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# Effects of Pace and Stress on Upper-Extremity Biomechanical Responses in Sign Language Interpreters

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# EFFECTS OF PACE AND STRESS ON UPPER-EXTREMITY BIOMECHANICAL RESPONSES IN SIGN LANGUAGE INTERPRETERS

By

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# Abstract

Repetitive motion injuries (RMIs) are disorders of the soft tissues due to repeated exertion and excessive movement of the body. Sign language interpreters who have to move their fingers, hands, wrists and arms repeatedly are susceptible to RMIs. One of the major research voids in the studies of RMIs in sign language interpreters is the lack of quantification of biomechanical exposures. The objective of this study was to analyze the impact of pace and psychosocial stress of sign language interpreting on the biomechanical responses in a quantitative manner and compare the results with the industrial high risk benchmarks.

Twelve professional sign language interpreters participated in this study with a one-half hour interpreting task. Biomechanical variables in flexion/extension and radial/ulnar planes of wrist motion in different pace and stress conditions were measured. It was found that pace has a significant positive effect on bilateral biomechanical responses while a positive stress effect was found only for the left hand. The dominant hand was significantly more physically stressed than the non-dominant hand, as indicated by wrist kinetic variables and other wrist motion variables measured in this study. In addition, wrist kinetic variables of sign language interpreting were found similar to or higher than the high risk industrial benchmarks. The results of this study proved with quantitative data that sign language interpreting is a high risk job of RMIs, requiring highly deviated wrist positions, ballistic wrist movements, and highly repetitive wrist motions. The results also shed light on how different factors may influence the biomechanical responses of sign language interpreters.

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# CHAPTER 1

# INTRODUCTION

Repetitive motion injuries (RMIs) such as carpal tunnel syndrome have long been associated with adversely affecting the industrial workforce. However, RMIs are even more prevalent among sign language interpreters than in industrial workers. The pain and dysfunction associated with RMIs have lead to significant loss of work time for many interpreters and forced some of them to abandon the profession entirely. RMIs threaten the health and livelihood of interpreters and have contributed to the national shortage of interpreters despite an increased demand of their services. While the physical intensity of interpreting is easy to appreciate, what may be overlooked is the high cognitive demand placed on the interpreter as he/she adapts to new subject content, changes in speaker's pace, and various psychosocial pressures. Better understanding of the factors that affect the development of RMIs among interpreters is necessary to reduce the occurrence of RMIs and to develop effective strategies for sign language interpreters who suffer from the disorders.

A considerable amount of work has been performed to investigate and quantify exposure to RMIs in industrial workers, and recent work has begun to evaluate the effect of psychosocial factors on biomechanics of the back in industrial settings. However, less attention has been paid to RMIs in sign language interpreters. Research that quantifies the biomechanical parameters of upper extremity during interpreting is very limited and there is a lack of literature studying the effect of psychosocial stress on the biomechanical responses in sign language interpreters. Thus, the main objective of this study was to

analyze the impact of pace and psychosocial stress of the interpreting task on the biomechanical responses in a quantitative manner. This work was also intended to establish benchmark values of biomechanical exposures of sign language interpreting, which can be used to compare to previously established thresholds of high risk industrial tasks.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 RMIs and its Prevalence

RMIs are disorders of the soft tissues of the body– most frequently the tendons and nerves – due to repeated exertion and excessive movement of the body (Rempel et al., 1992). These disorders have also been referred to as repetitive strain injuries, cumulative trauma disorders, repetitive stress syndrome, or overuse syndromes. Upper extremity RMI refers to a variety of inflammatory conditions of the fingers, hands, wrists, arms, shoulders, upper back, and neck including carpal tunnel syndrome (CTS), tendinitis, synovitis, myofascitis, and tenosynovitis with symptoms of pain, tenderness, tingling, swelling, numbness, cramping, stiffness and loss of function. Unlike instantaneous trauma, "repetitive" means that the injuries are caused by repeated stress over a period of time.

