Effects of Cinematic Factors on the Perception of Wrist Postures when Viewed on a Video Display

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ABSTRACT

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A study was conducted to investigate the effects of certain cinematic choices on people's ability to judge the posture of the wrist from video images. Deviated wrist postures, which are associated with the performance of many tasks, have been reported to play a role in hand and arm discomfort and in a variety of disorders.

The goal of this study was to gain a better understanding of people's performance in judging wrist posture as well as people's ability to judge their performance. One objective was to determine the relative performance effects of one still image, two still images, and full-motion images. Other objectives were to determine the effect on performance relative to three different views and ten different wrist positions. It was also of interest to begin to understand how these three independent factors may interact with one another and also how the three dependent variables—accuracy, certainty, and decision time— related to one another.

A second experiment also investigated the display effects of a single still image vs. full–motion video. A second factor that was investigated was the performance

effects of more complex hand positions (i.e., while holding objects and performing real tasks).

In the first Experiment it was found that a view which was normal to the thumb–side of the hand resulted in significantly better performance than a view oblique to the hand. This effect held for each of the Display Methods and for seven of the ten wrist positions. It was hypothesized that this effect may be due to the inherent superiority of one view over another. An alternative possibility is that the thumb–side view offered participants the opportunity to compare what they saw on the screen to their own hands. It was suggested that these alternative possibilities be tested as the results may either support efforts to find "the best view" or to develop ways to provide "comparison postures."

In the first experiment there were significant main and interaction effects for the dependent variable, accuracy. There were also significant main effects found for certainty and decision time, but no interaction effects were found. An interesting finding from the first experiment was that people were generally overly confident of their performance. In most instances, participants' performances were not related to their *perceived* performances. For the full–motion images, half of the participants' perception of their performance was negatively correlated with actual performance.

As would be expected, two views were generally found to be better than one view. However, it was also found that a particular single view (thumb–side) resulted in a level of performance that was not significantly different from two–still combinations which did not include the thumb–side view.

No significant effects were found for the second experiment and the levels of performance were found to be similar to the first experiment under the oblique view condition.

As a background to the experimental investigations, literature pertaining to these four areas was reviewed: The relationship of wrist posture to hand and arm disorders, methods of observing posture, advancements in video technology, and considerations regarding the nature of video as a two–dimensional display format. Also explored were differences in public perception about the task–related "causes" of hand and arm disorders vs. the clinical and observational findings that were reviewed. It was suggested that the ergonomic community bears some responsibility for these differences. Better methods are needed not only to observe human factors, but also to communicate our observations amongst ourselves, to other professionals, and to anyone who could benefit by such knowledge.

ACKNOWLEDGEMENTS

I would like to thank Dr. Robert J. Beaton and Dr. Gregory Buhyoff for their support of this research. I would also like to express my gratitude to my husband, Bob Stenstrom, for the support, good humor, and perspective he provided. This research and my graduate education would not have been possible without the financial support of the Bush Foundation.

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INTRODUCTION

The human factors investigation presented here combines two specialty areas within human factors: the display of information (displays) and industrial ergonomics. These specialties are combined because it is recognized that video, as a display medium, may be valuable as an observational aid in industrial ergonomics.

This research investigates the human-machine interface for an ergonomics assessment tool. According to the report *Research Needs for Human Factors* (Chapanis and Hennessy, 1983), applied methods (tools) in human factors have not often been the focus of investigation nor have they been "treated as a topic deserving attention in (their) own right." The report which was published by the Committee on Human Factors of the National Research Council (NRC), states that research is needed "to improve existing methods and to develop new methods that will provide the data and information needed in current and future human factors work." Real time video recording was listed among other "generally known applied methods" which required further investigation to establish its efficacy in human factors work.

Since the 1983 report of the NRC committee, there have been numerous advancements in video technology. Along with cost reductions and image quality improvements, it is now possible to view and manage video on a personal computer. These achievements make it likely that video will be used as a tool in field and laboratory methods, thus it becomes especially important to "improve and develop" the interface to video research tools. Consideration must be given to specific human factors applications since different applications will make different demands of a video tool.

This paper discusses a human factors application for which video may be particularly well-suited. The application is *assessing the deviation of the wrist*. Excessive wrist deviation has been associated with the development of several impairments which are collectively referred to as *cumulative trauma disorders (CTDs).* These disorders are reported to have reached "epidemic levels" in certain industries and are also reported to be one of the leading contributors to occupational illness in the nation. A low-cost, reliable, and easy-to-use tool is needed to understand the relationship of wrist deviation to hand and arm disorders.

For the proposed experiments, CTDs provide the problem context for considering a video-based assessment method. The factors affecting the use of this video information provide a focus for the experimental manipulations.

Applied methods are formal means for acquiring and organizing information about human factors characteristics that arise in the context of an applied setting (i.e., a factory, an office, etc.). Examples of these methods include task analysis, collection and analysis of survey data, and structured walk-through analyses. According to the NRC, "much human factors work is performed under constraints of money, time, and opportunity that preclude the use of the kind of experimental methods used in laboratory research" (Chapanis et al., 1983). This does not mean that the applied methods themselves—and the tools to support those methods—cannot be investigated experimentally. It is the premise of this research that such methods and tools *must* be tested through controlled experimentation.

Visualization is a concept gaining acceptance in many scientific domains to create, interpret, and communicate data through enriched visual presentation formats. For many scientific disciplines, visualization offers an opportunity to "see the unseen." Interactive graphics, for example, play a central role in the research of molecular structures for advanced work in genetic engineering and drug design. Mathematicians employ imagery to visualize complex computations in order to ensure the integrity of their analyses and to provoke and communicate insights. (McCormick, DeFanti, and Brown, 1987). Visualization—if it is to be used by human factors specialists—could be expanded to include not only that which is *unseen* (e.g., the internal workings of the human body), but also that which is *difficult* to see.

Video assessment offers certain advantages over other possible means of assessment. Unlike direct observation, video provides a permanent record that can be analyzed repeatedly by different people. It is also possible to view two or more scenes at once and, thus, be able to make relative judgements. Unlike position–measuring systems designed for laboratory use, video acquisition systems require little investment and expertise to implement in field settings. Before relying on such systems as a principle data source, it is important to assess whether the video data format will facilitate correct and appropriate interpretations for the research objectives. Given the CTD focus as stated above, it is important to assess whether people will be able to make correct judgements of wrist posture when this information is presented in a two-dimensional display format.

It is the paradox of film and video to both reveal and disguise the true nature of things as they exist in a three–dimensional world. It is important, then, to understand how certain cinematic choices and presentation methods will reveal or disguise the true posture of the wrist, and whether observers will categorize wrist posture at an acceptable level of accuracy.

As an information display issue, the research question is: *To what extent can the medium of video be used beyond its normal mode of recording events?* As an industrial ergonomics issue, the questions are: *To what extent can we trust the field studies that have used video data to assess wrist posture?* and, *How can video data acquisition techniques be optimized for assessment purposes?*

The problem context chosen for this experiment (i.e., *hand and arm disorders*) is different from many other human factors topics as it is a topic that is currently receiving great attention in the lay press. To people who are coming to know this profession through the popular press, a disproportionate amount of their understanding may be based on ergonomics as it relates to hand and arm disorders. Thus, it may be important to view this problem not only as an important human factors issue in its own right, but also as an opportunity for the human factors profession to demonstrate the beliefs and methods of our profession to other professionals and to the public. The popularization of this topic also carries with it the liability that if human factors practitioners do not "meet the challenge" on this issue or worse, cause harm, a shadow may be cast on the profession in general.

LITERATURE REVIEW—RELATIONSHIP OF WRIST POSTURE TO DISORDERS

The Association of Hand and Arm Disorders with Wrist Posture

There are a great many disorders associated with the soft tissues of the hand and arm. *Cumulative trauma disorders* is a relatively new term for a special class of musculoskeletal disorders affecting many parts of the body, including the hands and arms. Kroemer (1989, p. 274) gives the following operational definition:

> Cumulative trauma disorders, CTD, is a collective term for syndromes characterized by discomfort, impairment, disability or persistent pain in joints, muscles, tendons and other soft tissues, with or without physical manifestations. It is caused or aggravated by repetitive motions including vibrations, sustained or constrained postures, and forceful movements at work or leisure.

CTDs of the hand and arm have received a great amount of attention in the lay press in recent years. These articles report: the steep rise in incidence or "epidemic" of cumulative trauma disorders due to "work-related factors" (Houston, 1989; Johnston and Baker, 1990; Kilborn, 1990; Tarbox, 1991); fines levied by the Occupational Safety and Health Administration (OSHA) for "willful violations" which have resulted in "injuries to the hands and wrists" caused by "repeated awkward motions" (eds., The Wall Street Journal, 1989), the reduction of OSHA fines for companies which implement "ergonomic programs" (Goozner, 1989; Johnston et al., 1990; Karr, 1989; Swoboda, 1990), and legislation to enforce "ergonomic standards" (Baker, 1991; Swoboda, 1990; Tarbox, 1991).

In the scientific and medical communities, work-related "causes" of cumulative trauma disorders are not without debate. Armstrong, Fine, Goldstein, Lifshitz, and Silverstein (1987, p. 831) state that controversy has arisen among investigators searching for the causes of hand and wrist disorders and that "it is almost always possible to find cases to argue for one factor or set of factors over another." What is particularly disputed, according to Armstrong, is the work-relatedness of these disorders. Kroemer (1989) and several other investigators who have discussed the work related risk factors of CTDs have also mentioned non-task related risk factors including age, gender, and chronic disease. Hadler (1985, p. 454) rejects the emphasis on work related risk factors when he states: "Carpal tunnel syndrome is probably no more prevalent in any industry or consequent to any task....the pathophysiology of the upper extremity use-associated discomfort is indeterminate and...the symptom complex defies current nosology." Nathan, Meadows, and Doyle (1988, p. 167) found "no consistent association" between the type and the level of occupational hand activity and the prevalence or the severity of clinical findings associated with carpal tunnel syndrome.

According to Sauter, Schleifer, and Knutson (1991, pp.151-152):

> Ergonomic improvements in the design of VDT tasks and workstations have been widely embraced as a primary measure for preventing musculoskeletal problems in VDT work. Available epidemiologic data, however, do not permit clear or definitive conclusions regarding the contribution of workplace ergonomic factors to these problems.

Several criticisms—many directed to ergonomists—are being articulated by Nortin M. Hadler, MD, a professor at the University of North Carolina School of Medicine. Hadler's criticisms begin with the terminology. Hadler believes that the commonly used term, *repetitive strain injury* (RSI), and other "use–associated" terms are ill-used as they "imply damage and task–related causality before corroborating evidence is in hand..." (Hadler, 1985, p. 454). He also believes that the "sophistry" being perpetrated on workers by ergonomists is not benefitting workers and that it may, in fact, be causing great harm by generating fear and hostilities among workers towards their employers (Hadler, 1990):

> ...ergonomists are currently acting, seeking political influence, and demanding fiscal rewards for their convictions—not for the demonstrable benefit of their interventions or even the substantive nature of their tenets. This is not science, academics, or altruism (p. 39).

One suspected risk factor—a deviated wrist posture—is the impetus of this investigation. Armstrong (1986, p.559) states: "Posture probably is the most frequently cited risk factor of occupational cumulative trauma disorders. Movements of the wrist, flexion–extension, and radial–ulnar deviation cause the tendons to be displaced past and against adjacent anatomic surfaces. For example, flexion and extension of the wrist are associated with tenosynovitis of the flexor and extensor tendons in the wrist and with carpal tunnel syndrome."

One reason that wrist posture, in particular, merits study is that it is amenable to change. By changing the configuration of various tool handles—a soldering iron (Chaffin, 1973), a pliers (Tichauer, 1978), a knife (Armstrong, Foulke, Joseph, and Goldstein, 1982)—it has been demonstrated that the wrist can maintain a more neutral position. It has also been demonstrated that a split keyboard whose parts are angled vertically and laterally, reduces wrist deviation (Nakaseko, Grandjean, Hunting, and Gierer, 1985). Schoenmarklin (1988) found that by bending the handle of a hammer, ulnar deviation decreased but radial deviation increased. These questions remain: Will such changes lead to fewer incidences of hand and arm disorders? Will the benefits realized from "bending the tool and not the wrist" outweigh the cost to redesign tools and equipment? And, where a redesign results in a *change* rather than a *reduction* in wrist deviation (as in the bent hammer), will the change have a positive effect?

There is a belief among researchers that wrist posture is an important factor to study. However, it has not been studied to any great extent due the difficult nature of this task—particularly in a field setting. Punnett and Keyserling (1987, p.1099) expressed a popular sentiment among researchers who have assessed wrist posture: "...the methods were extremely time and labour-intensive," and more "efficient techniques" must be developed.

Despite the perception that carpal tunnel syndrome and other hand and wrist disorders are a recent work task phenomena, the association of wrist posture to hand and arm disorders has been discussed in medical and scientific publications for several decades. These studies are difficult to compare since the methods, terminology, and the health end-points measured vary considerably from one study to another. The means used to assess wrist posture also vary considerably. For example, in some studies, specific measurements were taken of the wrist angle of persons, while in other studies, wrist deviations were merely surmised from patients' self-reported work histories.

In an effort to compare seemingly incomparable studies, several categories were developed and various studies were sorted according to these categories. Table 1 presents this information. Included are recent investigations as well as some of the earliest studies which discussed wrist posture as a possible etiologic agent for hand and arm disorders. The earlier studies are included because they are still quoted in contemporary reviews (Armstrong, 1986; Armstrong et al., 1982; Armstrong, Radwin, Hansen, and Kennedy, 1986; Feldman, Goldman and Keyserling, 1983;

Table 1

Investigations of the Association of Wrist Posture to Hand and Arm Complaints and Disorders.

Year	Principal Inves.	Wrist Posture Assoc. /(No association)	Condition	Type of Study* (N) CL	EX	FS	BIO	REC	HIS	CIT
1947	Brain, W.R.	(Flexion), Extension	Carpal Tunnel Syn.	6	**1**		Yes		6	
1959	Tanzer, R.C.	Flexion, Extension	Carpal Tunnel Syn.	22	12		Yes		**22**	
1964	Muckart, R.D.	Radial D., (Ulnar D.)	DeQuervain's Dis.	75			Yes		**75**	
1965	Lamphier, T.A.	Ulnar D.	DeQuervain's Dis.	103			Yes		103	**BIO**
1966	Phalen, G.S.	Flexion**	Carpal Tunnel Syn.	439					439	
1974	Duncan, J.	Ulnar D./Extension	Cramp, myalgia			**135**				
1975	Birkbeck, M.Q.	Deviation	Carpal Tunnel Syn.	658					658	**BIO**
1977	Smith, E.M.	Flexion	Carpal Tunnel Syn.		**8**		Yes			
1977	Tichauer, E.R.	Ulnar D.	Tenosynovitis			NS	Yes			
		Radial D	Tennis Elbow			NS	Yes			
		Extension	Tennis Elbow			NS	Yes			
1978	Tichauer, E.R.	Ulnar D.	Tenosynovitis			**80**	Yes			
		Ulnar D.	Tennis Elbow			**80**	Yes			
		Ulnar D.	Carpal Tunnel Syn.			**80**	Yes			
		All Dev. and Comb.	Fatigue/Patho.			NS	Yes			
1978	Armstrong, T.J.	Flexion, Extention	Carpal Tunnel Syn.				Yes			
1978	Hadler, N.M.	Deviation	Degen. Joint Dis.	**64**		**64**				
1979	Kuorinka, I.	(Deviation)	Upper Limb Strain	**93**		**NS**				
1979	Armstrong, T.J.	Extension	Carpal Tunnel Syn.			36				**CS**
1981	Gelberman, R.H.	Flexion, Extension	Carpal Tunnel Syn		**27**					
1982	Armstrong, T.J.	Not determined	CTD					250		
		Flexion/Ulnar	None stated			1				
		Flexion	Carpal Tunnel Syn							CL
		Ulnar D.	DeQuervain's Dis.							**CL**
1984	Armstrong, T.J.	Flexion, Extension	Carpal Tunnel Syn.		**6**		Yes			
1985	Nakaseko, M.	Ulnar D.	Less relaxed			**31**				
1987	Punnett, L.	(Flex), (Ext), (Uln),(Rad)	Persistent Pain			14				
1987	Armstrong et al.	(Flex), (Uln), (Flex/Uln)	Tendinitis	652		**NS**				
1987	Silverstein, B.A.	(Flex),(E.Ex),(Rad), (Uln)	Carpal Tunnel Syn.	652		**NS**				
1989	Szabo, R.M.	Flexion, Extension, Neut.	Carpal Tunnel Syn.		**28**					
1991	Sauter, S.	Ulnar, (Extension)	Arm discomfort			**40**				

* Types of Studies: Clinical study (CL), Experiment (EX), Field Study (FS), Biomechanical or anatomical argument (BIO), Safety records (REC), History (HIS), Citation (CIT). Note: CIT was coded only when this was the *primary* argument for or against the association of wrist posture. The primary means by which an association or non-association was made is indicated by bold type.

**Phalen is often quoted for reporting an association of wrist flexion to carpal tunnel syndrome. He believed that a flexed wrist with active finger flexion would "predispose to a carpal tunnel syndrome..." (Phalen, 1966,p. 219) but he also believed that "such occupations are not common."

Putz-Anderson, 1988; Sauter et al., 1991). These early studies are also referred to indirectly in the reviews by Kroemer (1989), who refers to the work of Putz–Anderson (1988), and Schultz–Johnson (1990) who refers to the work of Armstrong (1982).

Although this investigation pertains to the use of an assessment tool to be specifically used in field studies, other types of studies are explored here because they begin to reveal what is known as well as what is *not* known about the relationship of wrist posture to hand and arm disorders. This information is important for the design of future field studies and for the use of a video–based method of assessing posture.

Terminology Used in Table 1

Wrist position. Wrist positions in the two axes of wrist movement are pictured in Figure 1. According to Cailliet (1984), the wrist joint best resembles a *universal joint* found in machinery. The wrist joint simultaneously combines the movements in the extension–flexion and radioulnar planes and thus traces in space an irregular conical surface. Several authors have written about the range-of-motion along one or both axes. (Ryu, et al., 1991; Palmer, Werner, Murphy, and Glisson, 1985; Marin, Vernick, and Giredman, 1983; Cailliet, 1984; and Kapandji, 1982). It is interesting to note that there is quite a wide variation among their reports. For example, the mean ranges–of–motion in the flexion-extension plane reported among these authors vary from 133.3° (Palmer et al., 1985) to 170° (Kapandji, 1982). One source of variation may be due to location of a reference

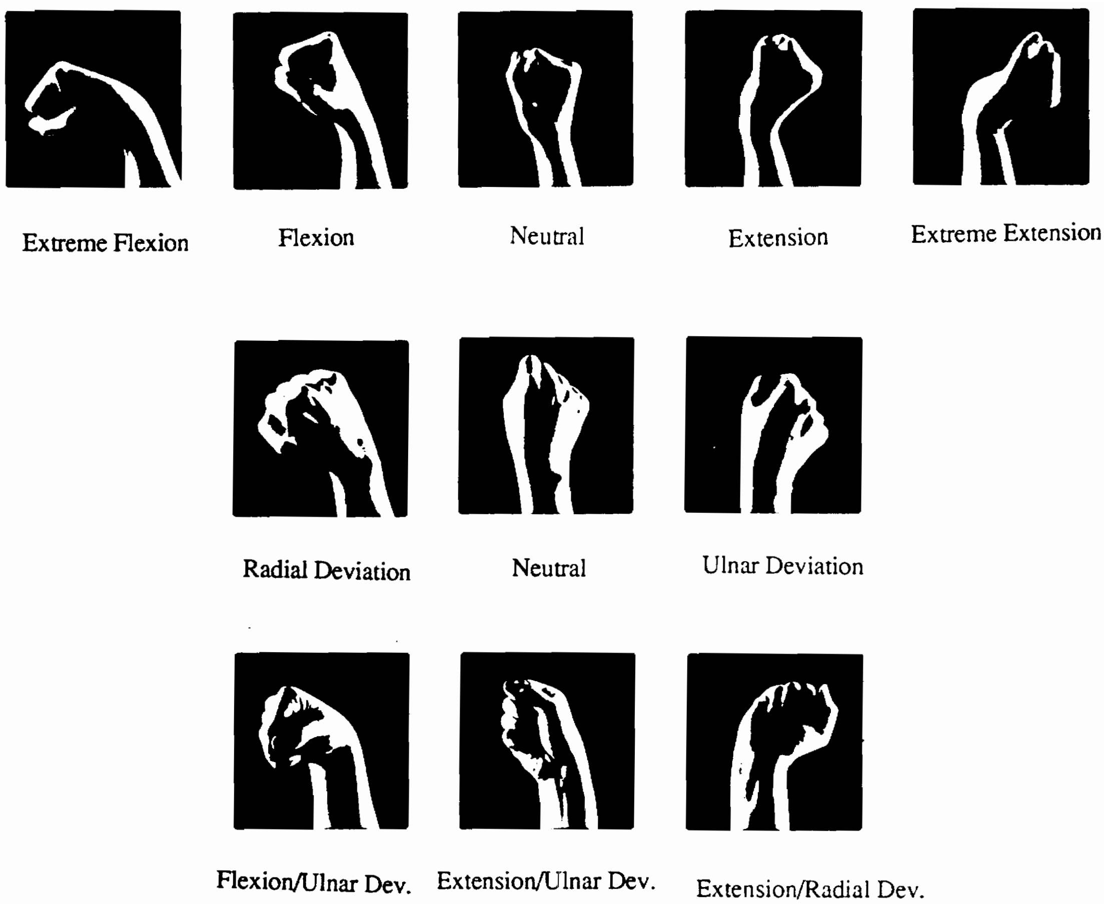

Figure 1. Wrist Positions

position. Kapandji (1982) demonstrated how substantially different postures can be derived based solely on where the reference position is defined (See Figure 2).

In an overview of cumulative trauma disorders, Putz-Anderson (1988, p.57) defines 0° deviation, *neutral*, and the position of "100% grip strength" as being the same position. Other authors suggest that these are not equivalent and interchangeable terms. According to Cailliet (1984, p. 3) the neutral (or "resting") position of the wrist is one of slight ulnar and palmer (flexion). Kapandji (1984, p. 162) describes the *functional position* of the wrist as one which "corresponds to the position of maximal efficiency of the muscles of the fingers especially of the flexors." Kapandji states that this position is achieved by slight extension of the wrist (40°–45°) and slight ulnar deviation (15°). The *functional movement of the wrist* has been described by Cailliet (1984) as cutting an oblique path from extension/radial deviation to flexion/ulnar deviation (e.g., a dart throwing motion). According to Cailliet, this plane of motion is due to the antagonistic muscle group pairings of the wrist and fingers.

Condition. This refers to the health end–points that were used in the various studies. These included specific disorders (e.g., carpal tunnel syndrome), generalized terms for non-specific disorders (e.g., tendinitis), and symptoms such as pain and discomfort.

Carpal tunnel syndrome (CTS). CTS is perhaps the most well known cumulative trauma disorder. According to Armstrong et al. (1987), this may be because peripheral nerve injuries are particularly disabling and perhaps too, because there are more objective diagnostic tests for nerve entrapment disorders (unlike tendon strain, etc.). CTS involves the entrapment of the medial nerve at the site of

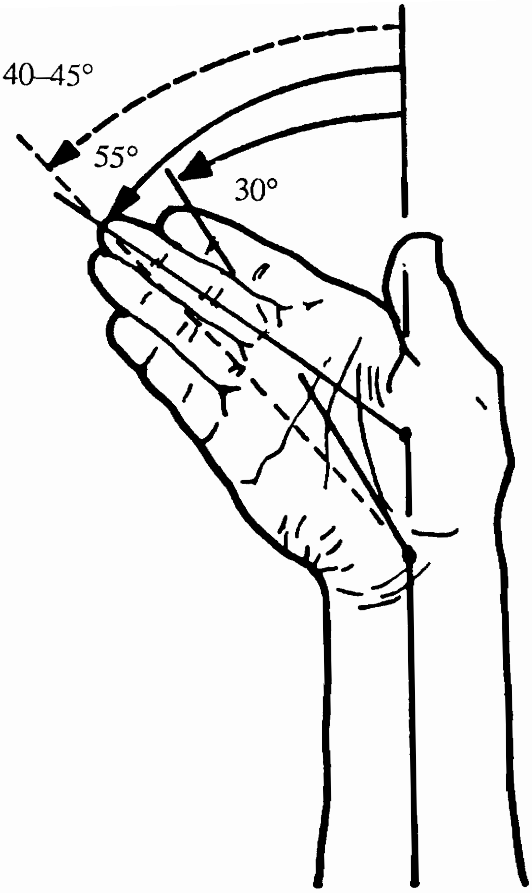

Figure 2. Different "reference positions" which may explain, in part, the different ranges–of–motion reported in the literature.

the wrist. Within the wrist joint is the anatomical structure of the carpal tunnel. The *dorsal* side of this tunnel (corresponding to the back of the hand) is formed by several carpal bones. The *palmer* side of the tunnel is formed by a ligament that wraps around the wrist bones. The median nerve courses through the tunnel with the nine tendons which allow the fingers to flex. The cross-sectional area of the carpal tunnel is about the size of a dime. Most authors agree that anything that reduces the space within the carpal tunnel—either through reduction of the size of the tunnel or through an increase in volume of the tunnel's contents—would tend to compress the median nerve.

Factors such as heredity, congenital abnormalities, age, and gender have been recognized as possible predisposing factors. "Work related" factors include: force, direct trauma to the wrist, vibration, cold environments, repetitive motions, and posture of the wrist. (Armstrong et al, 1987).

De Quervain's disease. De Quervain's disease affects the tendons on the side of the wrist and at the base of the thumb. It is the most recognized form of stenosing tenosynovitis. Stenosis refers to a progressive constriction of the tendon sheath. Symptoms of aching discomfort are localized at the base of the thumb with radiation into the hand and up the forearm. (Putz-Anderson, 1988).

Tennis elbow. This popular term for "lateral epicondylitis" is a form of tendinitis. In this disorder, the tendons at the site of the elbow (on the lateral side) become inflamed and become thickened and irregular. The fibers which make up the tendon may fray or tear (Putz-Anderson, 1988).

Tenosynovitis. This describes the inflammation of a tendon and its sheath (Taber, 1972). The symptoms include pain during any motion involving the tendon. The tendons most commonly involved are the dorsal extensors of the wrist, the extensor carpi ulnaris, and the long abductor and short extensor of the thumb (de Quervain's disease) (Cailliet, 1984). According to Calliet , in synovitis there is an invasion of the inflamed protective covering of the tendon (the synovium) into the tendon itself.

