0.70	0.70	16.11	Constant	11.09	4.35	0.00
				Actual Angle	0.86	18.43	0.00				Actual Angle	0.82	17.38	0.00
Fingertip	0.79	0.78	14.22	Constant	-5.46	-2.43	0.02	0.81	0.81	13.71	Constant	11.57	5.34	0.00
				Actual Angle	0.90	21.71	0.00				Actual Angle	0.95	23.65	0.00
Fingertip Dorsal 25°	0.51	0.50	21.37	Constant	-11.76	-3.48	0.00	0.68	0.67	14.17	Constant	6.92	3.09	0.00
				Actual Angle	0.71	11.44	0.00				Actual Angle	0.68	16.34	0.00
Palmar	0.76	0.76	15.15	Constant	3.52	1.47	0.14	0.62	0.61	18.91	Constant	11.76	3.93	0.00
				Actual Angle	0.89	20.06	0.00				Actual Angle	0.79	14.37	0.00
Radial*	0.91	0.91	9.07	Constant	-4.54	-3.16	0.00	0.75	0.75	12.84	Constant	13.77	6.79	0.00
				Actual Angle	0.96	36.04	0.00				Actual Angle	0.74	19.75	0.00
Radial Dorsal 25°	0.91	0.91	9.34	Constant	-5.92	-4.01	0.00	0.77	0.76	12.07	Constant	10.96	5.74	0.00
				Actual Angle	0.98	35.72	0.00				Actual Angle	0.72	20.48	0.00
Radial Proximal 45°	0.85	0.85	12.49	Constant	-9.37	-4.74	0.00	0.79	0.79	12.40	Constant	8.07	4.11	0.00
				Actual Angle	0.97	26.65	0.00				Actual Angle	0.81	22.25	0.00
Ulnar*	0.90	0.90	9.41	Constant	-6.00	-4.03	0.00	0.81	0.81	11.51	Constant	9.84	5.40	0.00
				Actual Angle	0.95	34.46	0.00				Actual Angle	0.78	23.22	0.00
Ulnar Distal45°	0.86	0.86	11.47	Constant	-8.91	-4.91	0.00	0.85	0.85	11.68	Constant	8.98	4.86	0.00
				Actual Angle	0.95	28.28	0.00				Actual Angle	0.92	26.95	0.00
Ulnar Dorsal 25°	0.84	0.84	13.26	Constant	-7.85	-3.74	0.00	0.83	0.83	10.46	Constant	9.84	5.95	0.00
				Actual Angle	1.01	26.03	0.00				Actual Angle	0.76	24.72	0.00

Exploiting surface qualities of the body

Visual cues offered by surface qualities of the body may help to compensate for parallax. Controlled studies are needed to determine which visual cues affect rating accuracy the most. For instance, studies using gloves to mask specific surface features can be used as controls. Studies using different hand postures such as gripping a tool or object may also help to control extraneous surface qualities. Video data collection can conducted to facilitate the use of these visual cues. For instance, using reflective markings can aid location of particular surface landmarks. Another means could be to use lighting techniques to exaggerate shading or contrast.

Subjective assessments of applied hand force

The findings from Chapter 4 showed that subjects exerted a constant %MVE regardless of the insertion force demand for the force demands in the range studied. Subjects underestimated the force demand, but it is expected that agreement between force demand, exerted force, and perceived hand force exertion would improve as demand approaches maximum. Exerted forces and perceived hand force exertions likely approach a minimum constant with decreasing force. An evaluation of the effect of the force demand from zero to maximum would answer this.

The differing effect of insertion direction on perceived hand force and perceived difficulty illustrate the importance of clear instruction to subjects regarding what aspect of a task is to be rated. It is not enough to benchmark subjects to a maximal grip exertion, as shown by Marshall, Armstrong, & Ebersole, (2004), but also that it be emphasized to the subject that they are to rate hand force and not discomfort or difficulty as perceived in other parts of the body.

Recommendations for Future Work

Future work is needed to continue this line of research and advance the body of knowledge for the improvement of the validity and accuracy of subjective assessment methods. By understanding the perceptual factors and biases that observers and workers are subject to, analysts can begin to account for their effects. Without this knowledge, researchers and practitioners assume that these effects are negligible, making questionable the reliability and validity of their findings.

- Viewing angle is only one factor believed to affect observational assessment of wrist posture. Many different factors such as lighting, masked body parts, gloves, etc. need to be investigated in a systematic manner to determine if and how much they affect these assessments. Until research like this is conducted, those using observational methods for epidemiological research of WMSDs will be subject to these potential sources of error.

- Wrist posture was the only joint examined in the studies on viewing angle because it is the usually the smallest joint that is evaluated with observational methods. Other rated parts of the upper limb, such as the shoulder and elbow are larger, but may still be susceptible to parallax effects. These other joints can be explored in further study.

- Historically, wrist posture has been assessed either in flexion/extension or in deviation. In reality, wrist postures are more likely a combination of both posture types. Currently there exists no reliable method to describe or to evaluate these specific postures because it is ambiguous how they should be rated. Development of ways to describe these postures is warranted.

- Novice subjects were used for the wrist posture experiments. The large inter-subject variability demonstrated that observational estimates of wrist posture were not consistent between raters. The effect of experience on observational ratings cannot be estimated from these data however, other studies have shown similarities of novices to experienced raters with low levels of accuracy (Ketola, Toivonen, & Viikari-Juntara, 2001). Conducting the same study with a participant pool of "expert" raters would determine whether their estimates of wrist posture are affected in a similar manner by viewing angle compared to novices.

- Knowledge of the viewing angle has the potential to influence the results. The subjects used in the study of static wrist postures were not informed of what the viewing angle was. Armed with both knowledge of the viewing angle and what effects are typical of such a viewing angle, an analyst may be able to adjust for the effect of viewing angle and incorporate them directly into the rating, minimizing the need for additional post-processing of estimated results.

- Viewing angle was demonstrated to affect wrist posture estimates differently for single estimates of static postures and aggregate estimates in dynamic situations. Observational assessment methods often have other criteria for evaluating wrist joint postures such as classifying observed postures into categories or intervals. Studies of viewing angle on methods that use different assessment protocols are needed to determine what the minimum size of the intervals should be in order to account for the potential effects of viewing angle.

- It was observed that subjects performed hose installations at similar levels of their overall capacity between different task orientations (66%). Subjects also rated insertion force similarly across insertions (~4.4/10). Development of a model to correlate perceived hand force exertions to actual forces for different activities would be a very useful tool.

- Hose installations are only one example where assessments using perceived hand force exertions are useful. Studying other situations and tasks that involve different grip postures, force demands, and/or more complex tasks would help to understand how applicable and robust worker ratings are.

- If the use of observational methods is to be continued for research studies on WMSDs, further research and development of training methods needs to be conducted. Using knowledge gained by controlled studies of potential factors, it may be possible for researchers to minimize effects of perceptual biases in data collection, rating, and/or data analysis. This has implications for ergonomics curriculum as well.

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