Since the early 1980s through 1994, the Bureau of Labor Statistics (BLS) reported a tenfold increase of RMIs in many segments of American industry. The agency also reported that the median number of days away from work for CTS was 30, which is even greater than the median reported for back pain cases (BLS, 1995). According to the data from the Occupational Health Supplement of 1988 National Health Interview Survey, among 127 million workers who worked during the 12 months prior to the survey, 2.0%, or 2.54 million either self-reported or were diagnosed with CTS, and 0.46%, or 588,000 reported that they experienced prolonged hand discomfort which was diagnosed as

tendinitis, synovitis, or tenosynovitis by a physician. Construction, food processing, assembly and repair service were some of the jobs with high prevalence of CTS.

RMIs started to be associated with sign language interpreters about fifteen years ago (Stedt, 1990). At RIT/NTID, approximately 45% of the sign language interpreters were either totally disabled from interpreting or were working with reduced interpreting load because of RMI symptoms (DeCaro et al, 1992) in the 1988-1989 academic year. In 1990, 60% of the 42 full-time interpreters at NTID were diagnosed with work-related tendonitis (48%) or nerve entrapment disorders (12%). Similarly, Stedt (1990) found that among 40 interpreters, the vast majority (88%) reported that they had experienced at least two symptoms (such as numbness, tickling, pin/needles sensation, and burning feelings) associated with RMIs at sometime. In a more recent survey of 145 interpreters, Scheuerle (2000) found that 119 (82%) had experienced disabling pain/discomfort during and following interpreting.

Investigation into the etiology of RMIs has identified three categories of risk factors for these problems: biomechanical exposures, psychosocial stressors, and individual risk factors (Bongers et al., 2002), which will be described individually in the following sections.

## 2.2 Biomechanical Risk Factors

Biomechanical exposures include factors such as repetitive motion, high forces, and deviation from neutral body alignments (National Research Council and the Institute of Medicine, 2001). National Institute for Occupational Safety and Health (NIOSH, 1997) reviewed over 30 epidemiologic studies examining ergonomic risk factors (repetition,

force, and posture) and their relationship to CTS. There is evidence of a positive association between highly repetitive jobs alone or in combination with other factors. In addition, forceful work was found to be positively associated with CTS. Strong evidence was found of a positive association between exposure to a combination of risk factors and CTS. NIOSH also reviewed studies that examined the relationship between those risk factors and hand/wrist tendinitis. Evidence of an association between any single ergonomic risk factor and hand/wrist tendinitis was found. There is strong evidence that tasks requiring a combination of risk factors (e.g., highly repetitive, forceful exertions and awkward postures) increase risk of hand/wrist tendinitis.

It has been agreed among investigators that the incidence of CTS is related to prolonged forces placed on the median nerve inside the carpal tunnel (Armstrong, 1979; Rempel et al., 1992). The tendons and median nerve wrap around the carpal bones and flexor retinaculum much like a rope wraps around a fixed pulley (Armstrong and Chaffin, 1979). The total force on the tendons goes up as the deviation of the wrist increases which results in greater compression force on the median nerve (Figure 2.1). The compression force interferes with nourishment of the tendon, synovial membrane and nerve tissue, thereby contributing to CTS and tenosynovitis. This model established the relationship between intra-wrist forces and wrist position, which suggests that exertions of the hand with a greatly deviated wrist would result in greater total force on the tendons than a less deviated wrist.