Tendinitis. Also called tendonitis. It is a form of tendon inflammation. Putz-Anderson (1988. p. 16) states that it "occurs when a muscle/tendon unit is repeatedly tensed. With further exertion, some of the fibers that make up the tendon can actually fray or tear apart. The tendon becomes thickened, bumpy and irregular...Without rest and sufficient time for the tissues to heal, the tendon may be permanently weakened." In a field study conducted by Armstrong et al. (1987, p.832) tendinitis (together with tenosynovitis) was diagnosed by: "localized pain and/or swelling over muscle-tendon structure that lasted more than 1 week...pain increased by resisted motions...or pain on passive range of motion; pronounced asymmetrical grip strength, more than 4 kg." Hadler (1990, p. 39) believes that "wrist soreness" would be a more appropriate clinical label since there is no "dystrophic (progressive weakening), atrophic (reduction in size), or overtly inflammatory state."

Type of Study. Many different types of studies were used as the basis for stating an association (or non-association) of wrist deviation to specific disorders and symptoms. As can be seen in Table 1, several investigators used more than one method to investigate hand and arm disorders. Where more than one type of study was employed, bold type indicates the method that was used as the *primary* basis for associating wrist posture with hand and arm disorders.

Clinical Studies/Surveys (CS). Studies in which clinical tests were used to establish specific conditions. Generally, the clinical studies were associated with an accounting of the patients history (i.e., work and hobbies) prior to the onset of symptoms. In some studies the "clinic" and the accompanying diagnostic tools were brought to the worksite.

Experiments (EX). Experiments on patients or cadavers for the purpose of measuring some phenomenon such as pressure in the carpal tunnel or the response of tissue to strain.

Field Studies (FS). Studies done in actual work settings. The wrist postures of an entire group of workers or "representative" workers were either measured or observed. This information was often (not always) compared with some health end–point.

Biomechanical and Anatomical Arguments (BIO). These were not studies as such with defined populations, etc., but rather arguments to suggest the pathogenesis of deviated wrist postures to CTDs based on mechanical, biological, or anatomical reasonings.

Records (REC). Standard safety reports based on the U.S. Occupational Safety and Health Act (OSHA Act) of 1970.

History (HIS). Formal or informal inquiry of people's self-reported history of health, work, and activities.

Citations (CIT). In many studies, investigators noted the association of wrist position to hand and arm disorders based on earlier studies rather than on their own findings. In these instances, the type of study in the *citation* was noted.

Summary of Investigations of Wrist Deviations to Cumulative Trauma Disorders

Clinical studies with patient histories.. The nine studies presented here took place from 1947 to 1975. More recent clinical studies where patient histories were were solicited have not been found. As shown in Table 1, the size of the populations in the clinical studies ranged from 6 (Brain, Wright, and Wilkinson, 1947) to 658 (Birkbeck and Beer, 1975).

In three studies, the role of wrist posture was made based upon the current work habits of their patients:

- Tanzer (1959, p. 627)

  > ...a careful review of the mechanics of exercise established that almost half of our patients had been engaged for varying periods of time prior to the onset of symptoms in prolonged activity involving forceful flexion of the fingers with the wrist either held in *flexion* or moving through some range of *flexor motion*

- Muckart (1964, p. 206)

  > ...analysis of the hand movements of patients suffering from de Quervain's disease show that a majority habitually used a *radial deviation* movement...

- Phalen (1966, p. 219)

  > Occupations that require active finger flexion with the wrist flexed should certainly predispose to carpal-tunnel syndrome...fortunately such occupations are not common.

The largest clinical study was by Birkbeck and Beer (1975). Wrist posture was referred to indirectly: "27.8% (of the women patients) gave knitting as their main hobby" (p. 220). They cited the works of Brain (1947) and Tanzer (1959) for more specific wrist posture associations.

Lampier, Crooker, and Crooker (1965) noted the occupations of 103 patients with de Quervain's disease but did not use this information to suggest the contribution of wrist posture. Rather, the association of ulnar deviation was based on the biomechanical analysis of a previous author, Eichoff (1927). Eichoff is quoted as saying "work requiring a constantly repeating movement of the wrist, especially in *ulnar deviation*, with the thumb fixed on some object, with each movement in this position causes the tendons to become taut over the styloid process...and press upon the tendon sheath, which is unable to avoid the pressure because it lies close to the bone." (Note: this is contrary to Muckart's belief stated previously).

It is important to highlight that in none of the clinical studies was it suggested that a deviated wrist posture acted as the sole etiologic agent. All of the studies suggested several other factors which may also cause, aggravate, or predispose people to hand and arm disorders. For example, Muckart (1964) reported that a firm grasp, or thumb grip in *combination* with radial deviation produced de Quervain's disease. He also found in his patient study of 75 people a "rapid rise in incidence between 40 and 60 years of age in women" and stated that this is "when collagen degeneration tends to occur and thus the retinaculum would be more vulnerable to strain..." Gender and age were highlighted in all of the clinical studies presented in this report. Brain (1947) does not call attention to these as contributing factors but describes his patients as "all middle-aged or elderly women" (Note: they were aged 37-67). The following quotes pertaining to age and gender are from other clinical studies:

- Tanzer (1959, p.626)

  > The prevalence of the disease among housewives at or near the time of the menopause support the hypothesis that some physiological change may render the nerve susceptible to compression at this particular period in life

- Muckart (1964, p.206)

  > The rapid rise in incidence between 40 and 60 years of age in women, when collagen degeneration tends to occur and thus the retinaculum would be more vulnerable to strain...support (the) theory...that de Quervain's disease is an acute episode superimposed on a chronic condition.

- Lampier et al. (1965, p. 850)

  > One interesting sidelight forthcoming from all published clinical data thus far has been that there are three times more women than men suffering from this crippling disease (de Quervain's). It is hypothesized that the greater joint angulation in females than in males contributes to this phenomenon.

- Phalen (1966, p. 217)

  > The fact that the majority of patients with CTS are women at or near menopause suggest that the soft tissues about the wrist may be affected in some manner by hormonal changes.

- Birkbeck et al. (1975, p. 218)

  > All series have shown a preponderance of female cases (of CTS), usually in a ratio of 3:1. This series was no exception...(Birkbeck's study of 577 patients also found that over half were in the age group 40-60).

Vascular abnormalities were often mentioned as being associated with the nerve entrapment disorder, carpal tunnel syndrome:

- Brain et al. (1947, p. 280)

  > ...it is probable that vascular degeneration in middle life increases the ischaemic effect of pressures which might be harmless in younger people. Moreover, the reaction of the nerve to pressure is oedema, which increases the pressure still further and so leads to a vicious circle.

- Tanzer (1959, p. 627)

  > Fifteen of twenty-five hands in which observations were recorded were found to have significant sensitivity to cold. In eight of these, vasospasm in the form of excessive sweating, color changes of the skin, or mild degrees of oedema was demonstratable. The presence of vasospasm in conjunction with median-nerve compression is certainly not unexpected...

- Phalen (1966, p. 218)

  > ...it is my strong impression that venous stasis is a factor in the production of symptoms (of CTS)...Vasodilatation and venous stasis accompanying sleep and inactivity could well explain the night pain. With engorgement of vessels in the flexor synovialis, increasing the volume of the contents of the carpal tunnel, pressure is applied to the median nerve. Active motion of the flexor tendons could then relieve the pain by mechanically decreasing venous engorgement within the carpal tunnel.

The following comments are indicative of other factors which were presented in combination with deviation wrist postures:

- Anatomic variations:

  "A most surprising finding was the presence of congenital abnormalities in seven of the (22) patients (with CTS)" (Tanzer, 1959, p. 629). Phalen (1966, p. 217–218) stated, however, that "a congenital abnormality is rarely the cause of compression." Muckart (1964, p. 207) stated that "the anatomic variations and arrangements of the affected tendons do not appear to play an important part in the production of de Quervain's disease since no single variation was found more commonly than would be expected in a comparable group of patients without wrist symptoms."

- Excessive Use of Hands:

  Birkbeck et al. (1975) believed that light, highly repetitive movements were the predisposing conditions of CTS. Brain (1947, p. 280) believed CTS to be occupationally related in that 4 of his 6 patients reported "much unaccustomed housework during the war." However Phalen (1966) reported that recent excessive use of the hands was thought to be an etiological factor in only 21 of the 439 cases he studied. Phalen also stated CTS was *not* an occupational disease since "men certainly subject their hands to more trauma than do women, but men contributed only 33 per cent of all cases in this series" (Phalen, 1966, p. 219).

Experiments. All of the experiments listed in this review pertained to the investigation of carpal tunnel syndrome. Brain et al. (1947) is the earliest investigator in this review to perform an experiment . Reference is made in his investigation to an even earlier experiment by Abbott and Saunders (1933) which demonstrated the affects of acute flexion on a cadaver.

Five of the six experiments in this review were investigations of the pressure in the carpal tunnel for various wrist positions in the flexion–extension plane. Table 2 compares the results of these experiments. The actual pressure measurements cannot be compared across studies since different methods were used. The *relative* changes within each study can be compared across studies. Brain, for example, measured the relative difference of carpal tunnel pressures for various postures and found that extreme extension produced pressures that were three times larger than extreme flexion. He also added the observation, "if the tip of the little finger is introduced into the carpal tunnel in the cadaver, it is easy to feel that there is much more room in it during flexion of the wrist than during extension. Moreover, on flexion of the wrist, as might be expected, the median nerve becomes slacker (p. 280)".

Table 2. Comparisons of investigations where carpal tunnel pressures were measured relative to wrist flexion and extension.

Study (Year)	N	Loc	Sub.	Load	Extreme Flexion		Flexion		Neutral	Extension	Extreme Extension
		Conditions			Intercarpal Pressures						
Brain (1947)	1	CT	CAD	—	100 (No Units)				0 (Ref.)		300
Tanzer (1959)	6	Prox	CTS	—	0-8 (No Units)				0 (Ref.)		2-7
	6		CAD	—	1-6				0		3-8
	6	Distal	CTS	—	-2 - 2				0		1-5
	6		CAD	—	-1 -1				0		1-6
						(60°)	(45°)	(30°)		(45°)	
Smith (1977)	8	In/Prox	CAD	—	260mmHg	—	—	—	—	—	360
	8	In/Prox	CAD	5 Lbs		301	216	186	76	32	
	8	In/Prox	CAD	10 Lbs		454	358	312	122	73	
Gelberman (1981)	12	Prox	NOR	—	31mmHg				2.5		30
	15	Prox	CTS	—	94				32		110
Szabo (1989)	6	Prox	NOR	—	17mmHg				5		27
	17	Prox	CTS-E	—	38				11		55
	5	Prox	CTS-A	—	12				4		35
	6	Prox	NOR	Post Exer					7		
	17	Prox	CTS-E	Post Exer					28		
	5	Prox	CTS-A	Post Exer					5		

Categories
LOC: Location in wrist where pressure measurements were taken. CT—Carpal Tunnel, Prox—Proximal half of carpal tunnel (towards body), Distal—distal half of carpal tunnel (towards the fingers), In/Prox— simultaneously inside tunnel and proximal wrist
SUB: Subjects. CAD—human cadavers, CTS—subjects with carpal tunnel syndrome, CTS–E—subjects with early/intermediate stages of CTS, CTS–A—subjects with advanced stages of CTS.NOR—normal subjects (without CTS)
LOAD: Weight or exertion that hand was subjected to. 5 Lbs/10 Lbs—static tendon loads on 4 finger tendons (to represent forceful pinch grip), Post Exer—pressure readings 10 minutes after exertion

Tanzer (1959) suspected that—contrary to Brain's findings—*flexion* played a larger role in the pathology of the disease, particularly since flexion held for one minute was known to elicit symptoms. In an "attempt to resolve (several) conflicting observations" (p. 629) by previous researchers, Tanzer measured pressure in the carpal tunnels of 6 patients with CTS and 6 "normal hands" of cadavers. He also measured pressure in two locations of the wrist, one being on the proximal (towards the body) side of the carpal ligament and one being on the distal (towards the hand) side of the carpal ligament. Like Brain et al (1947), Tanzer found that pressure was higher in extension than in flexion but only when it was measured on the *distal* side of the tunnel. The *proximal* measurements were comparable. Tanzer (1959, p. 633) observed in his patients that constriction was found predominantly in the proximal third of the carpal canal. Tanzer based his argument for the greater role of flexion on "a logical anatomical concept." He believed that when the wrist is in some degree of flexion *and* the fingers are also flexed, the median nerve is squeezed "between the taut flexor tendons within the canal and the unyielding anterior wall and proximal rim of the carpal canal with a force proportional to the degree of grasp exerted by the digits." Whereas in extension, no such constriction occurs.

Almost twenty years later, Smith, Sonstegard, and Anderson (1977) developed an experiment to test Tanzer's hypothesis of the combined effects of wrist flexion with finger flexion. Smith and colleagues subjected various finger flexor tendons to forces in order to mimic the forces of a pinch grip. Their findings (See Table 2) support Tanzer's hypothesis. They found no significant pressure differential with unloaded tendons until extreme positions of flexion and extension were reached.

When the flexor digitorum perfundus tendon to the second and third digits was loaded, significant and increasing pressure differences were observed for three intermediate levels of flexion: 30°, 45°, and 60°.

An important additional finding in this experiment was that when the flexor tendons were loaded, the wrist position defined as "neutral" had *more* pressure than when it was in 45° of extension. This may lend support to Cailliet's statement (1990) that the *functional* position of the wrist is that of 40-45° of extension and Brain's observation that "all powerful movements of the hand are done with the wrist in extension" (1947, p. 282).

The findings from Smith's experiment as shown in Table 2 were of readings from a long pressure transducer which replaced the median nerve. It covered both the proximal, antebracial (middle) and distal portions of the carpal canal and so pressures in these areas were not differentiated. Smaller transducers were later used to compare pressure readings in these areas. The researchers found that the extremes of passive wrist flexion and extension (no loading) cause considerable compression of the median nerve in both the distal and proximal regions. The greater pressures however were recorded in the antebracial region (Tanzer (1959) did not take measurements in this location). During *active* loading of the flexor digitorum profundus, the reverse was found: it was the proximal and distal portions of the canal that compress the median nerve to the greatest extents rather than the antebrachial region.

Another important finding from Smith's research was that of the twelve individual and combination tendon loadings that were studied, loads to the flexor digitorum perfundus to the second and third fingers caused significantly greater readings than other individual and combination tendon loadings. This indicates that it may not simply be *that* an object is held in a *pinch grip* but rather the *way* in which it is held that contributes to the increased pressure (in combination with a flexed wrist).

The research of Szabo and Chidgey (1989) is significant in two respects: it differentiates between early/intermediate and advanced stages of carpal tunnel syndrome and it also compares pressure readings between pre- and post- exertions. It was found that the pressure in advanced stages of CTS behaves more like that of normal wrists than of early and intermediate stages. When CTS cases are lumped together, significant pressure differences were found (compared to normal wrists) only in extreme extension (i.e., not in neutral or maximum flexion). When the early and intermediate stages were compared separately to normal wrists, there was significantly elevated pressure in all positions amongst the people with early and intermediate CTS.

In Szabo and Chidgey's investigation, the hands were repeatedly flexed and extended (passively) to maximum positions at the rate of 30 full cycles per minute for 1 minute. It was found that the group with early and intermediate stages of CTS not only had carpal tunnel pressures that rose significantly more after exercise, but 10 minutes post-exercise, the pressures remained high. The control group and the people with advanced stages of CTS did not have a measurable increase after exercise.

Several authors called attention to individual variations. Tanzer (1959, p 633) stated that "in the wrist operated upon there was marked individual variation in the size of the median nerve." The pressure readings from Tanzer's experiment (See

Table 2) also show considerable variation amongst subjects. Smith referred to large "specimen variability" (Smith, 1977). Muckart (1964) and Lamphier (1965) also discussed individual variations with respect to the anatomy of the thumb.

Armstrong, Castelli, Evans, and Diaz–Perez (1984) examined the histological changes in various tissues of the carpal tunnel on six postmortem wrists. They concluded that the location and character of the changes suggested that repeated exertions with a flexed or extended wrist were an important factor in the etiology of tissue changes. However they also suggest—since it was "doubtful that all of these specimens came from persons who suffered from carpal tunnel syndrome"—that "there is sufficient repetitive stress in nearly everyone's wrist to produce some tissue changes inside the carpal tunnel" (p.201).

Field Studies. Sauter et al. (1991) states that while some field studies have found positive associations between deviated work postures and musculoskeletal signs and symptoms, several other studies found no such associations. This lack of epidemiological evidence has been reported by other investigators as well. Silverstein, Fine, and Armstrong (1987, p. 343) state that "there has been little documentation of actual incidence or prevalence of occupationally related carpal tunnel syndrome in the scientific literature." Punnett et al. (1987, p. 1099) state that there exists "experimental evidence" and "strong biomechanical arguments" associating various deviated wrist postures with various disorders but "epidemiological research is needed to evaluate the possible associations between workplace exposures and adverse human health outcomes."

Despite his recent criticisms of ergonomists who have studied work-related factors to investigate a possible etiologic relationship to hand and arm disorders, Hadler (1977) at one time promoted this type of research saying: "...if defined patterns of usage were associated with defined clinical syndromes, such knowledge would have considerable therapeutic and prophylactic potential" (p.1019) and "there is little formal proof that pattern of usage...causes or precipitates any regional musculoskeletal disease...(and that) it is important to attempt to establish such a relationship if it exists" (p.1023).

Table 3 further categorizes the 12 field studies (as listed in Table 1) by duration of observation, and methods of observation and measurement. As can be seen, some studies found an association of wrist posture to symptoms or disorders, while other studies found no association. These 12 field studies range in sample size from 1 to 135. Often the size of the employee sample used to categorize wrist posture was much smaller than the sample size in the entire field study. For example, Punnett et al. (1987) investigated the work of 151 workers but analyzed the posture in just 14 workers. Armstrong et al. (1982) analyzed the posture of just one individual from a much larger group of workers. Investigations by Kourinka and Koskinen (1979) and Silverstein, Fine and Armstrong (1987) reported that a sub–sample of "representative" workers were assessed for wrist posture but did not say how many workers were studied.

The following is a synopsis of each of the field studies:

Duncan and Ferguson (1974). The purpose of this study was to observe the postures of the wrists and shoulders and compare these findings with symptoms of muscle incoordination (cramp) and aching. Symptomatic (n=90) and asymptomatic operators (n=45) of teleprinter machines were observed for one year and differences between these two groups were tested.

Table 3. Field studies which investigated the relationship of wrist posture to hand and arm disorders

Year	Principal Inves.	Association(No Association)	Condition	N/n[1]	Time and Duration of Observ.	Method
1974	Duncan, J.	Ulnar D./Extension	Cramp, myalgia	135/135	"more than a year"	Direct Obs
1977	Tichauer, E.R.	Ulnar D.	Tenosynovitis	NS/NS	Not stated	Not stated
		Radial D.	Tennis Elbow	NS/NS	Not stated	Not stated
		Extension	Tennis Elbow	NS/NS	Not stated	Not stated
1978	Tichauer, E.R.	Ulnar D.	Tenosynovitis	80/80	twelve weeks	Not stated
		Ulnar D.	Tennis Elbow	80/80	twelve weeks	Not stated
		Ulnar D.	CTS	80/80	twelve weeks	Not stated
		All Dev. and Comb.	Fatigue/Pathology	NS/NS	Not stated	Not stated
1978	Hadler, N.M.	Deviation	Degen. Joint Dis.	64/NS	Single	Direct Obs.
1979	Kuorinka, I.	(Deviation)	Upper Limb Strain	93/NS	Single	Video
1979	Armstrong, T.J.	Extension	CTS	36/36	Single,< 2 min/sub.	Video
1982	Armstrong, T.J.	Flexion, Ulnar	Not stated	57/1	Single, 15 sec	Video
1985	Nakaseko, M.	Ulnar D.	Less relaxed	31/31	Single, 15 min	Direct Obs.
1987	Punnett, L.	(Flex), (Ext), (Uln),(Rad)	Pain	151/14	Single, 1-10 min/sub	Video
1987	Armstrong, T.J.	(Flex), (Uln), (Flex/Uln)	Tendinitis	652/NS	Not stated	Video
1987	Silverstein, B.A.	(Flex), (E. Ext), (Rad), (Uln)	CTS	652/NS	Single, 3 cycles/sub	Video
1991	Sauter, S.	Ulnar, (Extension)	Discomfort	40/40	Single (static posture)	Goniometer

1 Size of the sample population: N=number of people in entire study, n=number of people whose wrist postures were observed

The researchers found that ulnar deviation was associated with 70% of the subjects and 39% of the controls. Wrist extension was found in 51% of the subjects and 20% of the controls.

Unique to this field study was that the two wrist postures observed were tested for a possible association. Associations were also examined between these wrist postures and the other postures observed. Ulnar deviation was associated with wrist extension, shoulder depression, shoulder abduction, and shoulder flexion ($p < .05$). Wrist extension was found to be associated with shoulder depression and shoulder flexion ($p <.05$).

Tichauer and Gage (1977). It can only be inferred from this paper that the associations relating specific wrist postures to specific disorders were derived from observations in actual work settings. The authors do not state this explicitly (i.e., by discussing sample size, methods of observations and diagnosis, etc.).

In this article, Tichauer et al. states that tenosynovitis is "often associated with continual ulnar deviation during rotational movements (e.g., screwdriving)..."(p. 634). Radial deviation "may lead to" tennis elbow (lateral epicondylitis) and this condition could also be precipitated by "violent extension of the wrist with the hand pronated" (pp. 633-634).

Tichauer (1978). In his book, *The Biomechanical Basis of Ergonomics*, Tichauer reports an earlier study of two groups of trainees in electronics assembly (n=40 in each group). One group used a conventional straight pliers and the second group used a bent handled pliers. After a period of 12 weeks, the subject population using the straight pliers—which required their wrists to be in ulnar deviation—reported 7 cases of carpal tunnel syndrome, 2 cases of tennis elbow, and 16 cases of tenosynovitis. By comparison, the control group—who could maintain a neutral wrist position with the bent-handled pliers—had 4 cases of tenosynovitis at the end of 12 weeks and no other disorders.

Tichauer does not state the circumstances by which wrist postures were measured or disorders were diagnosed in this study or in the other posture/disorder associations which he reports. The other associations are as follows:

"Ulnar deviation, combined with supination, favors the development of tenosynovitis" (p. 42).

"Radial deflexion, particularly if combined with pronation,...is conducive to epicondylitis or epicontylar bursitis" (p. 42).

"Four wrist configurations (flexion, extension, ulnar deviation, radial deviation), particularly when they approach the extremes of their range, are conducive to fatigue, discomfort, and sometimes disease. Especially unhygienic situations are those in which these positions...occur in combination with each other" (p. 41).

Hadler, Gillings, Imbus, Levitin, Makuc, Utsinger, Yount, Slusser, and Moskovitz (1978). This investigation tested three "stereotyped patterns" of hand usage and compared these findings with changes in the structure and function of the hand. The researchers found "highly significant task-related differences" which were "consistent with the pattern of usage" (p. 210).

The sample population consisted of 3 groups of female textile workers, each employed in a stereotyped manual task for at least 20 years. Pattern of usage was assessed by a single ergonomist. Hand structure and function were assessed though range of motion tests and radiographic methods by several examiners (3 rheumatologists and a physical therapist).

Among the findings were these: most of the task-related impairments were detected in the dominant hand and, among the bimanual tasks, bimanual impairment was significantly more prevalent than in the single-manual tasks. For example, in the operation where there was bimanual wrist motion (the *winding* task), there was a concomitant rise in structural impairment of both wrists.

The authors urged caution in extrapolating their findings to other populations.

Kourinka and Koskinen (1979). Ninety-three workers performing manual operations in a scissor making process were surveyed for work and health history and examined clinically for upper limb disorders.

Work methods—including postural assessment of the wrist joint—were analyzed for "a few workers from every station" (p. 41). The authors noted that their investigation did "not take into account individual differences" (p. 41) despite their observation that "a wide individual variation existed for the performance of each task" (p. 42).

In this study distinctions were not made among various wrist postures (i.e., flexion vs. ulnar deviation, etc.) but rather, "a deviation of more than 20° from a *basic anatomic position* was the basis for calculation." The authors do not state how the basic anatomic position was determined.

Assessment of wrist posture was made by observing videotapes. The authors do not state the conditions by which the videotapes were made (i.e., camera angle, number of cameras, etc.) nor the method by which the tapes were observed (i.e., number of observers, tests for validity, etc.)

No associations were found between deviated wrist postures and damage to tendons and tendon/sheets.

Armstrong and Chaffin (1979). The objective of this study was to investigate why "some people develop carpal tunnel syndrome while others do not" (p. 481). The work methods of two groups of women who performed production sewing tasks were observed. The first group (the *diseased group*) had either: a history of numbness or pain in the areas on the hand innervated by the median nerve, surgical decompression of the median nerve (i.e. carpal tunnel surgery), a positive Phalen's test, or thenar atrophy. The sample size for both the diseased and the asymptomatic control group was 20.

A single super 8 movie camera was used to record wrist positions. Wrist positions were classified as *extension* or *flexion* when they were greater than 15° from *neutral*. The authors do not define the neutral position. Less than two minutes of data was taken for each subject.

Armstrong et al. reports that "a small but significant ($p < .05$) relationship was found between wrist position class and subject class..." and that most of the association was due to "the more frequent use of the extended wrist position by the diseased group (32.3%) than by the control group (26.3%)" (p. 483). The histogram on page 485 shows that over 10% of the data was hidden from the view of the camera and that there was only a 2-3% difference in the observed neutral positions. A 1-2% difference was shown between groups for the flexed wrist position.

The researchers state that "findings of this and other studies indicate that it is advisable to minimize frequent deviations of the wrist from the *straight* (emphasis added) position, particularly during forceful exertions of the hand" (p. 486).

Armstrong, Foulke, Joseph, and Goldstein, (1982). This paper describes a study in a poultry processing plant that proceeded "from an analysis of health records to an analysis of work methods, postures and forces" (p. 103). The study concluded with recommendations for alternative work procedures and knife redesigns.

The review of the number and incidence rates of cumulative trauma complaints revealed that there were 32 incidences in the entire plant, 10 incidences in the *boning* department, and 10 incidences in the *thigh skinning* department. The authors of this article do not state the number of people who worked in the plant or in any department in the plant but rather, use the total number of hours worked as a basis for calculating incidence rate. Calculations based on these numbers reveal that there was the equivalent of 250.1 "full-time equivalent" workers (FTE) in the entire plant, 57.4 FTE in the boning department, and 7.7 FTE in the thigh skinning department.