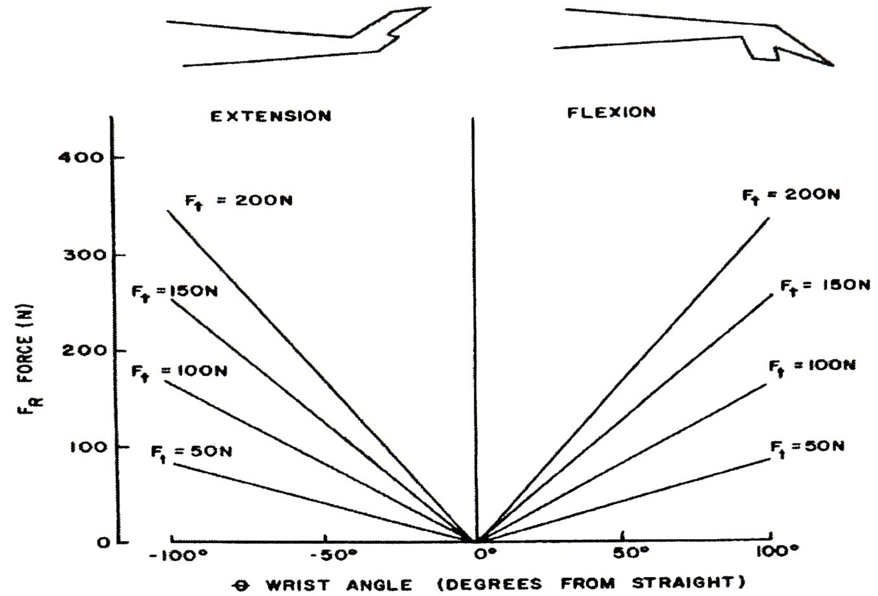


**Figure 2.1** Resultant reaction force (Fr), as modeled by Armstrong and Chaffin (1979) that is exerted against the flexor tendons as a function of wrist angle and tendon force (Ft). Adapted from Chaffin et al. (1999).

In addition to the static effects of wrist postures, dynamic components such as acceleration and velocity have been shown to affect the intra-wrist forces. Considering that repetition is essentially cyclic angular velocity and acceleration, Schoenmarklin and Marras (1990) developed a dynamic model of the wrist joint based on the above static wrist model proposed by Armstrong (1979). The dynamic model analyzes the effects of peak angular acceleration on the resultant reaction force from the wrist bones and ligaments. The resultant force on the tendons and median nerve from the carpal bones and flexor retinaculum increases when the wrist is accelerated in the flexion/extension plane. It should be noted that this increase in reaction force is due solely to the acceleration of the wrist without any external grasp or pinch force, which is typically the

case for interpreting. This analysis could also be applied in the radial/ulnar deviation plane.

Marras and Schoenmarklin (1993) performed a quantitative study in which workers' three dimensional wrist motions were monitored as they performed normal work activities in an industrial setting. The wrist motion parameters that were monitored for each subject were position, angular velocity, and angular acceleration. Descriptive statistical analysis of these measures indicated that generally the mean values for each variable were larger in magnitude for the group of high-risk subjects than that of their low-risk counterparts. However, only the velocity and acceleration parameters resulted in statistically significant differences between low- and high-risk groups. Jobs with low and high incidence of RMIs were determined from US Occupational Safety and Health Administration (OSHA) 200 logs, which are required by the US government to record occupational injuries and illnesses. This study demonstrated the importance of dynamic components in assessing RMI risk. The mean acceleration values of high and low RMI risk groups serve as preliminary benchmarks for establishing injuries and safe levels of wrist motion in industry. Similar studies have since been performed on meat processing workers (Marklin & Monroe, 1998), grocery store cashiers (Marras & Marklin, 1995), and typists (Serina et al., 1999). However, such biomechanical study on sign language interpreting was not found in the literature. One of the major voids in the study of RMIs in sign language interpreters is the quantification of the kinematics of wrist motions and how these motions are related to the risk of RMIs. The same methods used to evaluate dynamic wrist motion in industrial settings could be used for evaluating sign language interpreting.

Sign language interpreting requires highly repetitive wrist activities. It has been estimated that the frequency of motion during interpreting approaches 13,500 motions during a 50-minute session or 270 motions per minute (Wisowaty, 1996). The mean number of fundamental wrist motions of industrial workers measured by Barnes (1981) was 25,435 (sd = 12,921) per eight-hour shift or 53 per minute. By comparison, the frequency of motion of interpreters is approximately five times that of industrial workers. Silverstein et al. (1986, 1987) established repetition as a risk factor for CTS and RMI overall and found that the risk of CTS and RMI in high repetition jobs was 1.9 and 3.6 times greater than that in low repetition jobs. High repetition jobs was defined as tasks having cycle time less than 30 seconds or tasks in which at least 50% of the work cycle is spent performing the same fundamental movements. Sign language interpreting, which meets all these criteria, can easily be classified as a highly repetitive job.