In the second phase of the study—the thigh skinning department was investigated further due to the high incidence rate relative to other departments. Of the 10 incidences of cumulative trauma complaints in this department, there were *no* reports of a *nervous* disorder (e.g., carpal tunnel syndrome) and 1 report of a tendon disorder. The remaining 9 disorders were *nonspecific* which the authors define as "any complaint of soreness, aching, swelling, or knots, that could not be attributed to an acute episode. No distinctions are made regarding dominant hand nor the age nor gender of the workers.

Film recordings (one camera assumed) were made of two subjects. "Films from one subject were completely analyzed, while films from the second were used to verify the consistency of the first" (p. 114). The authors do not report the length of time that observations were made. A 15–second assessment is included in their report. The authors do not say whether the subjects studied had been among those who complained of hand disorders—only that they were "experienced" workers.

The authors' observations, combined with referenced reports of "occupational factors of cumulative trauma disorders" (p. 104), led them to recommend a reconfigured knife for the task of thigh skinning. The authors do not report whether this recommendation was implemented or, if so, what effects were noted.

Nakaseko, Grandjean, and Hunting (1985). The purpose of this study was to test "a keyboard concept based on biomechanical considerations..." (p.175). The postures of fifty-one trained typists were measured. An adjustable split keyboard in which the opening angles, lateral inclinations, and distances between sections were tried. Comments were elicited from the subjects pertaining to preferences, feelings of soreness, and feelings of relaxation. A split keyboard—in which subjects could maintain a wrist posture with less ulnar deviation (10° vs. 20° with a conventional keyboard)—was preferred by two-thirds of the subjects. When the split keyboard was combined with a *forearm-wrist rest* the subjects reported feeling "less tense" after 15 minutes of typing compared to a traditional keyboard with wrist–rest.

Punnett and Keyserling (1987). 14 jobs in a garment assembly operation were used to investigate a video-based tool for assessing "non-neutral postures (of the wrist) on a continuous basis" (p. 1099).

The health end–points considered were "persistent pain of the wrist or hand, experienced within the year preceding the survey date" (p. 1101). The outcomes were evaluated separately for both right and left sides.

The sample population (from which health outcomes were gathered) was 151 female workers. One worker from each of 14 jobs was selected for filming. The film was analyzed frame-by-frame at a recording speed of 4 frames per second. Wrist positions in the flexion–extension arc were defined as mild (15 to 45° from neutral) or extreme (46-90°). Ulnar deviation was at least 15° from neutral and radial deviation was at least 5° from neutral.

Relative to posture/symptom associations, some positive correlations were found but they were not significant. Where significant associations *did* occur, they were in the *opposite* direction of what was expected. For example, *less* wrist pain was associated with 45° wrist flexion (left hand) at $p < .05$.

The authors state that "error in the recording of postures could have been introduced by the need to correct for the angle of the camera relative to the worker's hand when viewing the film" (p.1112). They suggested that stereo cameras could provide more reliable results for future research but that it would also increase the time and labor costs of the analysis.

Another source of error suggested by the authors is: "...by filming only one worker, on one occasion, in each job, we were forced to assume negligible within-job (between individual) and within-individual (between cycle) variability in task performance. The validity of these assumptions has not been demonstrated" (p. 1112).

Armstrong, Fine, Goldstein, Lifshitz, and Silverstein (1987). In the statement of methods, this was described as a cross-sectional study to "evaluate the relationship between repetitiveness, forcefulness, and selected cumulative trauma disorders of the hand and wrist" (p. 831). The results section of this report adds additional occupational (e.g., wrist posture and vibration) and personal (e.g., use of birth control) factors. The authors do not discuss how data pertaining to these additional factors were gathered.

No significant differences ($p < 0.05$) were found for the percentage of work time spent in wrist flexion, ulnar deviation, flexion and ulnar deviation..." (p. 832). However, "significant differences in posture were observed between males and females and may, in part, account for the significant gender factor" (p. 832). The authors do not state the nature of the posture differences.

The authors also do not state how many workers were observed for the purposes of wrist posture analysis nor for what length of time. It is clear that assessments were *not* made of the entire 652 sample population: "Unfortunately, it was not possible to analyze enough postural data in the present study to compare within-job postural differences between males and females" (p. 833).

Despite their findings, the authors state that "...there is ample evidence that...certain postures are also important factors in hand and wrist tendinitis and should be considered as possible intervention routes" (p. 835).

Silverstein, Fine, and Armstrong (1987). A study was made of 652 workers to assess the prevalence of carpal tunnel syndrome and its possible relationship to work-related factors, including wrist postures. "At least three representative workers in each selected job were videotaped (two cameras) performing the job for at least three cycles...Postural data were abstracted from the videotapes three times per second for at least three cycles per subject. Wrist posture was characterized in terms of flexion and extension (more than 45° flexed, 15-45° flexion, neutral, 15-45° extension, and more than 45° extension) and deviation (ulnar, neutral, radial)" (p. 344). With respect to the workers chosen for study, the authors noted: "Within some jobs, there was considerable variability between the three workers and their job requirements...The variability between individuals with similar or identical jobs was probably greatest for wrist postural variables (p. 355)" and "Individual variation within jobs for all subjects was not taken into account in the analysis" (p. 355).

The authors reported that "The 'carpal tunnel syndrome jobs' had slightly more ulnar deviation.... but these differences were not significant" (p. 353). Despite their findings, the authors suggest that among other measures, "a change in postural factors...may result in a reduction in prevalence or incidence of occupationally related CTS" (p. 356).

Sauter, Schleiffer, and Knutson (1991). This investigation gathered self-reported data on musculoskeletal discomfort from 539 VDT workers and compared this with a sub–sample of the postures of 40 workers. The investigators chose to measure postures directly rather than rely on indirect assessments (i.e., using photographic images) in order to avoid "measurement error" (p. 152).

Regarding hand posture, the authors reported "ulnar deviation of the right hand proved significant in prediction of right arm discomfort." And "no such effect occurred for the left hand, and hand extension in either arm" (p. 161). It should be noted that in this task, the right hand/arm was devoted exclusively to keyboard operation whereas the left arm was used to manipulate documents on a document holder.

The prevalence rates for right wrist and hand were 12% and 13% respectively. According to the authors, these figures were overshadowed by discomfort in other regions of the body: right shoulder (15%), neck (27%), and back (25-33%). The authors noted the discrepancy of their findings to the "apparent predominance of wrist/hand disorders in recent outbreaks of musculoskeletal disorders among VDT users" (p. 164).

LITERATURE REVIEW—POSTURE OBSERVATION METHODS

Summary of Studies

A summary of the posture assessment methods reviewed are shown in Table 4. Of these 19 studies, 10 used video or film as the primary medium for data collection and 4 used direct observation. The remaining 5 methods used direct observation as the primary technique but also used video either to train the observers or to check inter–subject reliability.

The following categories were used to report how various authors of posture techniques tested the accuracy of observations: *inter–subject reliability (Reliab)*, where the responses of two or more observers were compared; tests for *validity (Valid)*, where observations were compared to actual measurements of posture or to

Table 4

Summary of Observational Methods Used and Proposed to Assess Posture in Field Settings

Year	Principal Author	Name of Method	Use of Film/Video	Checks Reliab.	Valid	Comp.	Wrist Posture
1974	Priel	Posturegram	No, direct observation	No	No	No	No
1977	Karhu	OWAS	No, direct observation	No	No	No	No
1979	Corlett	Post. Targeting	Yes, limited	No	No	*Yes*	No
1979	Armstrong .	Unnamed	Yes	No	No	No	No
1982	Armstrong	Unnamed	Yes	No	No	No	*Yes*
1982	Holzmann	ARBAN	Yes	No	No	No	No
1986	Waganheim	ARBAN	Yes	No	No	No	*Yes*
1986	Keyserling	Unnamed	Yes	*Yes*	No	*Yes*	No
1986	Silva	CPM	Yes	*Yes*	No	No	No
1987	Punnett	Unnamed	Yes	No	No	No	*Yes*
1987	Keyserling	Unnamed	Yes	*Yes*	No	No	No
1988	Wells	Unnamed	Yes, limited	No	No	*Yes*	*Yes*
1988	Fisher	Unnamed	No, direct observation	No	No	No	?
1988	Foreman	Unnamed	Yes, limited	*Yes*	No	No	No
1989	Chen	PWSI	Yes	No	No	*Yes*	No
1990	Kant	OWAS	No	*Yes*	No	No	No
1991	Stetson	Unnamed	Yes, limited	*Yes*	No	*Yes*	*Yes*
1991	Malchaire et al.	Unnamed	Yes	No	No	No	No
1991	Kivi	OWAS	Yes, limited	*Yes*	No	No	No
Total Studies: 19		"Yes":	10 (video as primary source) 5 (limited use of video)	7	0	5	5

"staged" postures; and *comparisons (Comp),* where one observational technique was compared to another.

As seen in Table 4, 7 of the 19 observational techniques included tests for inter–subject reliability and 5 compared the results of two methods of observation. Of the 19 techniques presented, there were no instances where tests were performed to challenge the validity of the observations and tests for validity in general were not discussed.

A minority (6) of the observational methods in this review included the wrist joint in the assessment process.

The observational techniques, presented here in chronological order, reveal that there is little concurrence among various investigators as to an "ideal approach" and no method has been widely embraced. Instances where methods developed by one researcher and later used by others were always within a geographic location or research community: the *OWAS* method was developed in Finland and it use has been reported only in Finland and The Netherlands, the *ARBAN* method was developed in Sweden and its reported use has only been in Sweden, a method was developed by The University of Michigan researchers and its use has only been reported by researchers at the University of Michigan.

A common theme among these methods is that they be simple to use and easily taught. The following is a synopsis of each method.

Priel (1974)

This was a proposed system which would allow postures to be numerically defined and recorded. This method was designed for direct observation since (according to the author): “Pictures are limited to two dimensions and therefore contain no perception of depth unless much trouble has been taken to produce it.”

Priel noted that prior to his proposal, no other technique had been developed in the human factors literature which would define a *base posture* which could be used for reference purposes and that only “sitting, standing, and lying down” could convey a “certain amount of standardized information” (p. 577). He stated that “the astounding versatility of body movements has been left undefined on the mistaken assumption that such a task would fill volumes” (p. 577).

Priel believed that his proposed method could be easily learned and he envisioned that a *library of postures* could be set up for the use of designers.

From his drawings and the sample form, it appears that the two axis of motion of the wrist joint was to be included in the analysis. As with all other joint articulations, each degree of freedom of the wrist joint was divided into 10 sections.

Karhu, Kansi, and Kourinka (1977)

The Ovako Working Posture Analyzing System *(OWAS),* was designed as a “practical method for identifying and evaluating poor working postures” (p. 199). The first part of the method, an observational technique, was meant to be used by work-study engineers in their daily routine and after “a short training period.” The second part of the method was an evaluation which related the postures found in part one to factors such as health, safety, and discomfort. The evaluation component was designed to be done by experienced workers and ergonomic experts.

"Photographic material" was used for training purposes only. OWAS was designed for direct observation.

The authors report that this method has been used successfully in the steel company for which it was developed: "The results have led to improvements in comfort in individual jobs and have greatly contributed to the reconstruction of some production lines" (p. 201). A "by-product" of OWAS, according to the authors, "has been a growing interest in working conditions in the firm in which it has been applied" (p. 201).

Corlett, Madeley, and Manenica (1979)

Posture Targetting was developed as a quick technique to record positions of the head, trunk, upper and lower limbs. It does not appear the the wrist joint is included in this assessment technique. It was designed to be simple, easily taught and reliable in use at technician level.

Unlike Priel's method in which 40 postures were recorded for a single static posture, a Posture Targetting chart required just 10 marks for a given, whole body, posture. This method was also designed to give a graded recording of each joint observed, unlike the OWAS method in which 3 to 7 choices were made for each body segment. The authors believed that such a grading was necessary in order to evaluate different extents of the same posture.

Like the Posturegram and OWAS, Posture Targetting was designed to be used with direct observations rather than from photographic images. The developers of Posture Targetting did, however, state that photographic methods should be used where "records are needed of extensive and changing body movements..." (p. 363).

Similar to the previously mentioned techniques, Posture Targetting methods were not tested for reliability (between observers) or validity (observations compared with actual measurements). The developers did, however, compare the observations of a trained observer with data derived from a *memo-motion* camera, about half of the correlations reached significance ($p < 0.05$).

This system was developed because it was recognized that "what is currently lacking is a reasonably comprehensive model of posture and its effect sufficient for establishing design and performance criteria" (p. 366). Reports of the use of Posture Targetting have not been found in the literature.

Armstrong, Chaffin, and Foulke (1979)

This was the first method found in the literature for which a cinematic method of recording postures was discussed. The method was also the first which was designed specifically for the purpose of "determining work methods associated with occupational wrist injuries" (p. 131).

The authors describe the use of a single camera (super 8 mm) which was used in conjunction with an apparatus for recording electromyographic (EMG) readings to estimate hand forces. Although wrist injuries were the impetus for this method, the actual wrist joint was not assessed, but rather, the position of the hand (i.e., pinch grip, etc.).

The positions were recorded at the rate of 4 frames per second and later reviewed frame by frame. The authors did not report what, if any, consideration was given to the position of of the camera relative to the hands, only that the camera was placed to facilitate EMG readings so that "both hand position and EMG were recorded in each film frame" (p. 132).

The use of the method has since been reported by Armstrong et al. (1987); Punnett et al.(1987); and Silverstein et al. (1987).

Armstrong, Foulke, Joseph, and Goldstein (1982)

This was the first method found in the literature which was designed specifically to assess postures of the upper extremity (i.e., shoulder, elbow, wrist, and hand). As in the preceding method, posture was assessed from filmed recordings.

Postures of the wrist were categorized into one of five positions in the flexion/extension plane and one of three positions in the radioulnar plane. 15 seconds of wrist posture analysis is shown for a worker in a poultry processing plant.

The authors do not discuss camera position. Tests for reliability and validity were not reported nor was the film-based assessment compared with any other method (e.g., direct observation).

The use of the method has since been reported by Silverstein et al. (1987) and Punnett et al. (1987).

Holtzmann (1982)

The *ARBAN* posture assessment technique was developed so that "all phases of the analysis process that imply specific knowledge on ergonomics are taken over by filming equipment and a computer routine" (p. 82). It was developed in Sweden as a "quick and inexpensive method...(to respond to) an increasing demand for ergonomic evaluations" (p.82). ARBAN was "designed to enable both man and machine to do what they can best accomplish, thus reducing the risk of error" (p. 82).

The first step in the ARBAN process is to record workplace situations on video or film. Later, when postures are being categorized, "ambiguous parts of the film may be repeated and experts can be consulted" (p. 83). The author suggests that it may be desirable to synchronize two cameras, "giving the analyzer a three-dimensional view of the workplace" (p. 83).

Ergonomic stress is calculated based on effort due to posture, dynamic muscle effort, static muscle load, and vibration. Holtzmann suggests that the results of this technique are easily interpreted by non-specialists in the field of ergonomics.

Wangenheim, Samuelson, and Wos (1986)

The authors of this article describe ARBAN's evolution since it was first reported by Holzmann (1982). The purpose of this technique was again described as providing a "simple and reliable method for studying work situations" and one in which "experienced ergonomists and persons with limited knowledge of ergonomics" could carry out "qualified ergonomic analysis..." (p. 243).

In this version of ARBAN, the data is captured with a two-camera video system. The video produces a split image which, according to the authors, allows "reliable analysis of rotated postures" (p. 244).

This report is the first found in this series which used the audio track of the videotape to record descriptions of the subjects anthropometric measurements, size and weights of materials, etc. Workers watched tapes of themselves at work and their comments were recorded to accompany these images. Comments regarding perceived muscle effort, how hard different aspects of the job appear to them, general comments about their personal health, and ideas for improving the job are solicited.

Postures throughout the body are matched with posture charts and used to assess stresses. The body is divided into 14 parts, so-called functional units (FU). There are three postures for the hand unit that are available for categorization. The posture as observed on the videotape, along with a verbal overlay of the worker's subjective ratings of the applied forces, allow the trained analyzer to make estimates of forces.

This review presented the use of ARBAN in two construction sites in Sweden: comparing alternative scaffolding methods, and finding the optimal man-machine combination in laying concrete slabs.

Keyserling (1986)

This technique for posture assessment is a video-based method designed to analyze and describe the posture of the trunk and shoulders of workers in automobile assembly operations. Keyserling reviewed the methods by Priel, Corlett, Armstrong, Karhu (also included in this review) and others. He then developed a system which he felt would integrate the best features of each.

The technique was developed with the aim of providing a practical system which could be easy to learn and use, reliable, and interface easily with a computer for data reduction, storage, and analysis. The "computer performs all the timekeeping and clerical functions required ...(so that) the analyst can devote uninterrupted attention to observing the videotape" (p.575).

This was the first method of this review which discussed a method of assessing the reliability of the system. Results among five people who assessed the working postures of a person performing spot welding were compared. When the observations were compared it was found that the analysts were most in agreement when the operator was in a neutral position and for severe posture of one shoulder. It was felt that when analysts were in disagreement it was due to differences in criteria and when the postures were near boundary zones.

Two analysts independently assessed postures in a work cycle using the method developed by Keyserling and another video-based method. Keyserling states that the difference in the results of the these two methods "is perhaps explained by the fact that both analysts were required to process information presented by a two-dimensional display (i.e., the video monitor) to develop a three-dimensional representation of posture" and that "regardless of the postural analysis system used, discrepancies of this type are likely to occur as long as two-dimensional displays are used to represent three-dimensional postures" (p. 578).

Regarding video camera methods, Keyserling states: "In making the videotape, it is essential that the camera angle be chosen so that the joints of interest...can be clearly seen during playback" (p. 574).

Though this method was developed to assess postures of the trunk and shoulders, Keyserling states that the method could easily be extended to other joints in the body. "It would require that the videotape provide an unobstructed, high-resolution view of the joint" (p. 581). The author suggests that inter-observer reliability could be improved with better training procedures.

Silva (1986)

This method was developed to categorize postures assumed during performance of activities of daily living by older adults. The technique was derived from a need to quickly assess, categorize, and code postures for computer input. The system allows the rater to categorize gross postures (i.e., leaning, bending, stooping, etc.) and within these postures code a full range of arm positions.

Reports of this method being used have not been found.

Punnett and Keyserling (1987)

The purpose of this study was to test the work analysis techniques developed by Armstrong, et al. (1982) in 14 garment assembly jobs. As described earlier in this review, Armstrong's method was video-based and it assessed the posture of the wrist joint among other joints of the upper body. The cinematic technique described by Armstrong and Chaffin (1979) was used (as described earlier in this review). As described earlier, this technique did not discuss parameters relative to camera techniques.

The authors do not discuss tests for inter–subject reliability (or if more than one person was used to assess posture). Validity tests were not mentioned (i.e., comparing video-based assessments with actual measurements). In their concluding remarks, the authors state that "...error in the recording of postures could have been introduced by the need to correct for the angle of the camera relative to the workers' hand when viewing the film" (p. 1112).

The authors found these methods to be: "...extremely time and labour-intensive (and that) the development of more efficient work analysis techniques will facilitate their wider use in epidemiologic research on the health effects of ergonomic stressors" (p. 1099).

Keyserling and Budnick (1987)

This paper presented a video-based posture analysis technique. The posture measurements were to be used as inputs to a biomechanical strength prediction model. The findings were that subjects were able to distinguish different work postures and intra-subject bias (of five observers) was not significant.

The authors discuss that of the factors believed to contribute to overexertion injuries—the resultant force when lifting or moving an object, the frequency and duration of the handling activities, and the posture of the body—it is posture that is the most difficult to measure and describe. Several previous posture *measuring* techniques were described but it was concluded that these techniques were impractical for field settings. The authors also discuss methods of posture *observation* (also described in this review) and describe why these methods are insufficient for the purpose of developing a biomechanical model: the posture categories of *OWAS* were found to be too broad to provide the necessary level of precision, and the angles recorded in *Posture Targeting* could not be used directly to build a model.

Relative to the use of video, Keyserling and Budnick do not discuss production parameters such as camera orientation relative to the posture being observed other than to say: "When making the tape, it is important that the camera angle be chosen so that all joints of interest can be clearly seen during playback" (p. 255). They also say that the camera should be portable, able to capture *freeze frames* and have high resolution.

While analyzing the videotape, observers positioned a three–dimensional manikin and "when satisfied that the manikin is in the proper configuration, the location of the manikin's hands and major articulations ... are entered using (a) space tablet pointer and digitizer" (p. 256). The digitized data is then processed with the *Posture 3-D* software package which generates a graphical representation of the posture. The observer then "checks the digitized posture against the posture seen on the videotape" and "re-enter(s) the location of any incorrectly positioned joints" (p. 256).

Keyserling and Budnick tested both inter- and intra- subject reliability of this method. Transparencies made from freeze frames from videotapes were used for both reliability tests. Ten transparencies (representing ten different postures) were shown to five observers. Examination of the raw data of subject observations indicate a mixture of high and low concurrence (inter-subject reliability). For example, the mean angle for the *right elbow* joint was found to be 104° among the 10 observers with a range of observations between 49° to 157°. The *right knee* however showed much greater inter-subject consistency with a mean of 155° and a range between 140° and 159°. The authors state that: "Subjects reported difficulty in using the information provided by a two-dimensional display...to generate a three-dimensional posture...(and that) "This was particularly true for joints with multiple motion axes..." (p. 262).

The intra-subject differences (described as "pure error") were generally small.

The postures which were observed in this study did *not* include the wrist joints.

Validity tests were *not* performed: "direct measurements of body angles were not taken at the time of videotaping, the true values of the 15 angles were not known" (p. 258).

The authors suggest two remedies for the problems associated with a two–dimensional display format: 1) use two , synchronized cameras in the field and 2) have the analyst observe the actual job in the field setting. "Having once viewed the job in a true three-dimensional setting, an analyst should be better able to translate the two-dimensional manikin posture" (p. 262).

Another perceptual problem that was noted was that of interpreting postures of joints which were covered by clothing. The subjects were instructed to "look though" the worker's clothing but they reported that "this was not always easy to do" (p. 262).

Wells, Moore, and Ranney (1988)

This paper discussed a system for recording the movements of the hand and wrist during occupational tasks in an effort to "provide insights into causes of repetitive strain injuries..." (p. 101). It combined four types of information:

standard video images of the hand and arm, electromyographic activity of four arm and shoulder muscles, kinematics of the hand, and information from four force transducers.

Although the "system requirements" for this method included usability under both laboratory and field conditions, the authors do not explicitly state where (or if) their method was tried in a field setting. (Reference was made to *the* subject being isolated from electrical hazards (p. 103), so it may be assumed that the method was tried on a single subject and most likely in a laboratory setting).

Like the method developed by Armstrong et al. (1979), one audio channel was used to record the EMG data. Two other sources of information—force data from strain gauges and kinematic information from the *Data Glove™*—were also added to the stereo sound channels. On playback, this digitally encoded information is seen on and synchronized to the video image.

The developers of this method state that: "Despite the availability of the other information, the video image remains an important resource for interpretation" (p. 101).

Fisher and Tarbutt (1988)

Fisher and Tarbutt discuss the process they undertook to find a suitable method for assessing working postures. They noted that in their search: "Methods and tools for collecting and analyzing observational data are not as well documented" (as electromyography techniques and subjective measures of discomfort) (p. 627).

Among several system requirements were that the system be: entirely observational (i.e., non-intrusive), "easy enough for use by both specialists and persons with little or no training in either anatomy or ergonomics" (p.628), and one in which "the data format would allow comparison of postural elements both between subjects and within subjects" (p. 628).

It is not clear how (or if) the wrist joint posture is recorded in the technique that was eventually developed. Also, it is not clear if this technique was actually used. The authors make no mention of video equipment so it may be assumed that this technique was developed for direct observation.

Foreman, Davies, and Troup (1988)

This direct observation method was developed to record and analyze gross body movements for use in the working environment—specifically, a hospital ward. Like the earliest method presented in this review, it rejects an indirect photographic method: "(The methods of Holzmann, 1982, Keyserling, and others) rely largely of the angle of view of the video camera and the skill of the operator, which, in a hospital ward, may be constrained by want of space." And these methods are expensive and time-consuming" (p. 286).

The authors also rejected the earlier systems stating: "none give any information about what the hands are doing in terms of position and activity in order to provide some indication of stress on the spine" (p. 286).

The authors added another drawback to video, stating: "From a two dimensional screen no three dimensional angles can be determined and there is often a question of whether an activity is presumed or whether it can actually be seen." They add: "This can not be the case when working in the field, as the observer, unlike the camera is able to move around..."(p. 288). Although a video-based method was rejected as a primary data source, it was used to compare observations between two observers as: "there seemed no other adequate method of determining inter-observer reliability..."

This system requires the observer to be present for the entire working shift. The authors do not discuss whether or not this method had been tried in a field setting for which it was developed.

Chen, Peacock, and Schlegel (1989)

This paper described the observational method of *Physical Work Stress Analysis (PWSI)* as a means to address the weaknesses in traditional work study techniques and work physiology methods. The authors state that one of the major weaknesses of *work study techniques* is that postural information—an essential component in assessing physical load—is not accounted for. "Many errors in work study result from the use of averages rather than taking into account human variability over time, between individuals and in different conditions" (p. 167).

According to the authors, the weaknesses of *work physiology methods* are (1) interference with the worker and (2) the requirement of expensive equipment and highly qualified personnel.

The authors discuss the attempts by Priel (1974), Karhu et al. (1977), Corlett et al. (1979) (also included in this review) and others to assess posture though detailed observational techniques. They state, however, that "most of these techniques have to keep track of time, thus further adding the the workload of the observer" (p. 168). The development of PWSI came about because of "the availability of video recording methods coupled with the application of statistical sampling..." (p. 168). An important aspect of PWSI—according to the authors—is that the data capture requires little training.

Relative to the wrist joint: "This model does not deal directly with small joint stresses as in the wrists...However, where the sampling process indicates high static loads it is implied that the more distal segments will be implicated" (p. 170). The stress on the wrist joints is calculated from the distance the hands are from the body (i.e., if a person picks up an object far from the body, the stress to the wrists is assumed greater than if the object is close to the body). The authors conclude by stating that "further development of the technique that deals with primarily light but highly repetitive work involves greater refinement of upper limb and trunk postural analysis" (p. 176).

Preparation of a videotape or 35mm slides is listed as the first task in the PWSI routine. The authors do not describe camera input parameters. Tests for reliability (inter-observer) and validity tests for posture assessment were not discussed. However, the physiological effects represented by heart rate for the various tasks were measured and compared to the stress calculated based on observational techniques. These two measurements were found to have a "very close linear relationship" (p. 173).

Kant, Notermans, and Borm (1990)

The *OWAS* method (discussed previously in this review) was used to assess the working postures of mechanics. The authors describe this as "a substantial extension of the original OWAS method" (p. 209) because it computerized the data analysis allowing comparisons to be made between working posture and work activity. During the observations of workers (auto mechanics), the authors noticed that they applied "various work methods to several work activities" (p. 213). In other words, different mechanics employed different postures when performing the same task.