Sign language interpreting is not only highly repetitive, but also requires internally generated high force and awkward postures of the fingers, hands and wrists. All of these factors lead to high incidence of RMIs based on the conclusions of the aforementioned research. In an investigation conducted among educational interpreters from RIT/NTID, DeCaro et al. (1992) observed a high occurrence of RMIs among sign language interpreters working in a classroom environment and found that certain work behaviors were attributed to those interpreters who were experiencing RMI symptoms. The study found that interpreters working with pain exhibited fewer rest breaks, greater numbers of wrist and hand deviations, greater number of excursions from a predefined work space (work envelope excursions), and a more rapid pace of finger and hand movements than those who worked without pain.

## 2.3 Psychosocial Risk Factors

Psychosocial stressors at work include factors such as high-perceived workplace stress, low-perceived social support, low-perceived job control, and time pressure (Bongers et al., 2002; Huang et al., 2003). Sign language interpreting is not only physically demanding, but also psychosocially stressful with high cognitive demands. Stress is a complex psychological state deriving from the person's cognition appraisal of their adaptation to the demand of the (work) environment (Cox et al. 1983). It has been suggested (Cox, 1985) that the process of (primary) appraisal takes into account at least four factors: the demand on the person, their individual characteristics, skills and general ability to meet those demands, and the constraints that they are under when coping and the support received from others in coping. Recent research suggests that work style, or how a person responds to work demands, may be related to upper extremity symptoms (Haufler et al., 2000). Bongers et al. (1993) reviewed the relevant literature and found that stress symptoms were often associated with musculoskeletal disease, and indicated that stress symptoms contribute to the development of this disease. After reviewing 26 studies, Bongers et al. (2002) found an association between work-related psychosocial factors and adverse upper extremity symptoms.

Clearly, numerous occupational demands affect the overall interpreting task that may contribute to interpreter stress and burnout. Sign language interpreting is a high-pressure job with a lack of control over the working conditions, lack of peer cohesion, and high volume of work. The stress of interpreting includes the demands directly or indirectly related to the material being interpreted, such as speaker's communication speed, clarity, voice volume, use of technical vocabulary, interpreter's familiarity with

the content, as well as his/her receptive and expressive skills (Dean, 2001). In addition, as is the case with many occupations, psychosocial factors may affect the demands of the interpreting task. These include factors related to the settings where interpreting assignments take place, the presence of other parties, and physical/psychological factors pertaining to the interpreter alone.

The relationship between psychological stress and resulting biomechanical responses has only recently been addressed within the context of industrial settings. An experiment was performed by Davis et al. (2002) to explore how the interaction of specific psychological factors (types of mental processing and work pacing) and individual factors (personality and gender) might influence the biomechanical response and subsequent spine loading above and beyond that resulting from physical work design. It was found that mental stress acted as a catalyst for the biomechanical responses, resulting in the overreacting of the musculoskeletal system, which leads to increased spine loading. Different personalities also lead to differences in spine loading. These results may help to explain the contributing factors of musculoskeletal disorders other than physical demand.

Compared to the research related to biomechanical causes of RMI, investigation of the relationship between psychosocial factors and RMI is fairly new. Some researchers have noticed the contributing role psychosocial factors may play in the development of RMIs in sign language interpreters. Recommendations are made that address psychosocial interventions to prevent the incidence of RMI, such as self-exploration or self-assessment, constructive thinking, reflection, venting, prayer (NTID, no date). Others (Sanderson, 1987) recommended guided imagery, and meditation.