This method was not video-based.

Wrist postures were not incorporated in this method.

Stetson, Keyserling, Silverstein, and Leonard (1991)

In an unpublished pilot study, a system of quantifying the risk factors associated with cumulative trauma disorders was tested. For assessment of wrist postures, direct observation was compared with observations from videotapes.

The authors found that the direct methods "required considerably less time" than did analysis methods using a frame-by-frame review of videotapes (p. 1). The authors state that a "...drawback of videotape analysis is that the camera angle remains relatively constant while the forearm, wrist and hand can rotate through many different axes of motion. Detection of posture changes and identification of stressful postures is particularly difficult when the hand/wrist is oblique to the camera" (p. 3).

The authors state in two sections of this paper that: "Posture analyses at the job-site provided more accurate data than did analyses of videotapes" (p. 1), and "...accuracy was greatest when analysis was done at the job site where the analyst was free to move in order to get a clear view of the hand" (p. 19). The authors report in other sections that "...there were no statistically significant differences between results from analyses performed at the job site versus those done from videotape" (p. 15) and: "The lack of significant difference between results from job-site versus videotape analyses suggest that the ability to slow down or 'freeze frame' the videotape was not an important benefit when using this analysis system" (p. 19).

Videotapes were used to test inter-observer reliability and it was found that there were no statistically significant differences among observers.

The authors noted considerable variability in work methods among the workers who were observed.

Malchaire, Rezk–Kallah (1991)

These researchers discussed an evaluation technique to assess the physical workload of 33 bricklayers. The technique included postural analysis as well as heart rate recordings.

Relative to the use of a video data format: "The activities recognized during the preliminary survey as possibly leading to musculoskeletal problems were systematically recorded with a portable video camera" and "the filming angle was chosen so as to visualize clearly the whole body and, whenever possible, the profile of the dominant side" (p. 111).

Despite the preliminary survey which revealed an incidence of 21.2% of wrist/hand complaints, the posture of the wrist was not a part of this assessment technique.

Kivi and Mattila (1991)

This is the third discussion of the OWAS method in this review of observational techniques. In this study, OWAS methods were tested within the building construction industry. This method was chosen above others because: it provides a "practical tool for daily analysis", its orientation towards "correcting measures, not only to problem identification," and for its proven "function as a tool for fruitful co-operation between different specialties in the company..." (p. 44).

Unlike the other discussions of OWAS in this review, this variation used slides and videotape to assess some of the tasks and determine inter-observer reliability. The percentage of agreements between two observers ranged from 86% to 94%.

Relative to the value of videotape, the authors state:

> The good documentation of the OWAS analysis, supplemented with video tapes and slides, offered a powerful and reliable basis for team work aimed at developing corrective measures. This documentation makes it easy to transfer the knowledge obtained by ergonomics analysis to the designers of production methods and to machinery and product designers. At the same time, it provides training material for new employees or for retraining experienced workers (p.47).

LITERATURE REVIEW—ADVANCEMENTS IN VIDEO TECHNOLOGY

Since the first video tape recorder was introduced in 1956, video recorders have dramatically improved in ease-of-use. Today's video camera/recorders (*camcorders*), have been developed for use by the general public and typically require little training to operate. Unlike film recording, video may be recorded in low-light conditions (as low as 1 lux for certain camcorders) without the requirement of auxiliary lighting equipment. Another important attribute of video is that it may be played back immediately to inspect and correct for any recording problems.

As a potential data gathering device for collecting data on wrist postures, video has several utilitarian advantages over other means of attaining such information. When compared to direct observation, video offers the opportunity to get much closer to an operation (i.e., with a telephoto lens) than may otherwise be safe or even possible. Certainly a distinct advantage of video over direct observation of tasks is that it allows for repeated viewing and analysis. Playback units which allow still-images (*freeze-frames*) and fast or slow motion are readily available. These features would be particularly valuable when assessing the deviation of the wrist. Certain hand movements may be quite rapid and analysis would require slow or freeze-frame capabilities.

Compared to measuring devices which may require attachments such as goniometers or light emitting diodes to the worker being studied, video provides a relatively unobtrusive and non-interfering method of data acquisition. Also, position measuring systems have been developed primarily for laboratory environments and require considerable expertise to attach the sensor devices and calibrate the system in order to ensure meaningful results.

It has been demonstrated that videotape may serve to capture a wide variety of data other than visual images. The combination of these synchronized data forms may be particularly useful. Barnes, Haith, and Roberts (1988) describe a technique which permits synchronization of video recorded behavior with discrete stimuli and responses. Information is recorded on a horizontal line above the visible video information and may be observed in single-frame playback mode or by *underscanning* the playback monitor. Silverstein et al. (1987) used a method in which electromyographic (EMG) recordings were incorporated into the video mixer system. Wangenheim et al. (1986) had workers view videotapes of themselves working. The workers' comments pertaining to perceived muscle effort, the relative difficulty of various aspects of the task, anthropometric data, etc. were placed on the audio track to correspond to the video images. Wells et al. (1988) combined signals from wrist sensors measuring finger forces, EMG data, and kinematic information from a data glove on the audio channel of a video camcorder which corresponded to the visual posture data.

The analog/serial nature of the most common video medium (videotape) has been the major limitation to the efficient use of video for analysis purposes. To get from segment A to section C on a videotape, you must pass through section B. In the past, this has been a slow and imprecise activity. Videotape playback units are now available which allow rapid (within seconds) and precise (within frames) access to video segments. Furthermore, editing equipment—once restricted to large post-production facilities—is now available (i.e.,easy to use and affordable) to non–specialists.

Optical media such as the laser videodisc, provide a carrier with which *random access* to frames of video is possible. (Access time for optical media is measured in milliseconds). Until very recently, laser discs have been restricted to high-volume use (primarily in educational and industrial training) due to the high cost of production (Haynes, 1989). Recordable videodisc systems are now available which make optical media a possible alternative for low-volume use (Brown, 1988; Christie, 1989; Fox, 1989).

Other areas of development which have substantially improved the manageability of video, are technologies which make it possible to view and manage video on a personal computer. *Video overlay boards* provide a means to view video on a computer monitor and to lay text and graphics over the video images. *Digitizing* boards have also been developed which convert the analog video signal to a digital signal. With digital video it is possible to store and retrieve video images like text and graphics and manipulate video information at the pixel level.

In software development, systems such as *InfoWindows*™ and *HyperCard*™ stacks have been developed for video management. These systems may be used to control video from serial (videotape) as well as optical (videodisc) sources.

Video hardware and software developments have made video a much more efficient medium to access and manage. Several researchers, however, have discovered that scientific inquiry demands even greater amounts of control in order to effectively integrate video as a manageable and mutable form of information. Mackay and Davenport (1989) suggest that researchers need a *constructivist* approach in which they are able to build, annotate, and modify video information. The Visual Computing Group at the Massachusetts Institute of Technology (MIT) has developed a visual workstation which integrates video into computational environments. The system, called *Athena Muse*, includes such features as: a *video iconifer*, a short clip of video used to represent the contents of video or other forms of information; a *video clipper*, an interactive symbolic videodisc editor that allows one to define video segments by directly searching for their start and stop frames (a more intuitive process than indirectly accessing video data through frame numbers or SMPTE code); and a *video annotator*, a tool for synchronizing text with video (Michon, 1989).

An experimental video annotator, *EVA,* was developed by Mackay (1989) for the purpose of gathering and analyzing human-computer interactions. EVA allows custom annotations to be made in real-time as the recordings are taking place and substantially reduces the amount of viewing time to analyze the video information. "The result is a random-access database of visual, auditory, and screen information from the session. Presentation of the information is very flexible, especially if the video has been transferred to a write-once videodisc" (p. 70).

A new technology *Digital Video Interactive (DVI)* has broken some important barriers to incorporating video in a computer workstation environment. DVI is a CD-ROM format which—being an optical medium—allows random access to video and other forms of information. Analog to digital conversion of full-motion video in a normal computing environment requires vast amount of storage space. DVI uses an algorithm which effectively compresses full-motion video for storage and then decompresses the video in real time playback. Fox (1989) describes digital encoding as "allowing ... simpler delivery systems (with a single monitor handling digital text, graphics, images, video)...and of fine control of the contents and of each frame" (p. 796).

The implication of these developments are that video workstations will be available for field research applications and will provide a much improved level of efficiency for manipulating video information. For the human factors specialist who wishes to investigate wrist posture, not only will video support the data acquisition phase of the investigation, such data may also be taken back to a computer workstation where it can be annotated with text, overlaid with graphical information, and combined with other video segments. Video data may be categorized, for example, by: tool, worker, work method, and hand postures. Such information could be shared with other specialists and researchers and contribute to a knowledge-base which could be used across several different industries.

As presented in the previous section, video assessment of wrist posture has not been validated.

LITERATURE REVIEW—CONSIDERATIONS REGARDING VIDEO AS A TWO-DIMENSIONAL DISPLAY FORMAT

The developments that were presented in the previous section suggest that video is a tool with considerable utility in human factors field research, and specifically in the assessment of wrist posture. These developments however, do not ensure the that full-motion video will be a *reliable* medium, only that it will be a more *useable* medium. Video is a two–dimensional representation of a three–dimensional world. This feature provides several opportunities for distortions and illusions.

The first movie cameras were made in an era in which stage magic and grand illusions were enjoying unprecedented popularity (Hutchinson, 1987). One of the most successful early filmmakers, George Méliés, was a stage illusionist who saw in film a way to extend his magic act (Rosenblum and Karen, 1979). That audiences would readily accept such illusions was, perhaps, what diverted attention away from motion-pictures as a tool for science to motion-pictures as an entertainment medium—the place where cinema has resided for almost 100 years.

Although we may sometimes think of cinema as a way to "capture reality," such a feat is currently unattainable. A first step towards reproducing visual reality would be to use central projection onto a hemispherical screen. A 180° field lens would be required for both taking and presentation. Since most people see the world with stereo acuity, a more perfect reproduction for two-eyed humans would require a stereo pair of cameras and accompanying stereo projection equipment. However, even if one were to combine stereo cinema with central projection, ideal reproduction would still be lacking since head-movement parallax would not be possible. That is, although the eyes would be free to scan the picture and gather information, movements of the head would not contribute to scene understanding in the way that is possible in a real scene. Perfect reproduction of *part* of the visual field in a manner that accommodates the head movements of the spectator (can only) be accomplished through motion holography (Salt, 1983). A technology which combines central projection, stereography, and holography does not exist.

Cinematic and editing techniques have developed, in part, to compensate for this lack of ideal reproduction. Scenes may be established with *long shots* and sequential combination of several *medium* and *close-up* shots can orient the viewer spatially. To compensate for the loss of stereo depth cues, lighting techniques and camera angles can be used to enhance monocular depth cues. Even the loss of head–movement parallax can be compensated by the use of a moving camera. If the camera is *dollied* in on an object or *tracks* an object, the object will move relative to its background and provide motion depth cues.

What is important to understand about such compensatory techniques is that they are entirely outside of the control of the viewer. Spatial orientation and provisions for depth cues are controlled by the cinematic and editing choices of the video maker.

Investigations of the task of categorizing the position of an object (or, for this investigation, the posture of the wrist) in a two-dimensional display format have not been found. Investigations of the perception of two-dimensional representations of scenes (in general), have addressed such things as: the effect of *monocular depth cues* on a viewers' understanding of size and depth relationships, *perceived layout of real scenes*, and *object recognition.*

Relative to research pertaining to monocular depth cues, assessment of *size* and *distance* is irrelevant. However, certain monocular depth cues may provide important position information. Depth cues are the characteristic patterns that are produced when the light from a three-dimensional layout is projected on a two-dimensional surface (Brooks, 1984). These cues include: aerial perspective, distant objects tend to appear hazy and tinged with blue; *linear perspective,* parallel receding lines converge; *shading,* objects appear rounded; and *occlusion*, masking a farther object by a nearer one (Frisby, 1980). Such cues provide the viewer with information that the image on the flat surface is related to an arrangement of objects at different distances in space (Haber, 1985). Static depth cues provide potent depth information even when we have full access to stereopsis, as when viewing a real scene. In the posture assessment task to be studied in this investigation, several cues for *depth*, may be likewise important for *position* (i.e., posture) determination.

Regarding investigations of perceived layout, Haber (1985, p. 109) states that a theoretical foundation of subjects' ability to determine spatial layout of natural scenes is non-existent in both perceptual and cognitive domains. "Most current perceptual theories do not consider perceived layout, preferring to focus on the much narrower concern of perceived radial distance of objects from the observer, ignoring concern for the relationships among the objects of the scene..." Similarly, "cognitive theories have paid little attention to the spatial relationships of scenes currently on view, so they can tell us little about perceived layout, only remembered layout."

An area of perceptual investigation that may bear somewhat on this experiment is object recognition. The recognition of objects—particularly from *novel* viewpoints—may provide insight into how camera position affects position judgements. Biederman (1985) proposed the theory of "recognition by components (RBC)." The assumption of this theory is that human image understanding is "based upon a modest set of components ... (which) can be derived from contrasts of five readily detectable properties of edges in a 2-dimensional image" (p. 13). Biederman relates this theory to the auditory concept of phonemes. (To code all the words in the English language, we need only 38 such primitive elements). In several experiments, the detection of these properties (and thus the object itself) was found to be "generally invariant over viewing position and image quality and consequently allows robust object perception when the image is projected from a novel viewpoint or degraded" (p. 13). If various *postures* are thought of as *objects*, then the theory of RBC applied to this research would predict that camera views will have little or no affect on performance. Perception will be based instead on properties of the object itself (i.e., posture "cues"). Camera views will be important only for their ability to reveal these cues.

STATEMENT OF RESEARCH OBJECTIVE

The goal of this research was to examine judgements of wrist posture from video format images. The anticipation was that the results of this research would provide clues regarding people's capabilities and limitations when using video data. These clues would help to interpret *previous* research which included video–based observation techniques and define questions upon which to base *future* research towards the development of video–based observation tools.

METHODS—EXPERIMENT ONE

Independent and Dependent Factors

Experiment 1 consisted of within–subject manipulation of three factors: *Display*, the way in which the image is presented on the video screen, *View*, the camera view relative to the hand; and Position, the position of the wrist joint. The performance measures were: *accuracy,* the correct or incorrect judgement of the position of the wrist joint; *response time;* and level of *certainty* as judged by the participants. The levels of each of the independent variables were as follows:

Position. Ten discrete positions of the wrist joint were presented in this experiment. In one axis of rotation, the positions were: Extreme Extension (EE), Extension (E), Neutral (N), Flexion (F), and Extreme Flexion (FF). Extension and flexion were each mid–way from the neutral position and the extreme positions. Postures in the radiolunlar plane—Radial Deviation (R) and Ulnar Deviation (U) will be at the most extreme positions.

Three additional positions were established by combining postures from both axes: Flexion/Ulnar Deviation, Extension/Ulnar Deviation, and Extension/Radial Deviation. Each of these "combination postures" were at the most extreme positions that were possible.In all positions , the configuration of the hand was of a fist.

View. Three orientations of the camera relative to the hand were established: Thumb–side, a view oriented normal to the thumb side of the hand; Back–side, a view oriented normal to the back side of the hand; and Oblique, a view which is directed to a point between the little finger side of the hand and the back of the hand. (See Figure 3 for Views and Positions.)

Display. There were three display formats in Experiment One: One Still, a single still image; Two Stills, two images simultaneously presented of the same Position; and Motion, a 2–4 second motion video segment with the wrist moving then coming to rest.

Collecting the Stimulus Material

Video images of a human hand were recorded using a Quasar S–VSH video camcorder. The camera was located approximately 20" to the wrist joint. A solid blue background was used and no other objects other than the hand and wrist were part of the picture. For each View and each Display Method, the wrist was positioned into each of the ten postures previously described.

Two methods were used to establish wrist postures: 1. A wire–frame shell was devised which—when placed over the fist—provided "reference positions" for the various postures. This was used to train the person whose hand was used for the stimulus material (the experimenter's hand). This was also used as a check prior to taping still images and upon the completion of the motion images. If a motion pattern ended in a posture that was *not* intended, the video procedure would be repeated until the correct posture was achieved. 2. Because it was felt that with two positions—Extension and Flexion—consistency would be more difficult to maintain, two additional templates were developed and used. These templates were rigid wires bent at angles that were mid–range from Extreme Flexion and Neutral, and Extreme Extension and Neutral. These were placed at the back of the hand at the wrist joint for training and checking the postures of Extension and Flexion.

Participants

Participants in this experiment were 12 volunteer subjects: 6 men and 6 women who ranged in age from 23 to 61. Their occupations were: truck driver, homemaker, professional illustrator, secretary, electronics technician, factory worker, retail sales clerk, musical instructor, science instructor, teacher's aid, farmer, and interior decorator.

Training

Training was in two areas: (1) learning the nomenclature developed for this experiment to describe hand positions and (2) learning the experimental procedure. Participants were trained in a categorization scheme used to describe the ten wrist postures. A special apparatus was used to train the participants (this was the

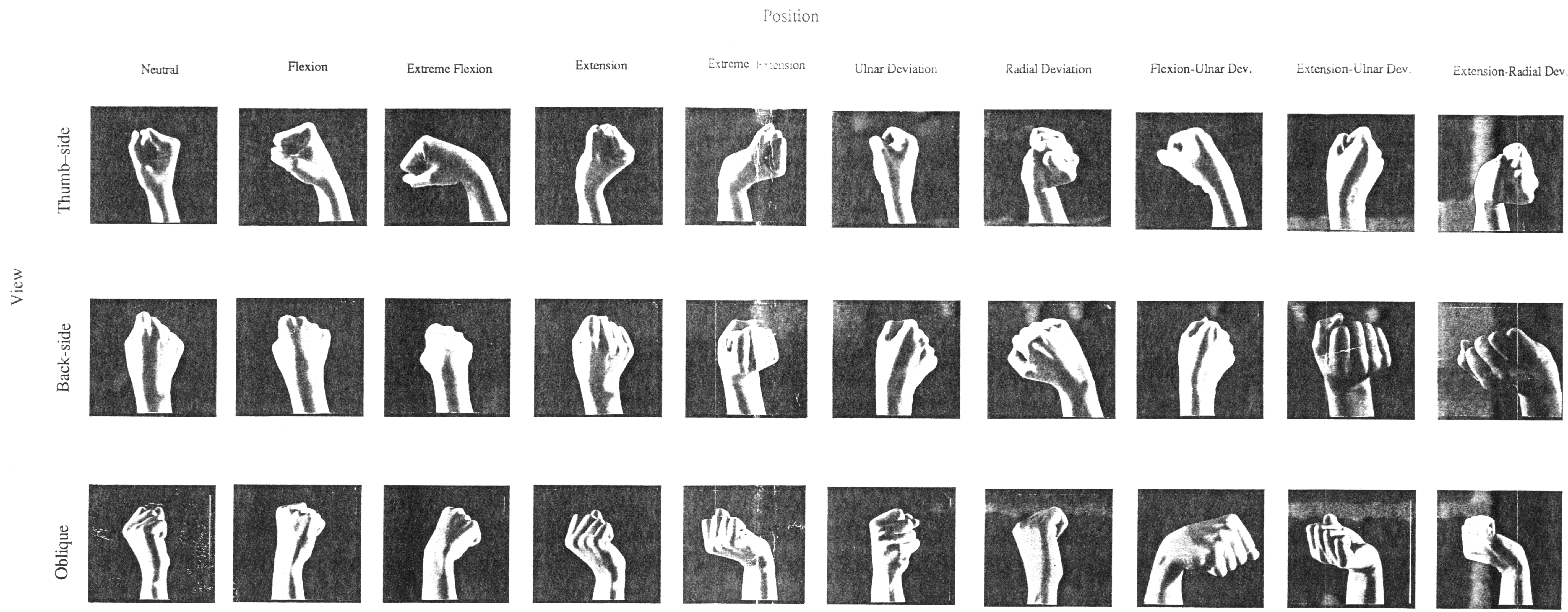

Figure 3. Views and Positions used for Experiment One. (Note: these are representations of the Views and Positions and not the actual video images).

same apparatus that was used to provide consistent postures in the collection of the stimulus material). It consisted of a transparent shell that—when held over the hand—showed the 10 postures of the hand. Participants were encouraged to walk around to see how a particular wrist posture (Position) would look from various viewpoints (Views). The experiment continued only after the investigator was convinced that the participants fully understood the categorization scheme and could correctly categorize all wrist postures. The objective measure of this was when the participants categorized 20 consecutive wrist positions with no errors. In addition, subjective criteria also had to be met. That is, did the participants seem sure of themselves rather than hesitant, etc.

The second part of the training acquainted each participant with the experimental procedure. Participants were shown several segments of video. As each segment was viewed, the participant was asked to judge the position of the hand. They were then asked to state how certain they were. Participants were <u>not</u> told whether or not they gave correct responses.

The experiment began when the experimenter decided that a participant was comfortable with the procedure.

Procedure

Each participant was asked to make 90 judgements of wrist posture based on video images. The 3 presentation variables (One Still, Two Stills, and Motion) were presented in counter-balanced order among the 12 participants. The other two variables—Position and View—were presented in random order.

The experimental sequence was as follows:

1. The experimenter located the segment of tape just prior to the stimulus [view(s) of a particular wrist posture]. The images on the video screen were not seen by the participant at this time.
2. The experimenter asked the participant to look at the screen (which was a solid blue background). After 2–3 seconds, the image of a hand appeared. At this point the experimenter began to time the response.
3. When the participant felt ready to respond, he/she said "stop." This marked the end of the response time. The participant then stated what he/she believed to be the posture of the wrist.
4. The participant then stated his/her level of certainty on a scale of 1–10 in which 10 corresponded to "100% certain", 5 corresponded to "50% certain" or "tied between two positions," etc..

This procedure was repeated until all observations were made. Participants were encouraged to take rest breaks throughout the experiment whenever they feel the need to do so.

METHODS—EXPERIMENT TWO

Independent and Dependent Variables

Experiment 2 consisted of within-subject manipulation of two factors: *Display Method* and *Hand Configuration.* The Display Method consisted of two methods: One Still and Motion. These were the same as described in *Experiment One Methods.* There were two Hand Configurations: one was a hand configured in a fist (similar to Experiment One) and the second was that of a hand holding and/or using an object (e.g., placing a book on a high shelf, turning a screw with a screwdriver, using a computer keyboard, wringing out a wet towel, etc.). The particular holding configurations were chosen in such a way that each of the ten wrist postures (described in Experiment One and shown in Figure 3) were represented once. The performance measures were the same as described in Experiment One.

Collecting the Stimulus Material, Participants and Training.

Video images of a human hand were recorded using a Quasar S–VSH video camcorder as described in Experiment One. Participants were the same people who participated in Experiment One. Training consisted of a refresher of the material that was presented during the training for Experiment One.

Procedure

Each participant was asked to make 40 judgements of hand position (10 judgements for each Display/Configuration category). The Display and Configuration factors were presented in counter–balanced order among the 12 participants.

The experimental procedure was identical to the procedure of Experiment One.

RESULTS—EXPERIMENT ONE

Interrelationships of the Dependent Variables

Spearman rank-order coefficients were determined to assess the interrelationships among the three dependent variables. The computed coefficients across all independent variables (N=1080) were: z=8.16 (p=.0001)[1] between accuracy and certainty, z=–4.41 (p=.0001) between accuracy and time, and z=–14.22 (p=.0001) between time and certainty. To test whether these relationships were maintained for each Display and for each View, the dependent variables were grouped by Display and by View. Additional groupings were made within each Display and within each View to test whether the relationships held for individual Subjects.

Figure 4 shows that the significant positive relationship was maintained between accuracy and certainty for the three Display Methods. Figure 4 also shows that when Spearman rank-order coefficients were calculated for each Subject within each Display Method, a significant positive relationship was maintained for 6 of the 12 Subjects in Two–Stills. No significant association was found between accuracy and certainty for the remaining 6 Subjects within the Two–Stills Display, for 6 Subjects within the Motion Display, and for all Subjects within One–Still Display Method. For 6 Subjects within the Motion Display Method, there was a significant negative association between accuracy and certainty.

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[1] For samples greater than N=50, the statistic $z=r_S\sqrt{N-1}$ is used where r_S is the Spearman rank-order coefficient (Siegel and Castellan, 1988).

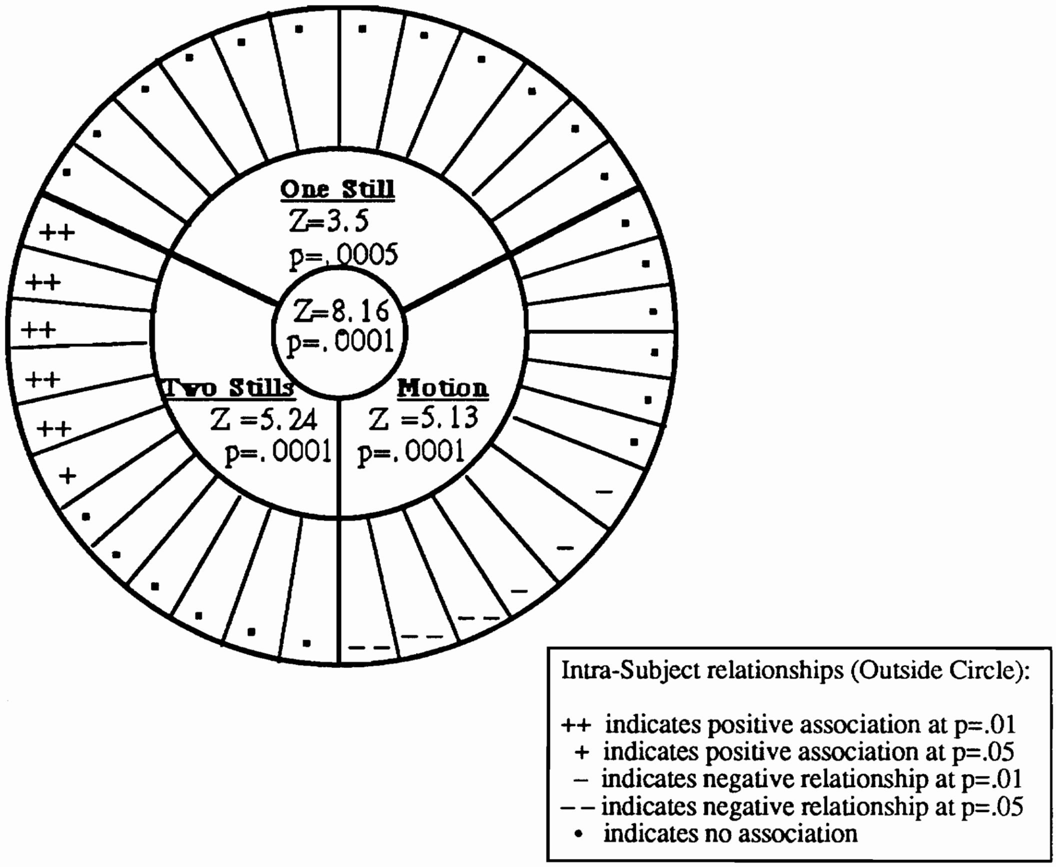

Figure 4. Relationship between accuracy and certainty across all independent variables (inside circle, n=1080), by Display Method (middle circle, n=360), and for each Subject within each Display Method (outside circle, n=30).

Figure 5 shows the relationships between time and accuracy, and time and certainty by Display Method. The negative relationships were maintained for each Display Method. When Subject's levels of accuracy and decision times were calculated, negative relationships were found for a minority of the individuals within each Display Method. A significant negative relationship between certainty and decision time was found for the majority of individuals for Two Stills and Motion.

Figure 6 shows that the relationship of the dependent variables was maintained for each of the three Views. For each Subject within each View, a significant positive relationship was maintained for a minority of individuals within each View.

Figure 7 shows the relationships between time and accuracy, and time and certainty by View. The negative relationships were maintained for each View. For all individuals within the Back-side View, and for all but one individual in the Thumb-side View, there was no relationship between accuracy and decision time. For four individuals in the Oblique View, there was a negative association. A negative association between time and certainty was present for 4 to 6 individuals within each View.

Average score (accuracy), level of certainty, and decision time were calculated for each subject. Spearman rank-order coefficients (N=12) were as follows: $r_S=0.31$ between accuracy and certainty, $r_S=-0.04$ between accuracy and time, and $r_S=-0.45$ between time and certainty. None of the inter-subject associations of the independent variables were significant at p=0.1.

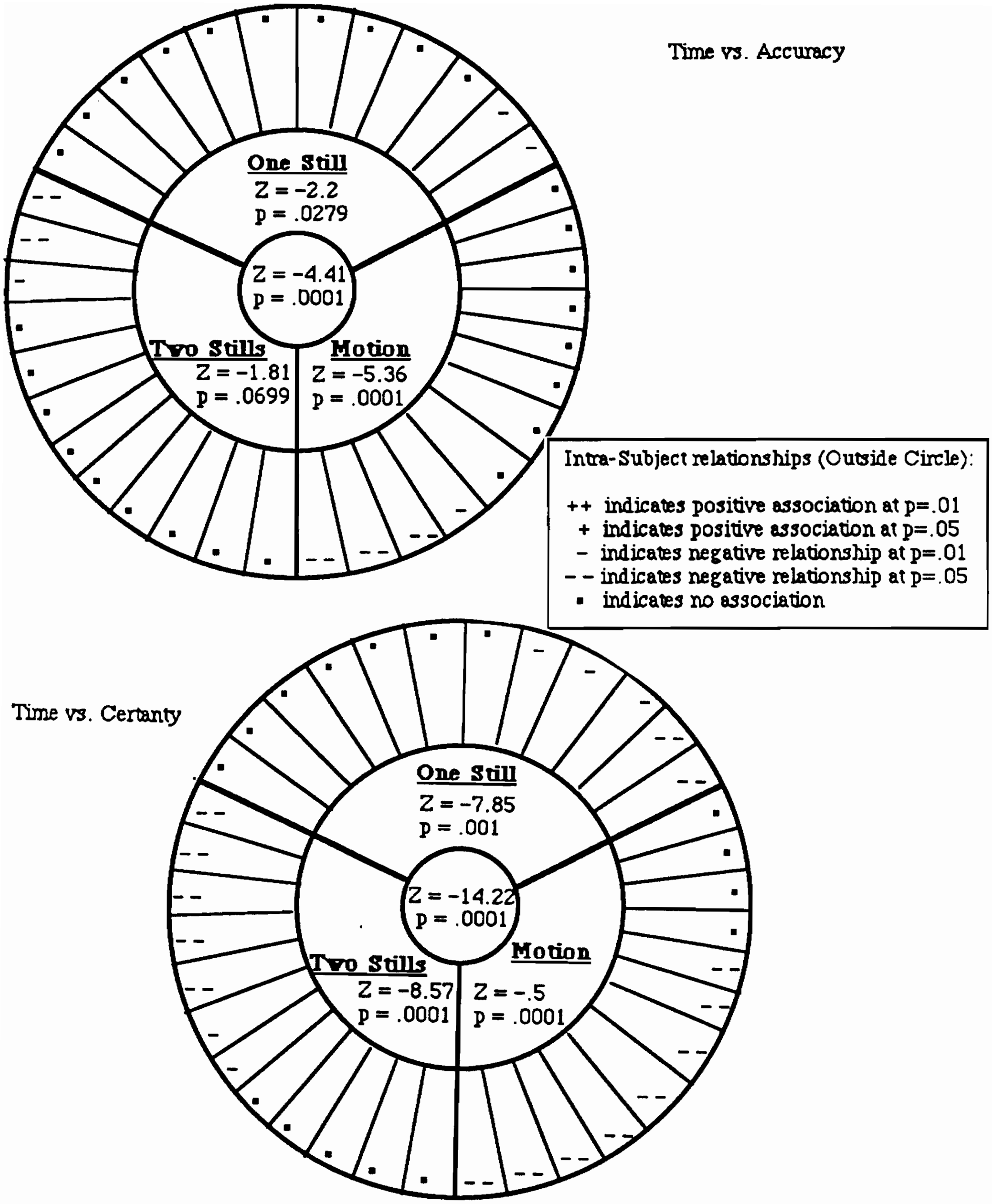

Figure 5. Relationship between time and accuracy, and time and certainty across all independent variables (inside circle, n=1080), by Display Method (middle circle, n=360), and for each Subject within each Display Method (outside circle, n=36).

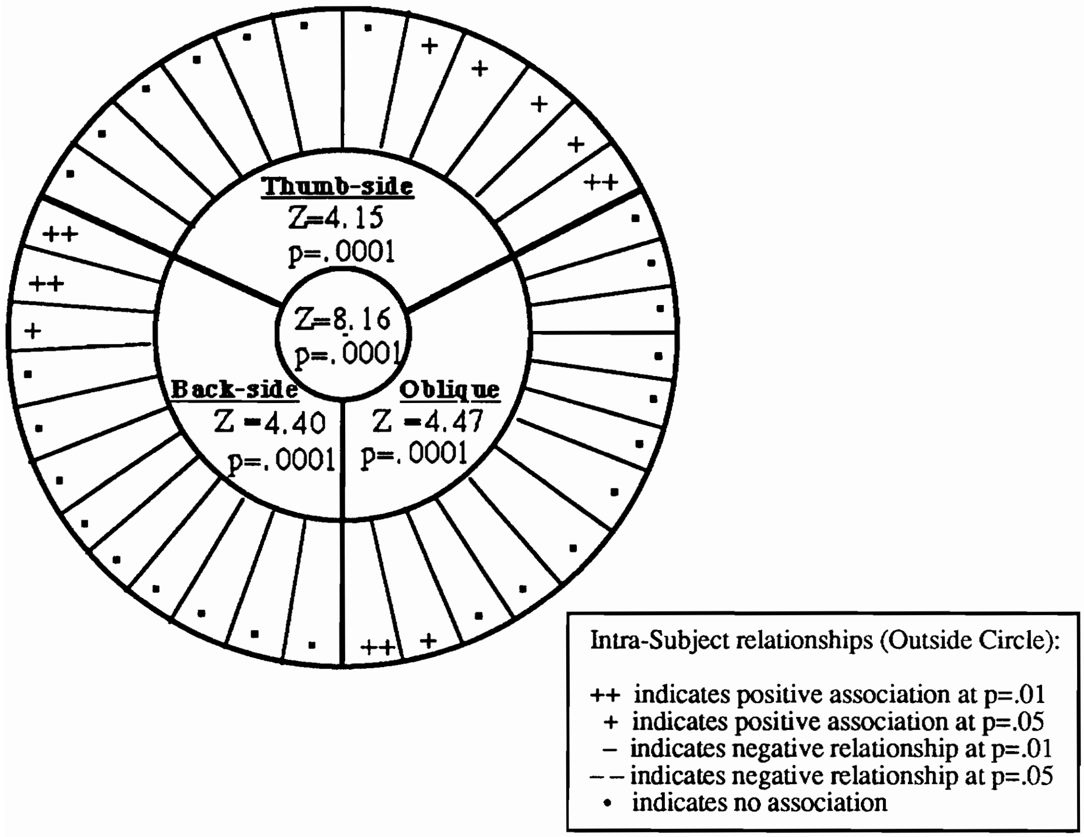

Figure 6. Relationship between accuracy and certainty across all independent variables (inside circle, n=1080), by View (middle circle, n=360), and for each Subject within each View (outside circle, n=30).

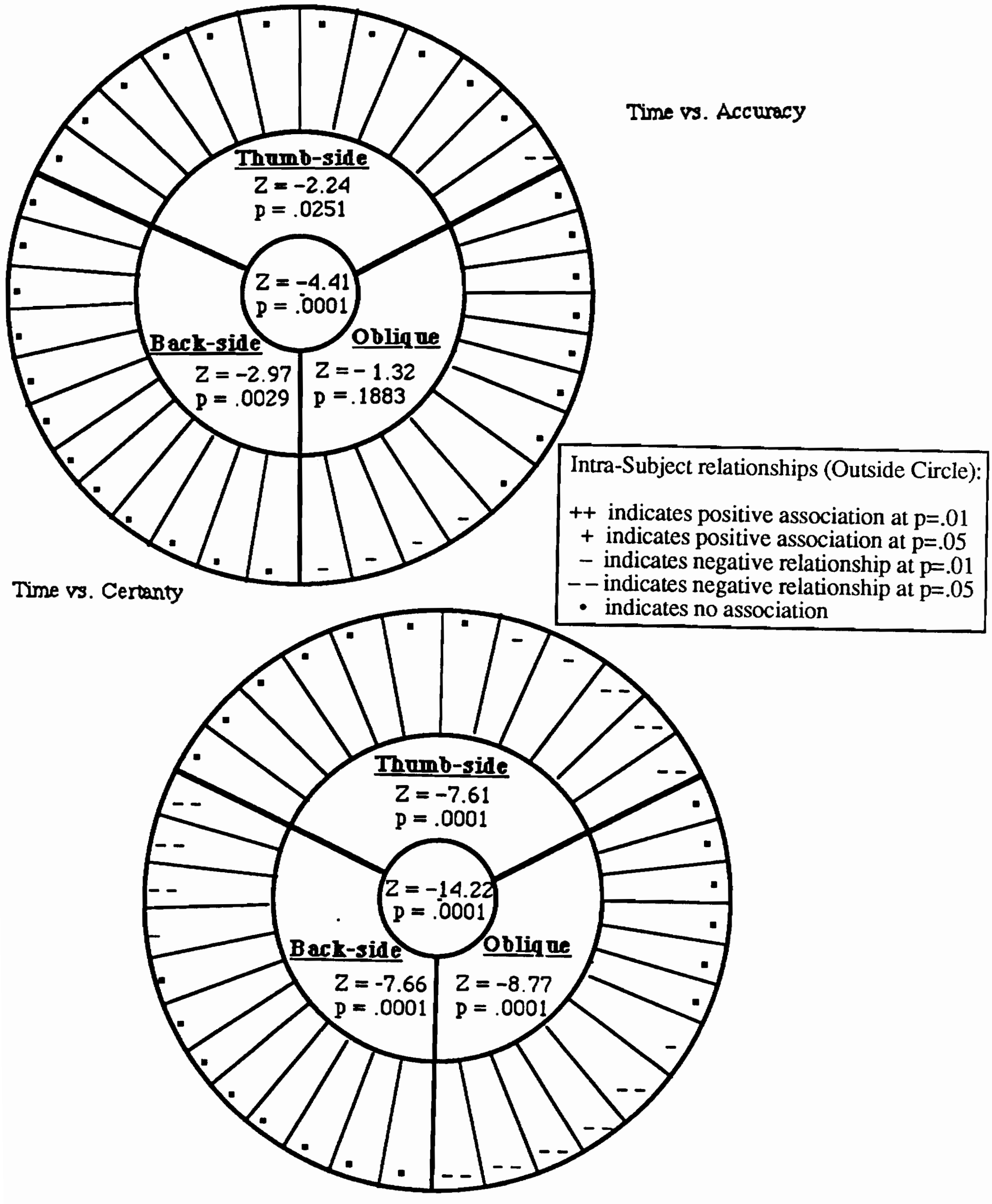

Figure 7. Relationship between time and accuracy, and time and certainty across all independent variables (inside circle, n=1080), by View (middle circle, n=360), and for each Subject within each View (outside circle, n=36).

ANOVA

The three dependent variables were subjected to a three-factor Analysis of Variance (ANOVA) procedure. Table 5 shows that for the the dependent variable, accuracy, the three main effects were significant at $p<0.001$ and all two- and three-way interactions were significant at $p<0.05$ level of significance. The Greenhouse–Geisser correction for sphericity was performed for all significant effects to correct for violations of homogeneity-of-variance-covariance assumption (Winer, 1971).

The ANOVA table for accuracy is shown in Table 5. After applying the correction factor, the three main effects were found to be significant at the $p<0.001$. All two- and three-way interactions were significant at $p<0.05$.

The ANOVA table for certainty is shown in Table 6. After applying epsilon correction factors to the significant p-values, all main effects were significant at $p<0.01$. There were no significant interaction effects at $p<0.05$.

Table 7 shows the ANOVA summary table for decision time. After applying epsilon correction factors to the significant p-values, only the main effects of Display and View were significant at $p<0.05$.

Main Effects

Display Method. Figure 8 presents the main effect means of Display Method for the three independent variables. Figure 9 shows the Newman-Keuls post-hoc comparison of these Display Method means. Horizontal lines group statistically equivalent means ($p<0.05$). For accuracy, the three means were significantly

Table 5

ANOVA Summary Table: Accuracy

Source	df	MS	F	p*
Subjects (S)	11	0.190		
Display Method (D)	2	2.808	21.345	<0.001
D x S	22	0.132		
View of Camera (V)	2	6.011	23.804	<0.001
V x S	22	0.253		
Position of Wrist (P)	9	1.626	10.380	<0.001
P x S	99	0.157		
D x V	4	0.640	5.494	<0.050
D x V x S	44	0.117		
D x P	18	0.412	4.133	<0.010
D x P x S	198	0.100		
V x P	18	0.677	5.150	<0.001
D x V x P	36	0.344	3.188	<0.010
V x P x S	198	0.131		
D x V x P x S	396	0.108		
Total	1079			

*After applying the Greenhouse–Geisser epsilon correction for violations of the homogeneity–of–variance–covariance assumption to significant effects (p <0.05).

Table 6

ANOVA Summary Table: Certainty

Source	df	MS	F	p*
Subjects (S)	11	0.952		
Display Method (D)	2	0.281	8.264	<0.010
D x S	22	0.034		
View of Camera (V)	2	0.274	8.952	<0.010
V x S	22	0.031		
Position of Wrist (P)	9	0.069	3.373	<0.010
P x S	99	0.020		
D x V	4	0.079	2.681	0.438
D x V x S	44	0.030		
D x P	18	0.039	1.597	0.064
D x P x S	198	0.024		
V x P	18	0.021	0.985	0.478
V x P x S	198	0.021		
D x V x P	36	0.030	1.452	<0.250
D x V x P x S	396	0.021		
Total	1079			

*After applying the Greenhouse–Geisser epsilon correction for violations of the homogeneity–of–variance–covariance assumption to significant effects ($p < 0.05$).

Table 7

ANOVA Summary Table: Decision Time

Source	df	MS	F	p*
Subjects (S)	11	2290.099		
Display Method (D)	2	347.562	3.600	<0.050
D x S	22	96.556		
View of Camera (V)	2	538.937	6.444	<0.050
V x S	22	83.628		
Position of Wrist (P)	9	149.586	2.262	<0.100
P x S	99	66.137		
D x V	4	67.877	1.687	0.170
D x V x S	44	40.227		
D x P	18	71.419	1.691	<0.250
D x P x S	198	42.226		
V x P	18	55.041	0.959	NA
V x P x S	198	57.416		
D x V x P	36	44.733	1.297	NA
D x V x P x S	396	34.483		
Total	1079			

*After applying the Greenhouse–Geisser epsilon correction for violations of the homogeneity–of–variance–covariance assumption to significant effects ($p < 0.05$).

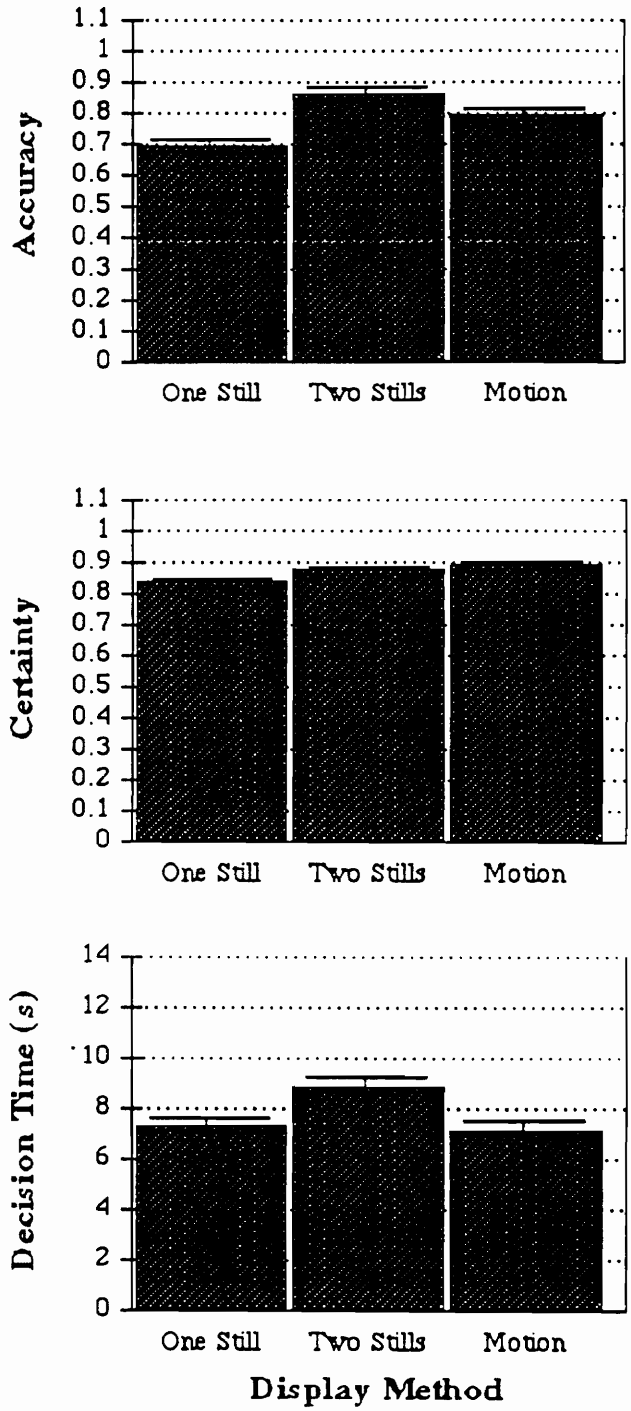

Figure 8. The main effect of Display Method averaged over Subjects, View, and Position (N=360) on accuracy, certainty, and decision time. Error bars show +1 standard error of the mean.

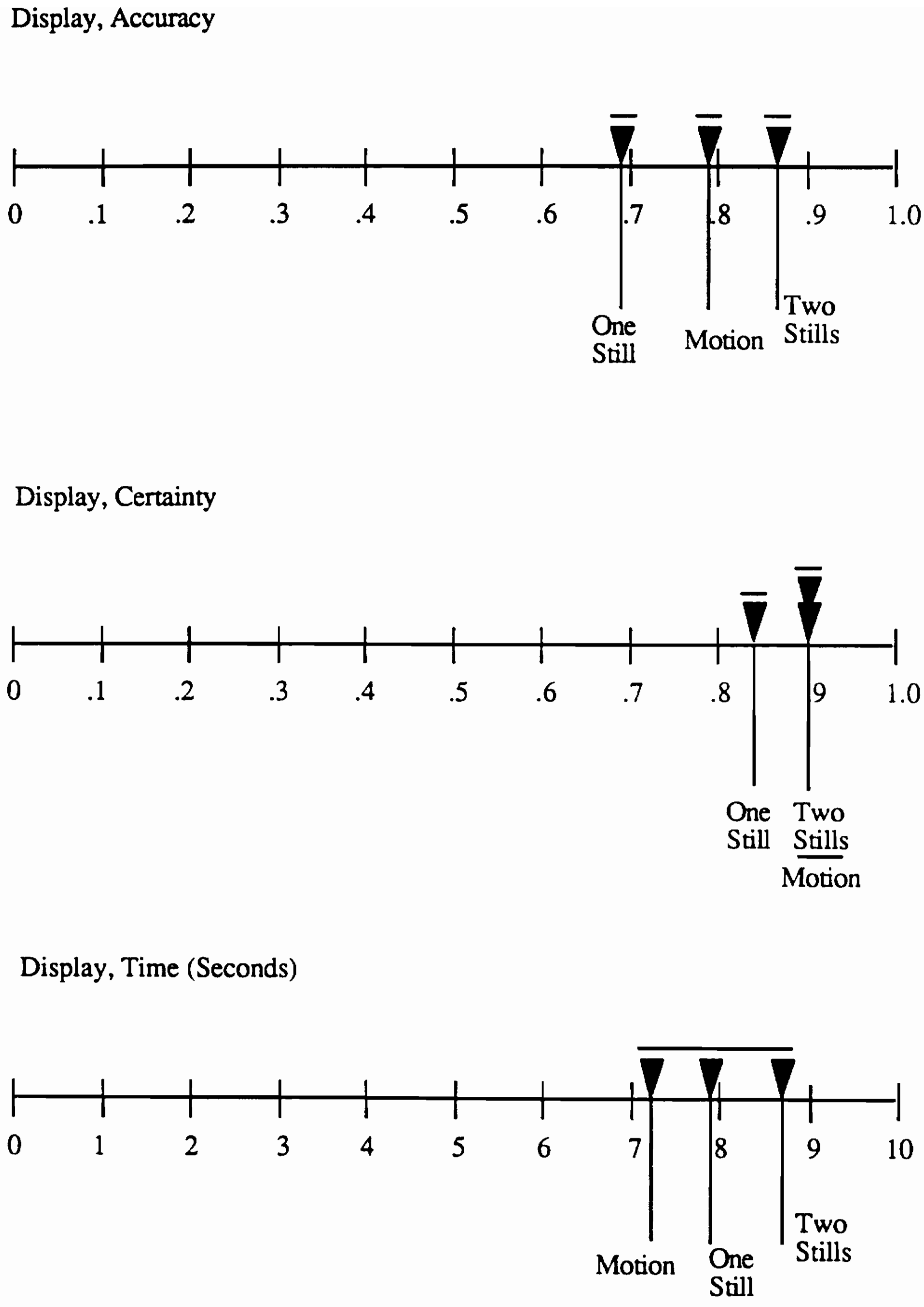

Figure 9. Newman–Keuls Comparison of accuracy, certainty, and decision time among Display Methods.

different from one another. The ranking from best to worst was: Two Stills (0.86), Motion (0.79), and One Still (0.69). The numbers for accuracy and certainty are in ratio form where 1 equals 100% accuracy.Certainty followed a different rank order: Motion (0.89), Two Stills (0.88), and One Still (0.84). The Newman-Keuls analysis as shown in Figure 9 reveals that people were significantly less confident with One Still than they were with the other two methods.

Decision Time had a rank-order of shortest to longest times as follows: Motion (7.1 seconds), One Still (7.3 seconds), Two Stills (8.9 seconds). The Newman-Keuls analysis shows that the decision time differences between Display Methods were not significant. It should be noted that the decision times for Motion used throughout this report include an interval of 1-3 seconds for each stimulus presentation during which the participants could not respond. This interval reflects the time when the wrist was moving from one position to another before coming to a complete rest. Participants then judged the position of the resting posture.

Comparisons of the three dependent variables are as follows:

1. Accuracy had lower ratio scores than certainty for all Display Methods.
2. Absolute differences were greater amongst accuracy scores than certainty levels.

View. The main effect means of View are shown in Figure 10. A Newman-Keuls comparison (Figure 11) shows that accuracy varied significantly between each contrasted pair of views. The rank-order from best to worst method was Thumb-side (0.89), Back-side (0.80), and Oblique (0.65).

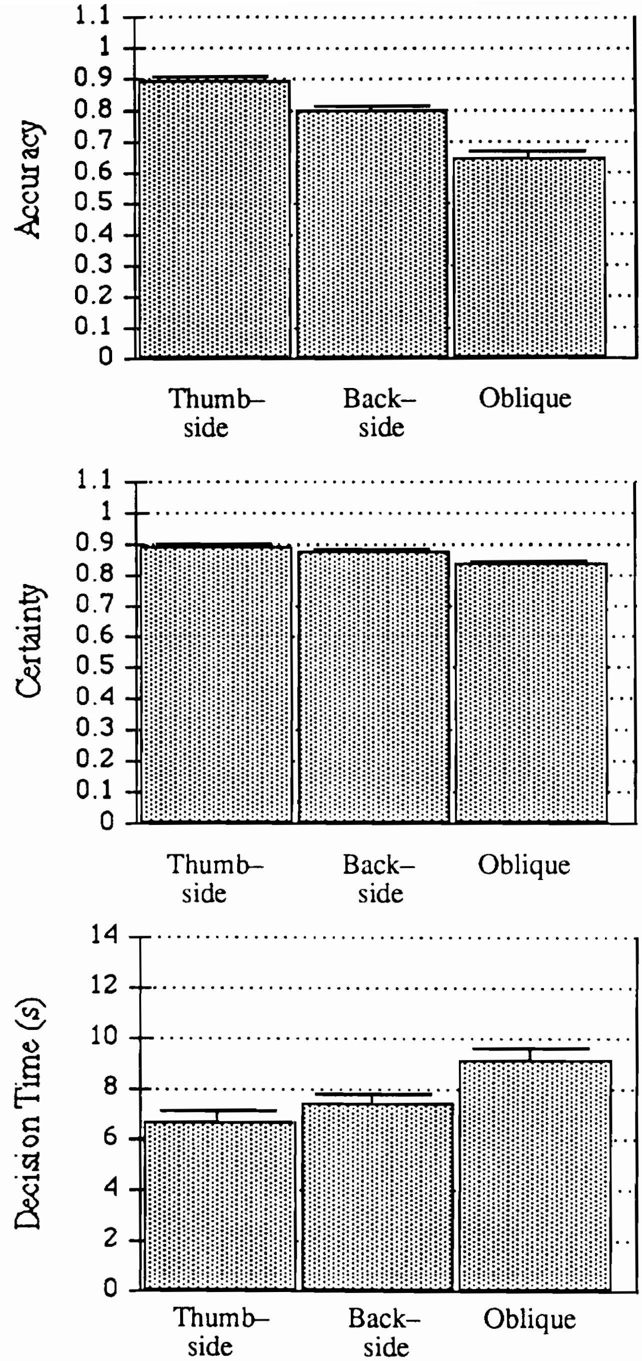

Figure 10. Main effect of View averaged over Subjects, Display Method, and Position (N=360) on accuracy, certainty, and decision time. Error bars show +1 standard error of the mean.