However, these interventions are mainly focused on self-adjustment, rather than the relationship between interpreters and the demands of their work. Feuerstein (1992) suggested the possibility that the high-risk work style of interpreting many reflect a heightened behavioral reactivity to physical and psychosocial stressors at work which needs further investigation. Dean and Pollard (2001) demonstrated that the combination of high demand and low decision control environment puts interpreters at high risk for stress-related illness, injury, and burnout. However, the major void of such studies is that the impact of psychosocial factors was not studies in relation with physical demands and no quantitative analysis has been provided to assess the impact of psychosocial factors on biomechanical responses during interpreting.

## 2.4 Individual Risk Factors

Individual risk factors of RMIs include gender, age, negative stress reactions, unsatisfactory leisure time, and additional domestic workload (Bergqvist et al., 1995; Fredriksson et al., 1999). The results of a survey conducted by Stedt (1989) indicate that besides the ergonomic risk factors (repetition, force, and deviated posture), age, gender, dominant/nondominant hand, and amount of finger spelling also may play a part in RMI development among interpreters. Risk is higher for interpreters who are female, older than 40, and/or who have smaller wrists or have had a previous wrist fracture. Additionally, Scheuerle (2000) concluded from a national survey that pain or discomfort experienced during interpreting is related to training, work history, and work schedule. This study also showed that pain and discomfort commonly occur not only in the upper extremity region, but also in the shoulders and back.

There are a number of individual factors known to influence the development of RMIs. It has been reported that CTS is from two to ten times more prevalent in females than in males (Phillips, 1967; Phalen, 1972; Birbeck & Beer, 1975). Similarly, Armstrong et al. (1987) reported a higher prevalence of tendinitis among females. Tanaka et al (2001) reviewed the 1988 National Health Interview Survey and found that bending/twisting of the hands/wrists at work and female gender were significantly associated with reporting of tendinitis, synovitis and tenosynovitis. In Armstrong's biomechanical model (Armstrong, 1979), it is suggested that the force applied on the tendons in carpal tunnel is negatively correlated with wrist size, which at least partially explains why CTS is more common for females than males since females normally have smaller wrists. This gender difference is particularly noteworthy for interpreters because of the predominance of females in this occupation. In studies of interpreters (Stedt, 1990; DeCaro, 1992; Feuerstein, 1992; Scheuerle, 2000), the percentage of females ranges from 75% to 90% of the workforce.

# CHAPTER 3

# METHODS AND PROCEDURES

## 3.1 Experimental Objectives

The main objective of this study was to analyze the impact of pace and psychosocial stress on the biomechanical responses of sign language interpreters in a quantitative manner. This work also sought to establish benchmark values of biomechanical exposures of sign language interpreting, which can be used to compare to previously established thresholds of high risk tasks of other occupations.

## 3.2 Experimental Design

A laboratory experiment was designed and conducted to attain the stated objectives. A $2^2$ factorial design of the experiment was used with stress and pace as the two independent variables. Pace of the speaker was chosen as a within-subject variable and psychosocial stress as a between-subject variable. A high and a low level were designed for each independent variable. Each subject was asked to perform a thirty-minute interpretation task which contained a fast paced (high) and a slow paced (low) segment of a thirty-minute, videotaped lecture. Subjects were randomly divided into a stressed (high) or non-stressed (low) group. The design of the experiment is illustrated in Table 3.1. Biomechanical responses included wrist kinematic data measured by electrogoniometers and trapezius muscle activity measured by EMG sensors. Additionally, heart rate, subjective rating of discomfort and psychological state of stress and arousal were collected during and after the experiment. The dependent and

independent variables are described further in the subsequent sections. Considering that fatigue might have a potential effect over the half-hour interpretation task on the dependent variables, half of the subjects in each group interpreted the slow segment before the fast segment and the order was reversed for the other half in order to counterbalance that effect.