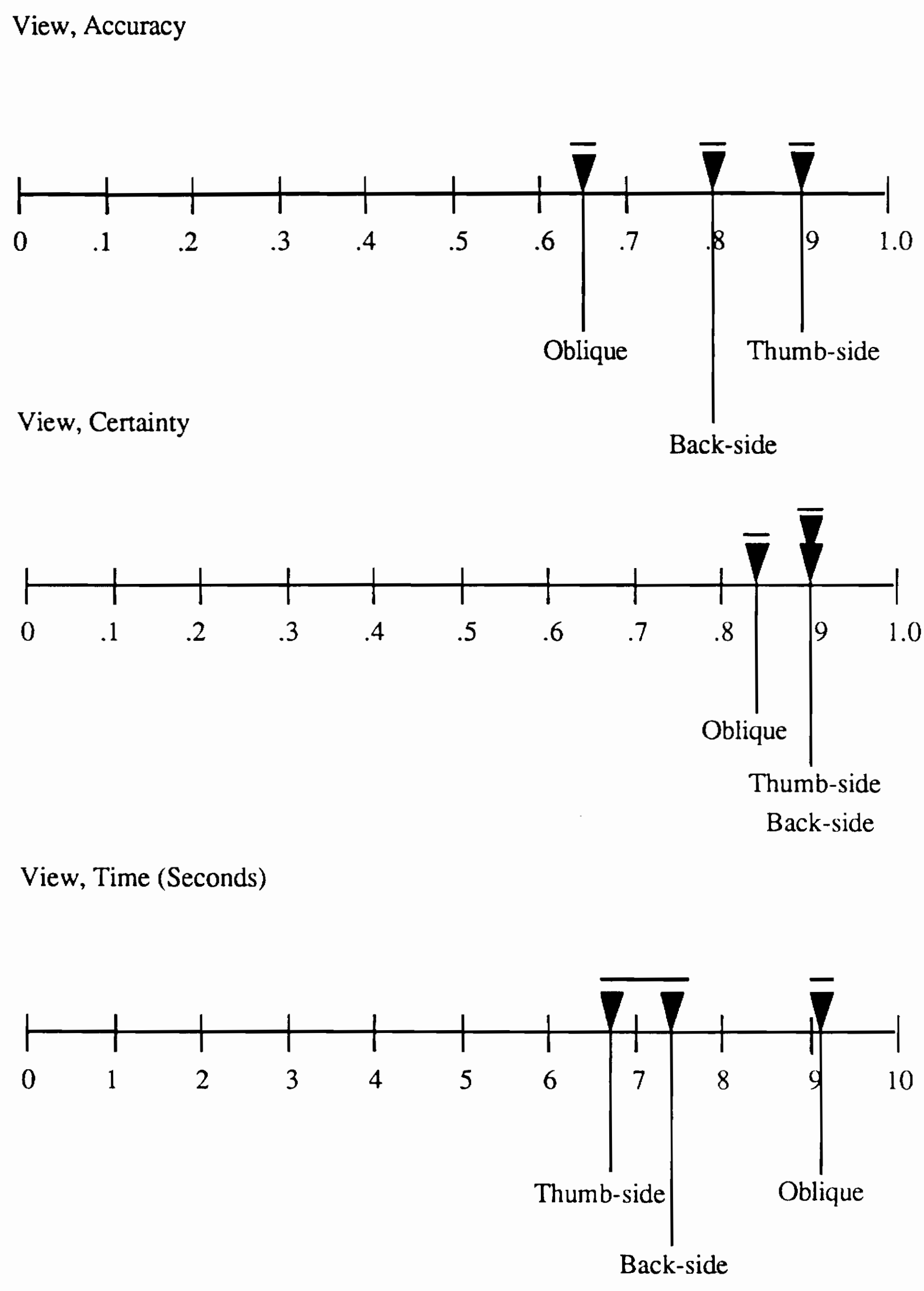

Figure 11. Newman–Keuls Comparison of accuracy, certainty, and decision time among Views.

Levels of certainty in rank order were as follows: Thumb-side (0.89), Back-side (0.88), and Oblique (0.84). Newman-Keuls analysis (Figure 11) shows that only Oblique View was significantly different from each of the other views. Decision Times from shortest to longest were: Oblique (9.1 seconds), Back-side (7.42 seconds), and Thumb-side (6.71 seconds). Newman-Keuls analysis (Figure 11) shows that the Oblique View required significantly more decision time than the other views.

Comparisons of the three dependent variables by View are as follows.

1. Accuracy had lower ratio scores than certainty for two Views (Back-side and Oblique Views). Accuracy was equal to Certainty for the Thumb-side View.
2. Absolute differences were greater amongst accuracy scores than certainty levels.
3. The View that resulted in the lowest mean level of accuracy (Oblique) was associated with the longest decision time.

<u>Position.</u> The main effect means of each of the ten wrist positions are shown in Figure 12. Newman Keuls analysis of accuracy (Figure 13) shows that two positions—Neutral and Flexion with Ulnar Deviation—were significantly better than each of the other positions. The position Extension with Ulnar Deviation was found to be significantly worse than the other positions.

Analysis of certainty levels (Figure 13) shows that Extension and Extension with Ulnar Deviation positions were significantly lower than other positions. Paired contrasts of decision times for the ten positions were not significant ($p<0.05$).

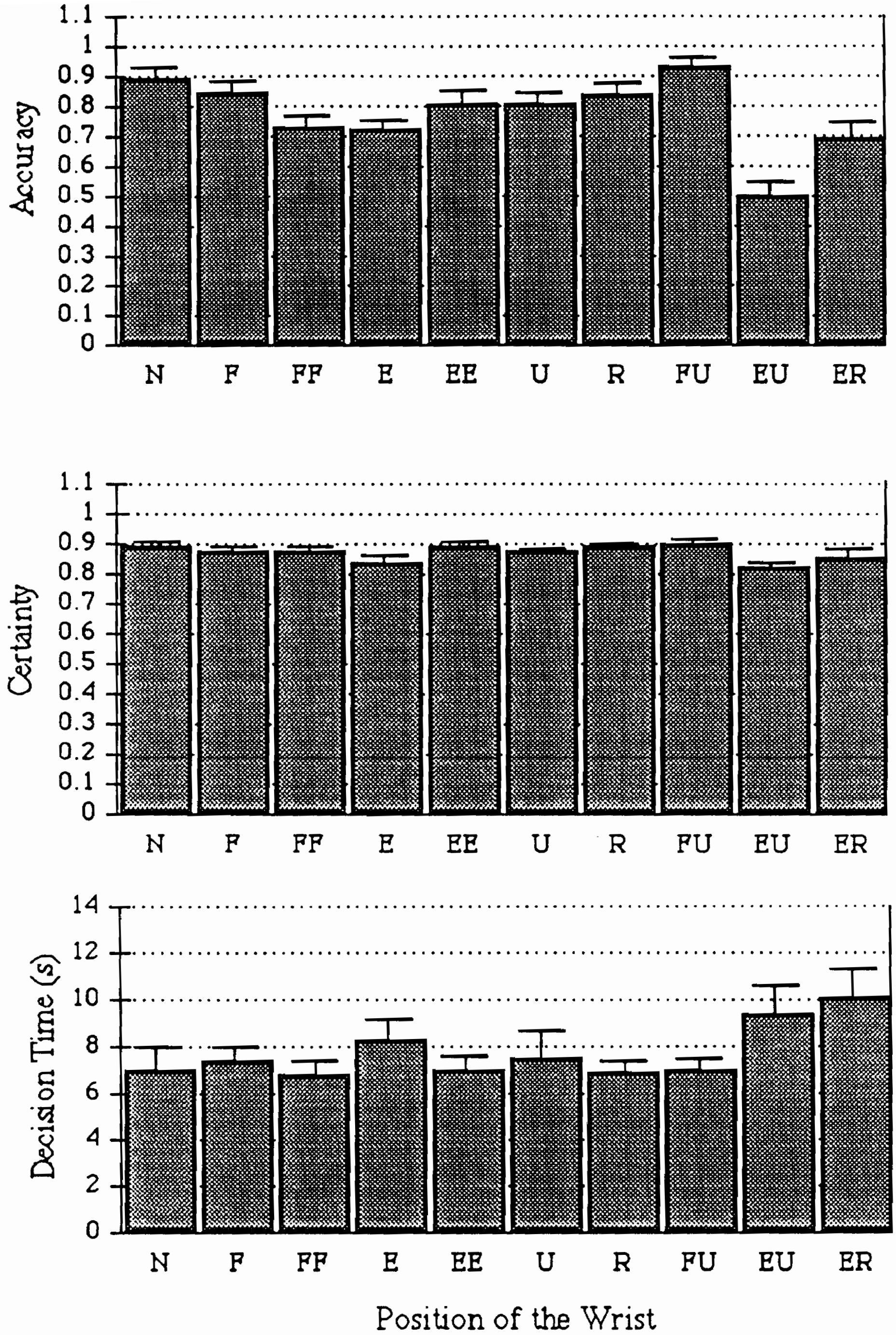

Figure 12. Main effect of Position averaged over Subjects, Displays, and Views (N=180) on accuracy, certainty, and decision time. Error bars show +1 standard error of the mean.

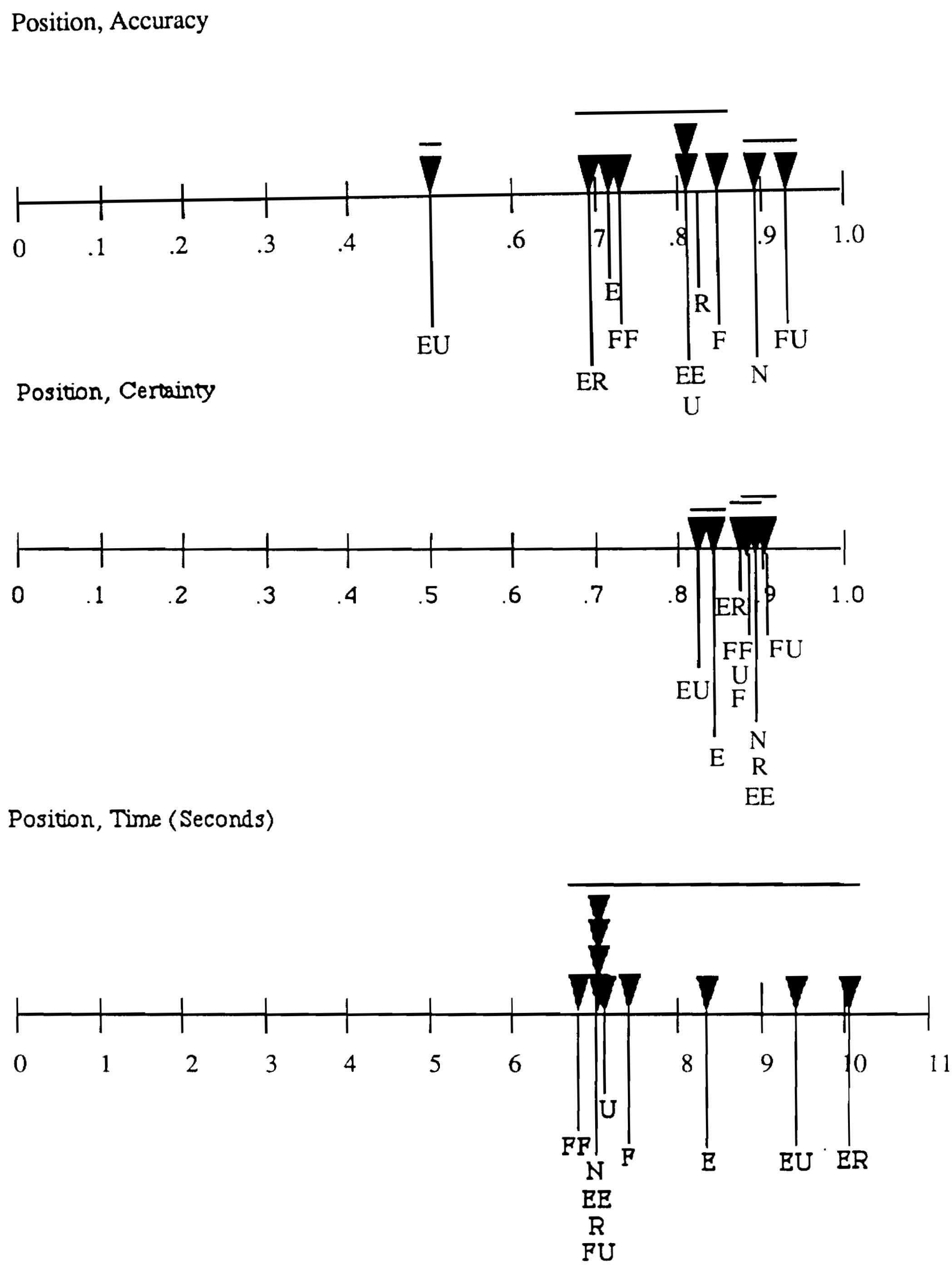

Figure 13. Newman–Keuls Comparison of accuracy, certainty, and decision time among Positions.

Two-way Interactions

Display Method x View. The rank order of main effect Display Methods—Two Stills, Motion, and One Still—was maintained for Thumb-side and Oblique Views as shown in Figure 14. For the Back-side View, Motion (0.91) was higher than Two Stills (0.87) and One Still (0.85).

The rank order of main effect Views —Thumb-side, Back-side, Oblique View—was maintained for One Still and Two Stills. For the Motion Display Method, Thumb– and Back–side Views were not significantly different.

Figure 15 shows which interaction effects were significantly different. Only Two Stills/Thumb-side was found to be significantly higher than all other Display x View pairs. One Still/Oblique View was found to be significantly worse than all other combinations.

The Display x View interaction for Certainty and Time were not found to be significant.

Comparisons of the three dependent variables for the Display x View interaction are as follows:

1. Accuracy had lower ratio scores than certainty for all interaction combinations with one exception. Two Stills/Thumb-side accuracy (1.0) exceeded certainty (0.92).
2. Absolute differences were greater amongst accuracy scores than certainty levels.
3. The Display x View levels of accuracy tended to be inversely related to Decision Times.

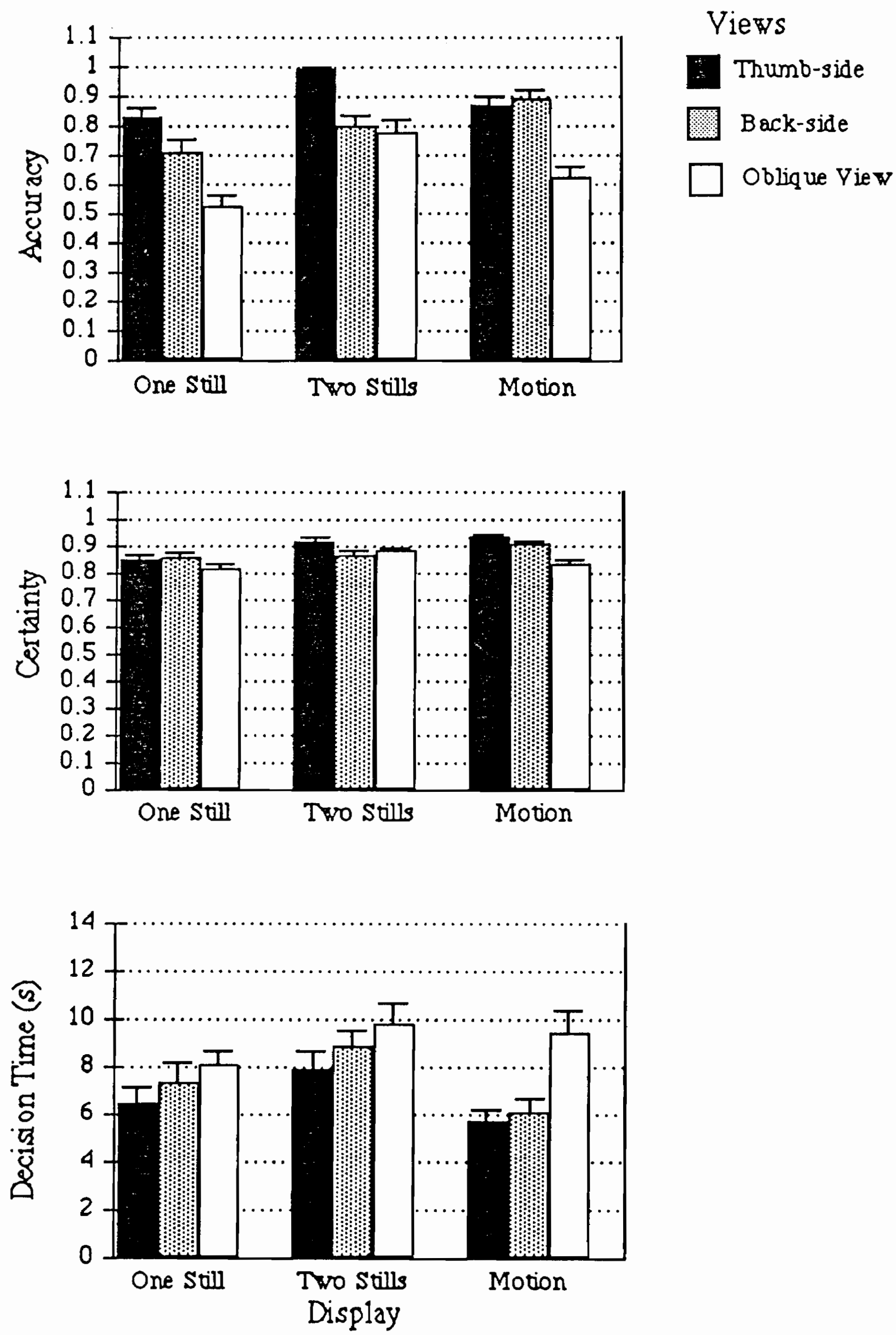

Figure 14. Two-factor interaction between Display Method and View averaged over Subjects and Position (N=120) on accuracy, certainty, and time. Error bars show +1 standard error of the mean.

D X V, ACCURACY

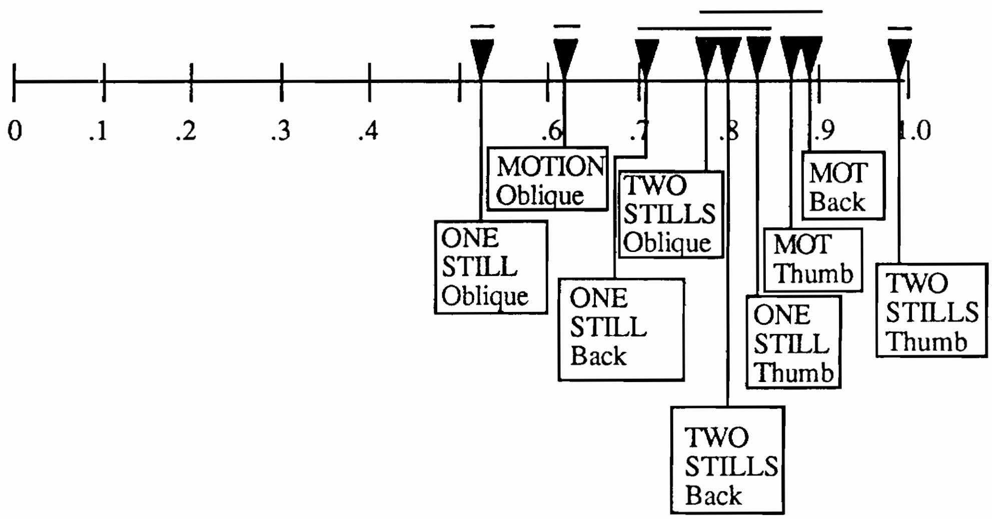

Figure 15. Newman–Keuls Comparison of accuracy at all Display Methods at all Views.

To reveal significant differences between accuracy levels of Display Methods within Views, simple-effect F-tests were performed. A 0.05 criterion level was used to determine significance. The results presented in Table 8 show that Views had significant effects at each Display.

The dependent variable certainty did not reveal significant differences.

Two Stills took more time across all views but these were not found to be significant differences at $p<0.05$.

Position x Display Method. The main-effect Display Method rank-order of accuracy—Two Stills, Motion, One-Still—was upheld for just two positions as shown in Figure 16. Two Stills resulted in the greatest accuracy levels in Five of Ten positions. One Still image registered the lowest accuracy level for eight of the Display Methods. For the position Extreme Extension (EE), One Still registered the highest level of accuracy. Motion resulted in higher levels of accuracy for Extreme Flexion (FF) and Flexion with Ulnar Deviation (FU). For Neutral (N) and Radial Deviation (R), the Display Methods of Two Stills and Motion were equal.

Figure 16 shows the interaction effect means and standard error of the means for the various Position x Display combinations.

Of the dependent variables, only accuracy was found to have significant differences across the Position x Display pairs.

Table 8

Simple-effect F-tests on View at each Display

Source	df	MS	F	p <
V x D x S	44	0.117		
Display = One Still	2	2.908	15.543	0.001
V x D1 x S	22	0.187		
Display = Two Stills	2	1.608	8.072	0.002
V x D2 x S	22	0.199		
Display = Motion	2	2.775	27.962	0.001
V x D3 x S	22	0.099		

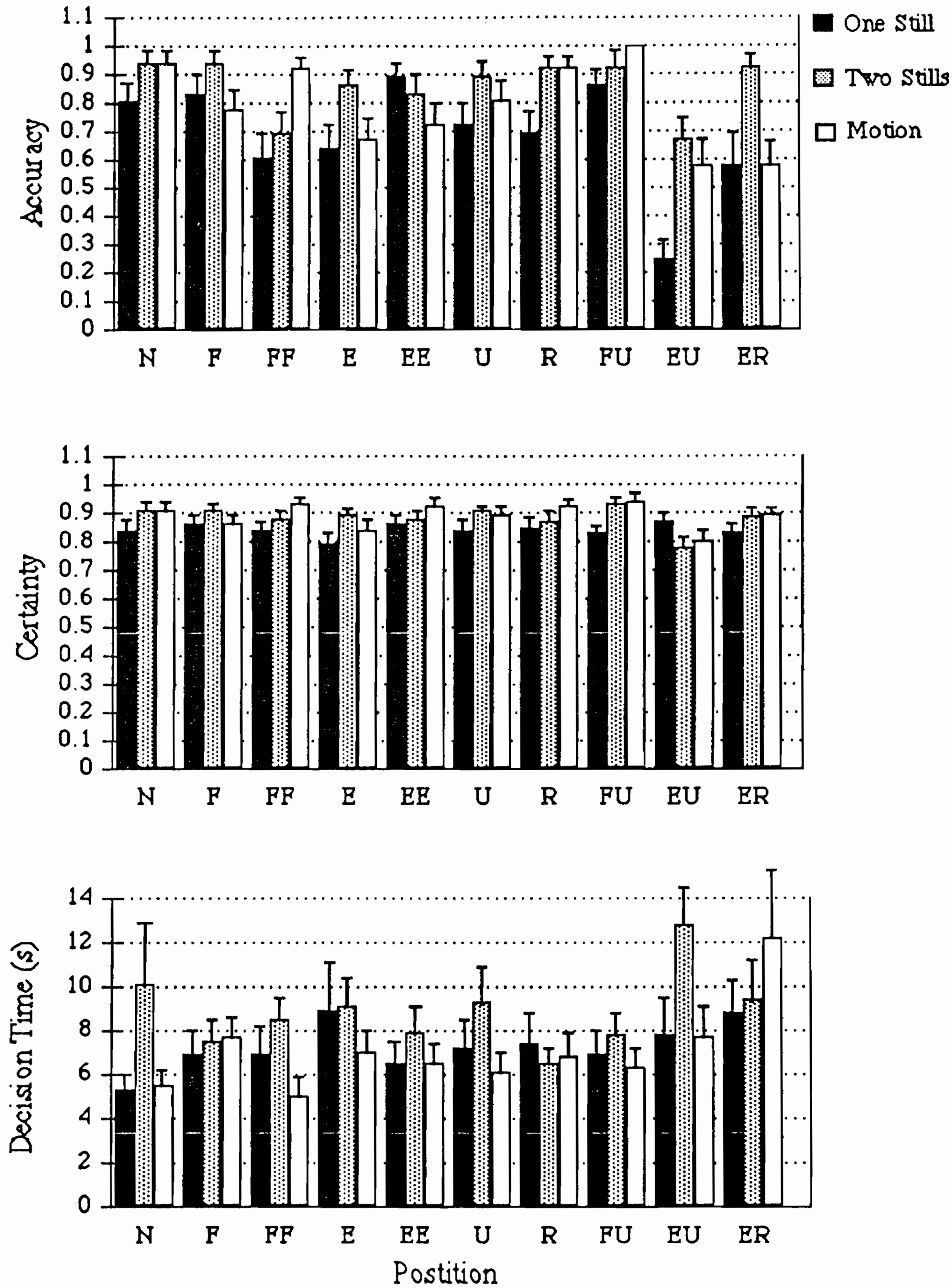

Figure 16. Two–factor interaction between Position and Display Method averaged over Subjects and View (N=36) on accuracy, certainty, and time. Error bars show +1 standard error of the mean.

Comparisons of the three dependent variables for Position x Display are as follows:

1. Accuracy generally had lower ratio scores than certainty for Position x Display combinations. Almost half (13) of the combinations resulted in accuracy levels that were lower than 0.8. There were only two instances where participant's level of certainty were below the 0.8 ("80% certain") level. An exception to this pattern was found where accuracy levels were higher than 0.9. In these instances, certainty levels were generally lower than accuracy levels.
2. Absolute differences were greater amongst accuracy scores than certainty levels.
3. The inverse relationship of accuracy to decision time was not found for any of the 10 positions. However in 4 positions, the highest levels (i.e., the "best") of accuracy by Display Methods was associated with the longest (i.e., the "worst") times.

To reveal significant differences between accuracy levels of Position among various Display Methods, simple-effect F-tests were performed. A 0.05 criterion level was used to determine significance. Table 9 shows that there were significant Position effects at each Display.