**Table 3.1** Experimental Design
(+ and – denote high and low level of the independent variables respectively)

| Factor | | Treatment | # of Replications |
|---|---|---|---|
| Pace | Stress | | |
| low | low | – – | 6 |
| high | low | + – | 6 |
| low | high | – + | 6 |
| high | high | + + | 6 |

## 3.3 Independent Variables

### 3.3.1 Pace

The first independent variable was pace. A thirty-minute presentation of a professor talking about industrial engineering and the related program at RIT was recorded before the experiment. The presentation was a brief introduction of different areas associated with industrial engineering and did not include a significant amount of jargon or technical terms so that interpreters with little or no background in engineering would also understand and be able to interpret. The original presentation was recorded with the professor's normal speaking pace. There was no major break in the presentation. The original tape was then digitized and two new versions were created using video editing software. The software was used to increase and decrease the speed of both the

video and audio content of the presentation. Through trial and error, a fast segment at the speed of 115% and a slow segment at the speed of 85% of the original pace were chosen for the experiment based on the criteria that there was a discernable change of speed without compromising intelligibility. Altering the speed resulted in a change of voice pitch with the fast segment having a higher pitch and the slow segment having a lower pitch. However, the changes of the voice pitch were still perceived to be within the normal spectrum of human voice.

Both versions of the interpreted videotape began with five minutes of the speaker's regular pace so that subjects could get used to interpreting with the sensors (described later) on his or her arms. For the first version, an eleven-minute slow segment (85% of normal pace) was followed by an eleven-minute fast segment (115% of normal pace). A one-minute and a two-minute transition period were added before and after the slow segment so that the change of speed would not seem too abrupt. The second version of the interpreted videotape, used for counterbalancing, was made using the same technique except that the slow and the fast segments were reversed (Figure 3.1).

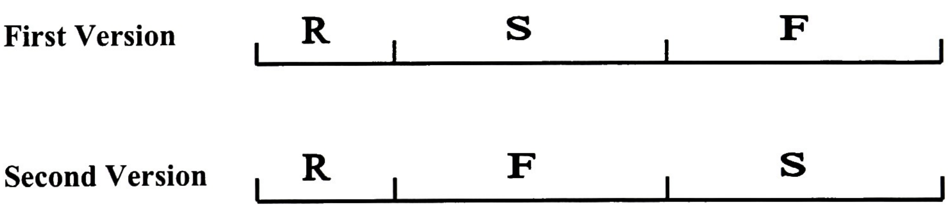


**Figure 3.1** Two versions of the presentation used in the experiment
R – Regular pace S – Slow pace F – Fast pace

### 3.3.2 Stress and Arousal

The second independent variable was psychosocial stress. Subjects were randomly assigned to one of two groups, "stressed" and "non-stressed". Two interpreting researchers at NITD provided the initial input on how to make interpreters feel stressed. Based on their knowledge and experience, it was suggested that significant stress would be induced by telling the interpreters that the video recording of their interpretation would be shown at the Registry of Interpreters for the Deaf (RID) national conference. RID is a national organization of professionals who provide sign language interpreting/transliterating services for deaf and hard of hearing persons. It was also suggested that the presence of personnel from the Department of Research at NTID may provide an additional stressor. The Department of Research at NTID conducts applied research on American Sign Language that improves teaching and learning processes. During the experiment, subjects in the stressed group were told that part of the video recording would be shown at both RID and Human Factors and Ergonomics Society national conferences and that two people from NTID Department of Research would be present during the experiment. The non-stressed group was not provided with the RID pretext and no other person was present during their experiment except the two investigators. Instead, the non-stressed group was informed that this study was conducted only to investigate the biomechanical characteristics of interpreting and the video tapes would be used for further evaluation.

The majority of studies examining the occurrence of potentially stressful events use some version of a checklist where the stress score is simply the total number of items checked as having occurred (Cohen, S. & Wills, 1985). Similarly, the stress and arousal

levels in this study were measured through the use of the Stress-Arousal Checklist (SACL) developed by Mackay et al. (1978). The thirty-item SACL consists of adjectives commonly used to describe one's psychological experience to stress and arousal. The SACL was originally tested with a sample of undergraduate students (Mackay et al., 1978). It has since been utilized in a variety of occupational populations including pilots (Cooper & Sloan, 1987), nurses (Hirosawa, Hatta & Yoneda, 1998), and computer entry workers (Sharit, Czaja & Nair, 1998). However, it is not known to have been used on sign language interpreters.