Table 9

Simple-effect F-tests on Position at each Display

Source	df	MS	F	p <
P x D x S	198	0.117		
Display = One Still	9	1.267	8.873	0.001
P x D1 x S	99	0.143		
Display = Two Stills	9	0.361	3.312	0.001
P x D2 x S	99	0.109		
Display = Motion	9	0.823	7.807	0.001
P x D3 x S	99	0.105		

Position x View. The rank-order of the main effect Views—Thumb-side, Back-side, Oblique View—was maintained in half of the wrist positions. Figure 17 shows that the greatest exception to this rank-order was: Neutral (N) in which the Thumb-side View at (0.81) was less than Back-side (0.94) and Oblique View (0.92). As previously stated, Newman-Keuls of the main effect Views revealed significant differences amongst all View pairs. Figure 17 shows that only three positions maintained different levels amongst all Views (instances where the levels of accuracy and standard errors of the mean did not overlap). The positions in which all three views were significantly different from one another were: Flexion (F), Extreme Flexion (FF), and Extreme Extension (EE). In each of these three instances, the rank-order found in the main effect View was maintained.

Of the dependent variables, only accuracy was found to have significant differences across the Position x View pairs.

Comparisons of the three dependent variables for Position x View are as follows:

1. Accuracy generally had lower ratio scores than certainty for Position x View combinations. Twelve of the 30 combinations resulted in accuracy levels that were lower than 0.8. There was only one instance where participant's level of certainty was below the 0.8 ("80% certain") level. Just as in Position x Display pairs, an exception to this pattern was found where accuracy levels were higher than 0.9. In 11 pairs, standard error bars reached 0.98, this level of certainty was reached for just one Position x Display Pair: Extreme Flexion/Thumb-side.

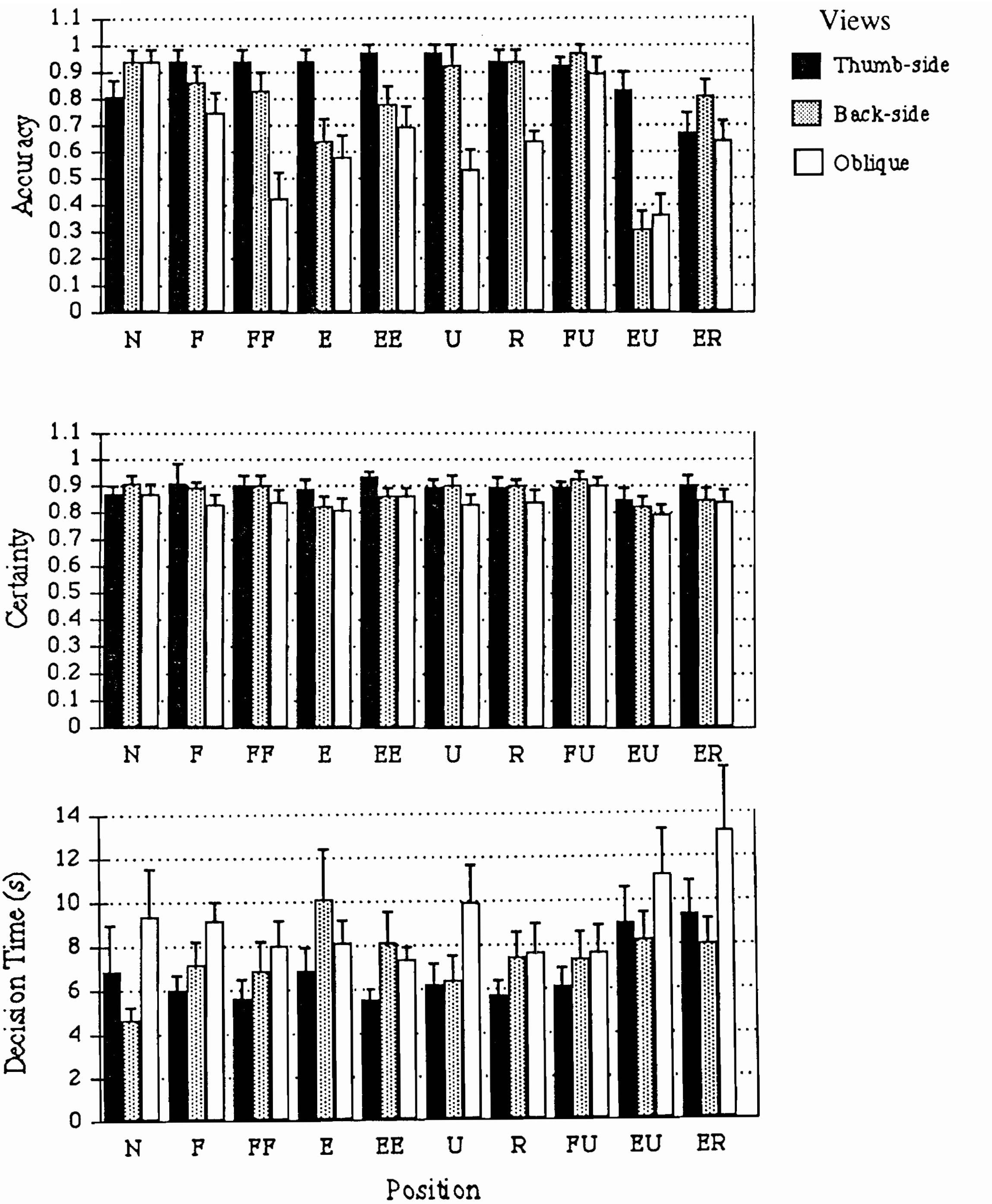

Figure 17. Two–factor interaction between Position and View averaged over Subjects and Display (N=36) on accuracy, certainty, and time. Error bars show + 1 standard error of the mean.

2. Absolute differences were greater amongst accuracy scores than certainty levels.
3. The inverse relationship of accuracy to decision time found in the View main effects were maintained in 4 of the 10 wrist positions.

To reveal significant differences between accuracy levels of Position among various Views, simple-effect F-tests were performed. A 0.05 criterion level was used to determine significance. Table 10 shows that there were significant Position effects within each View.

Three-way Interaction

Display x Position x View. Figure 18 shows the three-way interactions of the independent variable combinations for accuracy. The rank-order of Display main effects were: Two Still, Motion, and One Still. This order was maintained in 8 of 30 instances. In 4 instances, Motion resulted in significantly higher levels of accuracy than Two Stills. These combinations were: Flexion/Back-side, Extreme Flexion/Back-side, Extreme Flexion/Oblique View, Extreme Extension/Back-side. In one instance—Extreme Extension/Back-side—One Still produced a significantly higher level of accuracy than Two Stills. In 4 instances, Motion resulted in accuracy levels that were significantly lower than the other Display Methods. These combinations were: Extension/Thumb-side, Flexion/Oblique View, Extension/Oblique View, Extreme Extension/Oblique View, and Extension/Radial Deviation/Thumb-side.

The rank-order of View main effects—Thumb-side, Back-side, Oblique View—was maintained in 8 of 30 instances. In 9 instances, the Thumb-side View

Table 10

Simple-effect F-tests on Position at each View

Source	df	MS	F	p <
P x V x S	198	0.131		
Display = Thumb Side	9	0.344	4.758	.001
P x D1 x S	99	0.072		
Display = Dorsal Side	9	1.443	8.924	.001
P x D2 x S	99	0.162		
Display = Oblique Vies	9	1.191	6.429	.001
P x D3 x S	99	0.185		

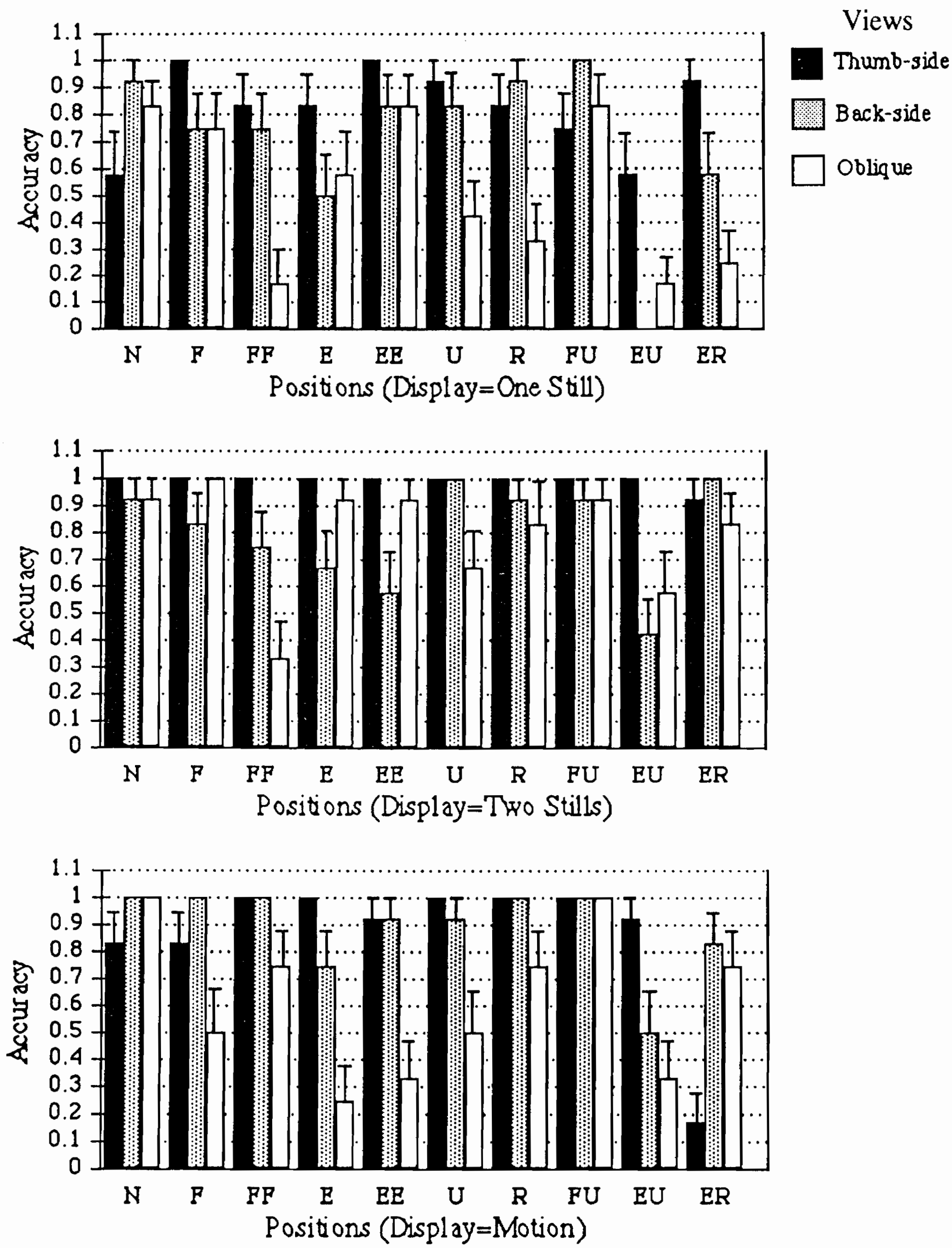

Figure 18. Three–factor interaction between Position and View averaged over Subjects (N=12) on the dependent variable, accuracy. Error bars show +1 standard error of the mean.

had significantly higher levels of accuracy.than the other Views. In no instances was the Oblique View the best of the three Views. In 3 instances the Thumb–side View resulted in significantly lower levels of accuracy: Neutral/One Still, Neutral/Motion, and Extension with Radial Deviation/Motion.

An interesting finding is that in almost one-third (27) of the three–way interactions, the average accuracy was a perfect score (1.0). If +1 standard error of the mean is considered, the number of perfect scores is 44, almost one-half all the interactions.

About one-tenth (10) of the possible combinations resulted in means (+ 1 standard error) that were less than 0.5 (50% accurate). All but two of these combinations were an Oblique View.

RESULTS—EXPERIMENT TWO

Interrelationships of the Dependent Variables

Accuracy, certainty, and decision time was averaged for each of the 12 subjects and subjected to a Spearman rank-order correlation. The obtained coefficients averaged over Display Method and Grasp (N=12) were: r_S=0.482 between accuracy and certainty, r_S=–0.439 between accuracy and time, and r_S=–0.601 between time and certainty. Only the negative relationship between time and certainty was significant at $p < 0.05$.

Main and Interaction Effects

ANOVA. A two-factor, within-subjects Analysis of Variance was performed for the three dependent variables. Across all of the main and interaction effects for the three dependent variables, only one significant difference ($p<0.05$) was revealed. For the dependent variable, certainty, it was found that the Display Method main effect was significant at $p=0.040$. ANOVA tables are shown in Table 11 for accuracy, Table 12 for certainty, and Table 13 for decision time.

Display Method. Figure 19 presents the main effect means of Display Method for the three independent variables. As previously noted, only certainty levels were significantly different. Participants were more confident of Motion Display Methods than they were of One-Still.

Comparisons of the three dependent variables are as follows:

1. Like Experiment One, accuracy levels were lower than certainty levels for all (both) Display Methods.
2. Unlike Experiment One, absolute differences were *not* greater amongst accuracy scores than certainty levels.

Hand Configuration. Figure 20 presents the main effect means of Hand Configuration for the three independent variables. No effects were found to be significant.

Table 11

Experiment Two, ANOVA Summary Table: Accuracy

Source	df	MS	F	p
Subjects (S)	11	0.019		
Display Method (D)	1	0.030	3.667	0.082
D x S	11	0.008		
Hand Configuration	1	0.001	0.061	0.809
H x S	11	0.014		
D x H	1	0.003	0.250	0.627
D x H x S	11	0.013	3.188	
Total	47			

Table 12

Experiment Two, ANOVA Summary Table: Certainty

Source	df	MS	F	p
Subjects (S)	11	0.086		
Display Method (D)	1	0.013	5.429	0.040
D x S	11	0.002		
Hand Configuration (H)	1	0.002	1.154	0.306
H x S	11	0.002		
D x H	1	0.002	1.213	0.294

Note: The Greenhouse–Geisser correction technique was not applied for the significant effect (D) as the epsilon factor was 1.

Table 13

Experiment Two, ANOVA Summary Table: Time

Source	df	MS	F	p
Subjects (S)	11	70.926		
Display Method (D)	1	15.300	3.815	0.077
D x S	11	4.011		
Hand configuration (H)	1	17.885	3.756	0.079
H x S	11	4.762		
D x H	1	0.827	0.387	0.547
D x H x S	11	2.138		
Total	47			

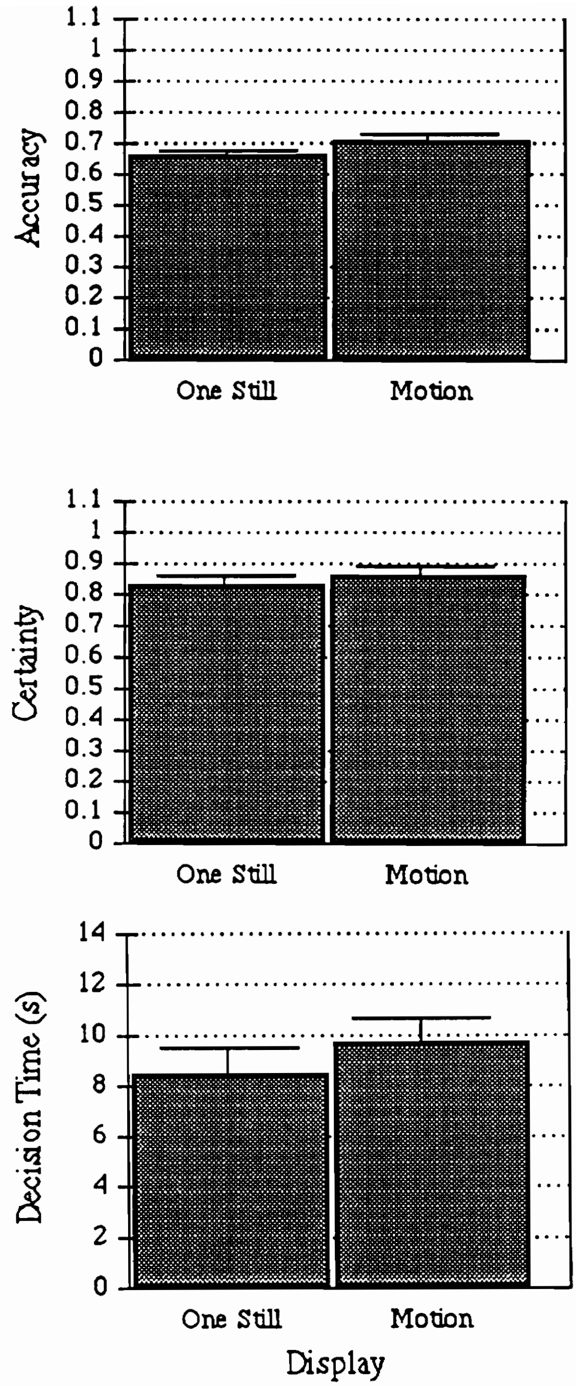

Figure 19. Main effect of Display Method averaged over Subjects and Hand Configuration (N=12) on accuracy, certainty, and decision time. Error bars show +1 standard error of the mean.

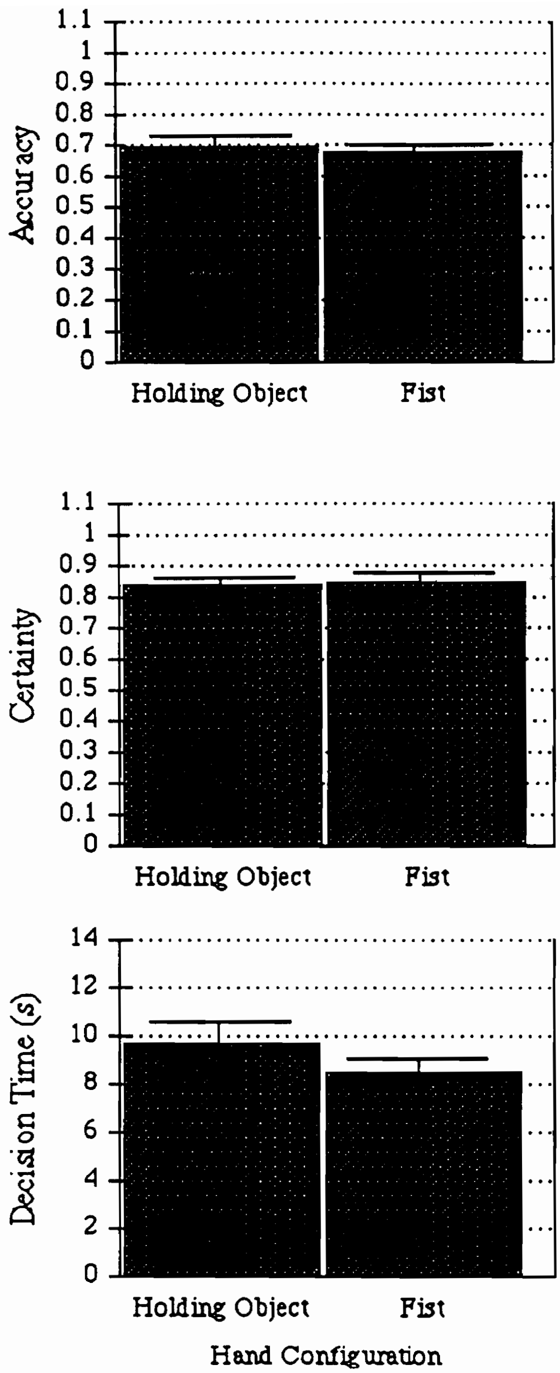

Figure 20. Main effect of Hand Configuration averaged over Subjects and Display Method (N=24) on accuracy, certainty, and decision time. Error bars show +1 standard error of the mean.

Comparisons of the three dependent variables are as follows:

1. Accuracy levels were lower than certainty levels for both conditions.
2. Absolute differences were *not* greater amongst accuracy scores than certainty levels (as was the case in Experiment One).

Display Method x Hand Configuration. Figure 21 shows the interaction effects of the two independent variables. For accuracy scores it is observed the when the hand was holding an object, the scores were less varied by Display Method than when the hand was making a fist.

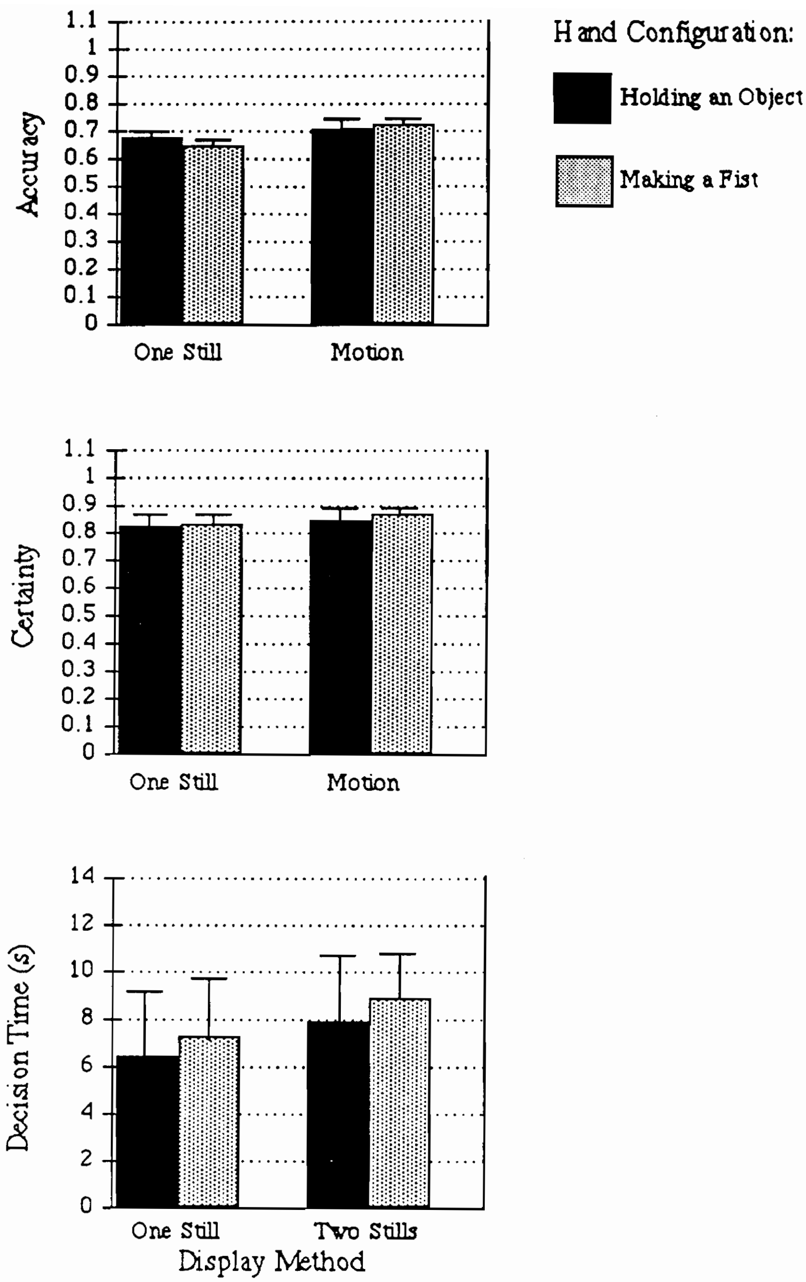

Figure 21. Two-factor interaction between Display Method and Hand Configuration averaged over Subjects (N=12) on accuracy, certainty, and time. Error bars show +1 standard error of the mean.

DISCUSSION

Performance

Of primary interest in Experiment One was the degree to which people, with minimal training, could correctly assess the posture of the wrist joint from video images. It was hypothesized that some factors—singly and in combination—could influence performance. Of the three factors studied in Experiment One—Display Method, View (of the camera), and Position (of the wrist joint)—each had a main effect on performance (both accuracy and decision time) and each possible interaction was significant for accuracy. There were no significant interaction effects found for time.

Are two views better than one? It is intuitive to believe that assessment performance will increase if a second view is available. When the main effects were considered, Two Stills did indeed result in a significant improvement over One Still image.

The second view for each of the Two Still conditions was normal to the palm-side of the hand. Therefore, in combination with the Thumb–side View, there was a 90° separation of Views and in combination with the Back–side View, there was a 180° difference between Views. The palm-side/Oblique View difference was an acute angle. When One vs. Two Still images were compared for each View, it was found that performance associated with Two Stills continued to be better than performance associated with One Still. For the Back–side View (180° separation), this performance difference was not significant at $p<0.05$.

As can be seen from the Newman Keuls comparison of Display Method x View means (Figure 15), *One Still* image from the Thumb-side View resulted in performance levels that were not significantly different from *Two Still* presentations of the Back–side/Palm–side and Oblique/Palm-side combinations. Therefore, while it can be said that a second view improved the performance of any given view, it *cannot* be said that two views are always better than one. It was found in this experiment that a single view could provide as much information as a two-view combination under certain conditions.

Where the Display x View x Position combinations are presented in Figure 18, it can be seen that Two Stills were more often associated with higher performance scores than One Still. It can also be seen that in several instances, performance means for One Still were above the 90% accuracy level while several Two-Still mean values were less than 70% accurate.

Why are some views better than others? Why was the Thumb-side View consistently better than the Oblique View under all Display conditions (Figure 14) and for seven of ten wrist positions (Figure 17)? Why were there higher levels of performance for a *single* Thumb-side View than there were for other *two-view* combinations? If pictures are simply patterns of light that represent a certain amount of information, it would seem that no one view would consistently provide more information than another view in a setting that has been controlled for light and background as in Experiment One.

The answer to these questions may have more to do with absolute vs. comparative judgements than they do with point of view. According to Biederman (1985, p.30): "Absolute judgements are judgements made against a standard in memory and are distinguished from comparative judgements in which both stimuli are available for simultaneous comparison ". Biederman and several others have stated that absolute judgments are limited by memory for physical variation and generally do not exceed 7± 2 categories. Quite in contrast to this limitation are comparative judgements that appear to be limited only by the resolving power of the sensory system. Biederman states that "comparative judgements can be made quickly and accurately for differences so fine that tens of thousands of levels can be discriminated." The judgements in Experiment One were of the *absolute* type. However, when making position decisions, Subjects were observed to use their own hands as references. For example, they would first look at the video image, then configure their own hand to correspond to the video image, and *then* make a decision. This method appeared to be easier to perform for the Thumb-side View and most difficult (almost impossible) from the Oblique View. Further analysis would be necessary to test this theory. If true, it may provide an explanation for why one view was consistently better than another.

The distinction between one view being inherently better than another view vs. an underlying phenomena of absolute vs.comparative judgement has important design implications. If the results of this research are interpreted to mean that a particular view (in this instance, the Thumb-side View) is *inherently* superior, then special attempts should be made to orient the camera in this way (or search for even better view). If *comparativeness* is what enhances performance, then special attempts should be made to provide comparative analysis. For example, the camera could be situated in the most convenient position and still images be made of the various wrist postures based on that particular viewpoint. These still images could then be used to make comparative judgements during the video posture assessment.

What is the relative value of motion? There would seem little point to investigating the relative merits of motion images vs. still images when it is just as easy to capture motion pictures with a camcorder as is to take still pictures with a camera. The reason for investigating the relative value of motion in this experiment pertains more to the *post-production* aspects of video analysis than with capturing images in a field setting. Given the amount of information possible from motion picture analysis (i.e., 60 still images every second), it is important to investigate at what point motion offers diminishing returns for the investment of analysis time.

As stated in the background section of this investigation, the combination of video technology with computer technology offers some exciting possibilities for a video-based assessment tool. Full-motion video however, requires large memory allotments in a computer system. If video/computer technology is to be used for posture assessment , it is important to begin to understand when full-motion is and is not essential.

Based on performance levels in Experiment One, the Newman–Keuls comparison of Motion suggests that it is significantly better than One Still image. However, Two Stills were significantly better than Motion (Figure 9). Therefore, if a particular posture or motion pattern is to be preserved for future analysis or comparison, Experiment One suggests that more information (i.e., data which will lead to better judgements) is provided by two simultaneous images from two locations than from several images (i.e., motion pictures) from one location. Further analysis of the Display Method x View interaction as shown in the Newman Keuls analysis in Figure 15 suggests that this interpretation requires qualification. For the Thumb–side and Oblique Views, the Two–Still Display was associated with significantly superior performance over Motion. The opposite was true for the Back-side View, the Motion Display Method resulted in significantly better performance than did the Back-side/Palm-side simultaneous views. Perhaps the 180° separation of cameras of this particular Two Still Display is inherently poor. The three-way interaction shown in Figure 18 shows that the Back-side/Palm–side Two-Still combination was significantly worse than the Oblique/Palm–side combination for 4 Positions. In the Motion Display, performance based on Back-side Views was never less than Oblique Views.

The Display x View interaction effects shown in Figure 15 indicated that View was a more potent indicator of performance than Display Method. Of the top four Display x View combinations, all three Thumb–side Views are included and there are no combinations that include the Oblique View. The three combinations that included the Oblique View are among the four lowest ranking Display x View combinations. All three Display Methods are represented in the top four conditions as well as in the bottom four conditions.

The design implications based on this observation indicate that time and resources to optimize a video-based posture system should be directed towards finding the best vantage point for a given assessment or toward the video capture of "comparison views" as discussed previously.

The Motion segments in Experiment One were contrived in such a way that the wrist moved from at least one position (often two) to another. Thus, there was information content in the motion itself and people could make comparative judgements of sequential positions. In a real-world setting, the benefit of motion would seem to be related only to the degree to which a task is dynamic. In

Experiment Two where real-world tasks were simulated, there was less movement from one posture to another in the motion segments. This could explain why performance measures failed to reach significance ($p<0.05$) between One Still and Motion Experiment Two.

Can the results from Experiment One apply to real-world assessments? Several controls were employed in Experiment One to provide greater reliability of the independent variables. These control factors included: the distance between the camera and the hand (about 20 inches), the background (solid blue), and the configuration of the hand (a fist). These controls are not likely to be present in a real-world setting. Experiment Two was designed to bridge some of the gap between Experiment One and what is more likely to be present in a real setting.

In Experiment Two, less attention was given to simplifying the background and maintaining a constant distance between the hand and the camera. One of the two independent variables of Experiment Two was Display Method: One Still and Motion. The second independent variable was Hand Configuration. Half of the experimental conditions were of the hand configuration of a Fist and half of the conditions were of the hand grasping an object (i.e, a screwdriver, a telephone receiver, etc.). A variety of views and postures were controlled for but not treated as independent variables in Experiment Two. The results from the second experiment suggested that wrist posture assessment was not significantly affected by the configuration of the hand. That is, there were no significant differences between the conditions in which the hand was making a fist (as in Experiment One) or grasping an object (as expected in a real setting). It was anticipated that in conditions where objects were grasped, performance would be reduced due to the greater complexity, or improved due to the added context. These phenomena may have been present but if so, they canceled each other.

The level of accuracy in Experiment One averaged over all independent variables (N=1080) was 0.78. The level of accuracy in Experiment Two averaged over all independent variables (N=48) was 0.69. The difference may be explained by the fact that the camera angles in Experiment Two were all oblique to the hand (unlike Experiment One where one-third of the views were normal to the thumb-side of the hand, and one-third of the views were normal to the back-side of the hands). The overall performance level of Experiment Two was similar to the performance associated with the Oblique View of Experiment One (N=360) which was 0.66.

Based on the more "task-like" situations in Experiment Two, it may be said that people exposed to nominal training may attain levels of accuracy that are less than 70%. When conditions are optimized, as demonstrated by Experiment One, performance levels may reach levels between 90 and 100%.

Interrelationships of Dependent Variables

Of interest in this investigation was the degree to which people were calibrated to their responses. That is, "did they tend to be more certain of their correct responses than of their incorrect responses?" The first examination of the relationship between accuracy and certainty in Experiment One across all independent variables revealed a highly significant positive correlation. It would be tempting to suggest on this basis that people were good judges of their own performance. Further analysis revealed that this was not the case.

At a practical level, there are two scenarios in which the relationship between accuracy and certainty would be important. The first scenario is where an individual is assessing wrist postures on videotape. Would the postures found to be most questionable to the person correspond to judgements that were more likely to be incorrect ? If so, the time taken to review the questionable posture in the field would be worth the effort. If not, the extra effort would be wasted and incorrect judgements would go untested. When individual scores (accuracy) and certainty levels were ranked and compared, it was found that—in general—they were not significantly correlated. Therefore, it appears that participants were *not* well calibrated to their responses and if they were to check their most questionable responses, they would be just as likely to check their correct responses as they would their incorrect responses.

There were exceptions to this non-association for some individuals under certain conditions. For the Display Method in which Two Stills were presented, half of the individuals were highly calibrated to their responses. Five individuals were also well-calibrated to their responses within the Thumb-side View. Just three individuals for Back-side View, and two individuals for the Oblique Views were calibrated to their responses. This suggests that two views may not only be beneficial for increased levels of accuracy but for increased levels of calibration as well. An important finding was that for the Display Method of Motion, half of the individual accuracy/certainty relationships were *negatively* correlated at $p<0.05$. In these instances, people would have been more likely to check their *correct* responses.

A second scenario in which the relationship between accuracy and certainty would be important is in situations where two or more people are assessing wrist posture from videotape. If one person is more confident of his/her responses, are those responses more likely to be correct than those of a less confident colleague? To test this inter-subject relationship, levels of accuracy and certainty were averaged for each subject . For both experiments, rank-orders for accuracy vs. the rank-orders for certainty were compared and it was found that there was no correlation.

Decision times were found to be negatively associated with accuracy and with certainty within all Displays and Views. By individual within each Display and View, negative relationships were much more prevalent for time vs. certainty than for time vs. accuracy. The interpretation of this finding is that either people tended to be overly confident of their quick responses, unduly pessimistic about responses that took a long time, or some combination of both phenomena.

When the times and levels of accuracy were averaged for each individual and ranks assigned, it was found in both Experiments that there was a negative relationship but it was not significant ($p>0.1$). That is, individuals who were fastest were neither better nor worse than the slower participants. When individual averages for decision time were compared with certainty, negative relationships were also present. In Experiment One the relationship was not significant ($p>0.1$). In Experiment Two, the relationship was significant ($p<0.05$). In other words, people who took longer for their responses tended to be less certain of their responses.

CONCLUSIONS

Current Findings Relative to Previous Studies Where Wrist Posture was Assessed

The literature review of posture assessment methods was interesting for what it revealed about investigators beliefs about film and video formats. Researchers' beliefs about motion picture data—stated explicitly or implied—fell into one of three groups. One group flatly rejected the use of film/video and relied, instead, on direct observation. Where stated, the reasons for rejecting this format included: "Pictures are limited to two dimensions and therefore contain no perception of depth unless much trouble has been taken to produce it" (Priel, 1974, p.576) and "...from a two dimensional screen no three dimensional angles can be determined..." (Foreman et al., 1988, p. 288).

Another group could be labeled "casual users" of a film or video medium. In a summary of 19 observational methods for assessing posture (See Table 4), 10 used film/video as the primary source of data and an additional 5 used video to train observers or to check inter–observer reliability. In many instances, researchers reported how they exploited the video medium as a means to record several types of non–visual data as well.

The term "casual" is used to describe this second group because within these reports, there was no mention of factors at the stage of data capture which could possibly influence perceptual performance at the stage of analysis. References made to camera use were of this theme: "make sure the object of interest is within the view of the camera." (Armstrong et al., 1979; Keyserling et al., 1986; Keyserling, 1987; Malchaire et al. 1991). In other instances, video was simply "used." In no instances were tests for validity taken to test the accuracy of people's video–based posture assessments nor was there ever any mention that such testing should be done in future studies.

In the few instances where tests for inter–subject reliability tests were made and discrepancies between observers were found, the video format was implicated as follows: "...discrepancies of this type are likely to occur as long as two–dimensional displays are used to represent three–dimensional postures" (Keyserling, 1986, p. 578) and "error in the recording of postures could have been introduced by the need to correct for the angle of the camera relative to the worker's hand when viewing the film" (Punnett et al., 1987, p. 1112) and "...subjects reported difficulty in using the information provided by a two–dimensional display...to generate a three–dimensional posture..." (Keyserling et al., 1987).

Of the field studies listed in Table 3, video observation (to assess posture) was the method of choice. Its use in these studies could also be described as "casual" for the reasons stated above.

The belief which defines a third group, is that there is basically "no difference" between observing posture directly and observing posture from videotape. Corlett et al (1979) stated that "cine records" may be useful for highly dynamic tasks, but that "...films...only transfer the problem from the shop floor to the analyzing room" (p. 359). Stetson et al. (1991) state that: "...the lack of significant difference between results from job–site versus videotape analyses suggest that the ability to slow down or 'freeze frame' the videotape was not an important benefit..." (p. 19).

Assuming that—contrary to the beliefs of Corlett and the findings of Stetson—there *are* significant differences between direct and video–based methods of observation, are the beliefs of the other groups valid? That is, should we reject video altogether as an untrustworthy medium or should we continue to use it casually?

The results of this research suggest that neither view is correct. There is reason to believe that people can, in fact, perform extremely well, but *only* under certain circumstances.

Encouraging signs that a video-based system is feasible (i.e., people were accurate) are these:

- Of the 90 three-way interactions in Experiment One, almost half (44) of the mean scores (+1 standard error of the mean) reached 100% accuracy.
- One of the Display x View combinations (across Subjects and Positions, N=120) reached 100% accuracy.

Considering that that the participants in this experiment were only briefly trained in a categorization scheme and received no feedback to their video–based judgements, these figures support the notion that—contrary to the thesis of Foreman et al. (1988)—people *can* judge three-dimensional postures from a two dimension display format.

The results of this research do not, however, support the contrary and popular view that video be used and exploited for its obvious benefits and because "it's there." In situations where the camcorder view was oblique to the hand (possibly the most likely case in past field research), accuracy was less than 70% in both experiments. Clearly this is unacceptably low for research purposes.

While the results of this research do not offer clear guidelines for the capture of video data, they do reveal that remedies presented by previous researchers to reduce observer error may not be as straight–forward as suggested. For example, several investigators have proposed a two–camera approach [e.g. ...the data is captured with a two–camera video system...(which allows) reliable analysis of...postures" (Wangenheim et al., 1986, p. 244)]. The current research revealed that , while a second camera generally improved the performance of each of the three views, a single *good* view may be as good or better that two *poor* views. (See Figure 19.) While it is tempting to suggest from these finding that the Thumb-side View was *inherently* superior to the other views, such a statement cannot be made. This particular view may have been associated with higher performance, simply because people could more easily *compare* the positions presented on the video screen with their own hands. This possibility suggests a direction for future research.

Despite the widespread use of film and video recordings in human factors research, there does not appear to be a theoretical foundation for its use nor any accepted guidelines. Comments by Carter and Anderson (1989) suggest that the technology of video in human factors research may be used "simply because it is there." In an issue of the *ACM/SIGCHI* (SIGCHI, 1989) devoted to the use of video in human–computer interaction, it was noted that "most video work...has been done in isolation...no books are available nor are there courses that teach about the effective use of video" for research purposes.

Attempts have been made in other disciplines to establish a theoretical foundation for filming human behavior. A general concept of scientific filmmaking was formed in the first decades of the century (Taureg, 1983). According to

Taureg, this lead to the *Institute für den Wissenschaftlichen Film (IWF)* in West Germany: "By the end of the 1950s, the IWF had set down elaborate rules regarding the scientific purposes of ethnographic filmmaking." These rules not only "guided anthropologists, who were usually unfamiliar with the medium of film," but were used as well by other disciplines such as biology, medicine, and technical sciences.

This research suggests that the human factors research community—specifically industrial ergonomists—may need to establish guidelines and possibly rules for the capture and use video data.

Inter–subject reliability: Can it replace validity tests? Of the field studies and posture assessment methods reviewed, there were no tests of validity. Inter–subject reliability was sometimes tested, presumably on the assumption that if more than one person judged posture in a given way, then it was likely to be correct. To test this hypothesis, 3 pairs of results were randomly chosen and compared for the answers given to the 90, One–Still Displays. In the first pair, the subjects were in agreement for 69 (77%) of the choices. However, among their agreed-upon choices, they had 9 mutual errors. The figures for the others two other pairs were: 79% agreement with 4 mutual errors, 76% agreement with 14 mutual errors. Also, comparing the responses of all 12 subjects to the 90, One–Still presentations, there were 11 instances in which *the majority* chose the same wrong answer. Based on this, it can be said that inter–subject reliability tests could give a false sense of security and they certainly they do not substitute for validity tests. If video-based methods are to be developed, validity tests must develop concurrently. In this research, it was considered adequate to *stage* the postures. If a video-based system were to progress to real-world settings, tests for validity would need to employ accurate measuring devices (e.g., electronic goniometers) not only to validate observational techniques but also to provide the necessary training for skilled observers.

Believing what we see: The problem of overconfidence. The Results and Discussion Sections of this investigation presented that people were—in general—over–confident of their performance. It is suggested that perhaps we are less skeptical of "what we see with our own eyes" than we are for other forms of data. For example, there were several investigations where the researchers discussed calibration techniques for the collection EMG data and force measurements. But in these same reports, they simply noted that "a video camera was used to record postures."

It is not only important to investigate video–based posture judgements to enhance performance, but also to develop ways to help people become better calibrated to their performance (i.e., to know when they should go back to the factory to "have another look").

Risk Factors Associated With Hand and Arm Disorders: Perception vs. Knowledge

"It is safer to be a soldier in Operation Desert Storm than to work in a packinghouse." (Harrington, 1991, p.3). This statement was made to a house sub–committee by Representative Tom Lantos (California) referring to "repetitive motion injuries" in the meat–packing industry. The following comments, taken from recent publications, are representative of a growing discussion of this problem in the popular press and government publications:

“Repetitive motions disorders often go away if you catch them early” (Freundlich, 1989).

“...injuries resulting from ergonomic hazards will be one of the greatest worker health and safety concerns in the next decade” (Swoboda, 1990, A3).

“Repetitive motion injuries, also known as cumulative trauma disorders, are injuries to the musculoskeletal and nervous systems from a worker being forced to repeatedly perform a job in an awkward position for extended periods of time” (Swoboda, 1990).

“Companies should not be allowed to cripple their workers and then forget about them” (Houston, 1989, p. IV,11).

“Warning: Your keyboard could be a crippler” (Editors, Business Week, 1988).

“...the Federal Government says tens of million of workers, like these keyboard operators here, are at risk of developing cumulative–trauma or repetitive–motion disorders” (Kilborn, 1990, p. 1).

Public perception of hand and arm disorders, as reflected by these and many other articles, are in contrast to the medical and scientific studies reviewed for this thesis. There appears to be a public perception that: hand and arm disorders have reached “epidemic levels,” that work–related factors are the primary culprit to these disorders, that “ergonomic fixes” to these problems exist, and that these fixes are relatively "simple." These beliefs have and are being translated into regulations, laws, and record fines. Yet none of these beliefs have been derived from scientific findings, nor have these concepts been sufficiently challenged by the rigorous methods of inquiry to which the human factors profession subscribes.

If the popular beliefs have been lifted from the studies surveyed in this review, they have been lifted out of context and have failed to appreciate the fragile basis upon which some associations were suggested. The bases of the association of wrist posture to hand and arm disorders have been: clinical studies in which patient histories were taken, occupational safety records, field studies, biomechanical arguments and laboratory experiments.

Of the clinical/history studies reviewed, there were no instances where a proper *cohort* group was included. Therefore, while it may be interesting to note that a certain percent of patients typed, knitted, played the violin, sewed shoes, etc, it cannot be concluded that these activities *caused* their hand related disorders or that the prevalence in these populations was greater than in the general population.

Regarding the increases in hand and arm disorders based on OSHA reports. According to OSHA (Bureau of Labor Statistics, 1989), increases in reported "repetitive motion disorders" are due in part to changes in record keeping requirements and the effect of these changes cannot be separated from real increases. According to the most recent reports to the Department of Labor, (Bureau of Labor Statistics, 1990; Bureau of Labor Statistics, 1989), there is "continued concern about the limitations of these data" and there is a need for a "major overhaul."

The field studies reviewed also offer no good basis to believe that a deviated wrist posture precipitates hand and arm disorders nor have they demonstrated that maintaining a more neutral wrist posture prevents these disorders or provides amelioration for them. The field study findings have been quite mixed as can be seen in Table 3.

In the field studies where design techniques were reported, *cross–sectional studies* were used. Kilborn (1988) states that this design is inherently weak for studying hand and arm disorders which generally have a long latency period and are most likely multi-causasional. He states that despite the "explosion of scientific publications" on upper limb disorders in recent years, "very little attention...has been paid to the cost effectiveness of interventions and unsuccessful interventions are seldom reported" (p. 735). Kilborn believes that the nature of any "intervention project is by necessity that of a quasi–experimental, epidemiological prospective study" (p. 738).

Biomechanical arguments have also been mixed with respect to the nature of the relationship between wrist postures and disorders. Brain (1947) believed that an extended wrist played a much greater role than a flexed wrist because "there is more room (in the carpal tunnel) during flexion. Tanzer (1959) believed that *flexion* played a greater role that *extension* and also based his beliefs on "a logical anatomical concept."

More recently, Tichauer (1978) reported that among trainees in electronics assembly, almost one–fourth developed carpal tunnel syndrome after just 12 weeks on the job. He suggested that this was due to the ulnar deviation required to hold a straight–handled pliers. Armstrong (1983, p. 3) states to the contrary that: "...it is doubtful that there is sufficient range of motion (in radioulnar deviation) to produce significantly more stress (on the median nerve) than when the wrist is straight."

Experiments have offered some insights to the role of a deviated wrist , but only in flexion–extension. These insights, however, do not suggest why some people develop hand disorders while others do not. The histological changes to various tissues within the carpal tunnels of cadavers led Armstrong et al. (1984) to state that "there is sufficient repetitive stress in nearly everyone's wrist to produce some tissue changes" (p. 201).

A legitimate question to ask is: How did the discrepancy—between public perception and scientific findings—occur? In reviewing articles for this research, this author found that these discrepancies may not have occurred at the point where scientific findings were translated into the lay literature. (As one might assume). Rather, they seem to have begun within the *scientific* literature itself. Numerous examples were found where: researchers failed to preserve the context of previous findings, failed to note the basis of past findings, tended to highlight associations while minimizing non–associations, reported associations found by other researchers where none were made, omitted important information such as sample size and duration of study, and wrote in such a way that would tend to confound a reader.

These failures and omissions have been compounded in that they have led to a list of "occupational risk factors" that is referred to and quoted directly throughout the ergonomics and medical communities.

Suggested Roles for Human Factors Regarding the Problem of Hand and Arm Disorders

The problem of hand and arm disorders in American industries is clearly an important area of investigation for ergonomists. However, this issue should extend beyond the purview of biomechanics. This thesis has presented reasons for addressing this issue within the human factors' domain of information displays. Video is a medium that has been widely used in investigations of hand and arm disorders and it is likely that this use will continue. In *Ergonomics Program Management Guidelines for Meatpacking Plants* (U.S. Department of Labor, 1990), "the use of videotape, where feasible, is suggested as a method for the analysis of the work process" (p. 8). This program has been described as the first of its kind and a model for government–regulated ergonomic programs of the future. What this research suggests however, is that the video medium, as a means of assessment, is untested as a reliable data source. Therefore, visualization of real–life scenes to assess work methods (i.e., posture) is an important area of investigation.

The review of both the scientific and lay literature suggested a third area of human factors involvement: the *communication* of human factors research findings within the human factors community, to the scientific community at large, and to the public. During this study, the following question arose: is there any point to developing more methods to gather more data—video or otherwise—if there are no effective means to communicate results to the wide range of people who "should know?" The following excerpt from *A Proposed National Strategy for the*

Prevention of Musculoskeletal Injuries (ASPH, 1986) suggests that communication may be the most "formidable" barrier to attacking this problem:

> Disseminating accumulated knowledge is essential to overcoming resistance to change and reconciling the initial costs of proposed interventions with anticipated long–term benefits. The disparity of backgrounds of professional people who must cooperate in advocating and evaluating interventions must also be overcome.
>
> For example, when dealing with musculoskeletal problems, most engineers are not trained in ergonomics or biomechanics while health care personnel are not knowledgeable about manufacturing technologies —yet these people must work together.
>
> The problems in cooperation common to all disease–prevention and health problems are now being recognized as a most formidable and potentially the chief roadblock in any prevention–oriented program.

Human factors researchers and practitioners who address this problem in the future cannot continue to be naivé to the "climate" surrounding this topic. They must be prepared to present their findings to people who have no understanding of research methods and may even hold such methods in contempt. In a congressional hearing pertaining to carpal tunnel syndrome, a congressman referred to "holier than thou scientific attitudes" to dismiss testimony on the limitations of a particular study.

Human Factors practitioners, likewise, need ways to incorporate relevant findings from other disciplines as this information becomes available. For example, the experimental findings of Szabo (1989) (See Table 2) suggest that carpal tunnel pressures for people with advanced stages of carpal tunnel syndrome behave more like that of asymptomatic people than of people with early and intermediate stages of the disorder. This suggests that we should differentiate between early and advanced cases of CTS in future field research and that failure to do so could contaminate the results.

Visualizing Human Factors

Visualization tools for scientific computing, as presented by McCormick et al. (1987), allow scientists to "assemble vast amounts of data in intellectually digestible form." McCormick states that certain scientific problems that have been "so difficult that they have resisted attack for years ... are beginning to be reexamined with (visualization) tools."

The challenges in communicating information in this area are that : the human hand and arm is a highly complex system, the causes of hand and arm disorders appear to be multi–causational, individual variation is likely to exist relative to all of the risk factors, and this problem is now cast in a social–political context (i.e., people have a vested interest in the outcome of research findings). Perhaps visualization—applied to hand and arm disorders—could be a graphically enriched, dynamic presentation of the inter–workings of nerves, muscles, tendons, etc. which would depict what we know, what we speculate, and what remains a mystery about the nature of hand and arm disorders. Perhaps this approach could advance our understanding of complex phenomena and lessen our desire to over–simplify. For human factors researchers wishing to investigate visualization concepts, they need look no further than their own profession for a rich opportunity.

The central issue presented in this thesis—using two-dimensional representations to gain a better understanding of some complex part of the human body system—was discussed 500 years ago by Leonardo da Vinci .

Da Vinci, *the biomechanician*, was intensely interested in the skeleton of the limbs and was the first to show the anterior and posterior aspects of the bones of the wrist and hand with any degree of accuracy. (Kelen, 1990). Seireg (1969 in Chaffin and Andersson, 1984) states that "Leonardo's penetrating biomechanical studies were far in advance of the state of the art at his time" (1452–1519). Da Vinci, *the artist*, was keenly aware of perceptual issues when one represents a three–dimensional world in two dimensions. He did not see this as a problem but rather, a challenge.

When one reviews the following writings of da Vinci and contrasts them with our current methods of observing human factors, one wonders if da Vinci isn't "far in advance" of *our* time and should therefore guide our current work. The following quotations of da Vinci's are from Kelen (1990).

Regarding human variation—

> Observe also the size of joints, since Nature is apt to vary considerably in this respect; and follow her example.
>
> Bodily dimensions are so various in Nature that one can never find one part of any animal that is exactly similar to the same part in another animal of the same species. Therefore study well the variation of forms...

Regarding how we observe the human body—

> The true knowledge of the shape of any body will be obtained by seeing it from different aspects.
>
> Note how the measurements of the human body vary in each member according to how it is bent, or seen from different views, increasing in one part to the degree that it diminishes is another.

Regarding the need for observational aids—

> The organ of sight is quick and takes in at a glance an infinite variety of forms; nevertheless is cannot really grasp more than one object at a time...never be without your little pad...make light sketches as the opportunity occurs.

> Consult Nature in everything and write it all down. Whoever thinks he can remember the infinite teachings of Nature flatters himself. Memory is not that huge.

Regarding how we represent the human body—

> The positions of the head and arms are infinite and I shall not enter into detailed rules concerning them. Is is enough to say that they are to be easy and free, graceful and varied...and not appear stiff like pieces of wood.
> The arms particularly should be pliant. No member should be shown in a straight line with any other adjoining member

Regarding "visualization"—

> It is not enough to believe what you see, you must understand what you see.

It has been said that a science progresses most rapidly when there exists a close interplay between theory, observation, and experiment and that "when theory runs too far ahead of what can be measured, a field becomes more philosophy than science" (Schramm and McKee, 1991, p. 352). Applying this precept to the issues raised in this report, it appears that the *theory* of the relationship of wrist posture (and task-related factors in general) to hand and arm disorders has proceeded far ahead of experiment and observation. This research presents a case for investigating issues pertaining to *human perception* of *human movement* through the use of motion pictures. The goal of such research would be to enhance the areas of experimentation and observation as well as the "interplay" between these two methods and between each to theory.

The "principle of motion photography," developed by Jules Marey in 1887, inspired Thomas Edison to order his assistant, William Dickson, to begin work on what was to become the first motion picture camera, and its companion viewer the Kintescope. Since *a better understanding of human motion* was the inspiration of

Marey's work, one could say that human factors investigations in this field will come full–circle to the original intentions of, and inspiration for, the moving picture medium.

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