The factors of SACL are bipolar, with some adjectives loading positively and some negatively. The 30 items consist of 18 items loading on the stress factor and 12 items loading on the arousal factor. For the stress subscale, the positive adjectives were items 1−10, and the negative items were 11−18 (Appendix D). The adjective for the arousal subscale were: positive = 19−25; and negative = 26−30. Thayer's original asymmetric response scale was used: 'definitely feel' (++), 'feel slightly' (+), 'do not understand or uncertain' (?), and 'definitely do not feel' (−). Each subject utilizing the SACL rated each adjective in terms of the intensity of his/her feelings. Positive adjectives were scored from 1(−) to 4(++), while negative adjectives were scored from 1(++) to 4(−).

There are no reports on the reliability of the SACL (Fischer & Corcoran, 1994). However, the SACL has been subjected to factor analyses by several researchers to investigate its internal consistency (Fischer & Donatelli, 1987; Mackay et al. 1978). Factor analysis has identified a two-factor structure, subsequently labeled stress and arousal. The SACL has demonstrated group validity showing, for example, that scores

increase as a consequence of a stressed situation among different groups of people (Burrows, Cox & Simpson, 1977; King et al., 1983). In addition, the SACL has also been shown to have concurrent validity, with scores correlating with various psychological scores (Burrows et al., 1977).

## 3.4 Dependent Variables

### 3.4.1 Kinetic Variables

Two biaxial electrogoniometers (SG 65, Biometrics Ltd, Gwent, UK) were used to measure bilateral wrist flexion/extension (FE) and radial/ulnar (RU) deviation (Figure 3.2). The measuring range of angles is ±150°. Goniometers were attached to the wrists while the arm rested at the subject's side, elbows flexed 90°, wrist straight and hand pronated to minimize crosstalk (Bucholz and Wellman, 1997). The distal endblock of the goniometer was affixed to the dorsal surface over the third metacarpal with the center axis of the hand and endblock coincident. While fully flexing the wrist, the proximal endblock was affixed to the forearm so that when viewed from the dorsal plane the axes of the forearm and endblock were coincident (Figure 3.3). Double-sided adhesive tape was used between the endblocks and skin, and single sided adhesive tape was placed over the top of the endblocks to secure the sensors during long period of testing. Cables were secured properly to ensure minimum interference with the subject's performance. Calibration of the goniometers occurred before data collection. Zero angles were set to present neutral position, and sign convention was different depending on which side of the body the sensor was attached. Positive angles (+) denoted wrist extension and radial

deviation, while negative angles (–) denoted wrist flexion and ulnar deviation for the right wrist. Signs were opposite for the left wrist (Figure 3.4).

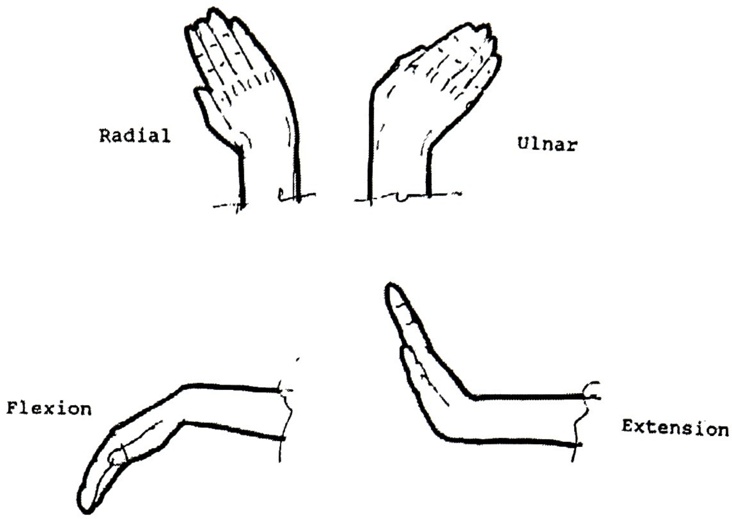


**Figure 3.2** Two planes of wrist movement

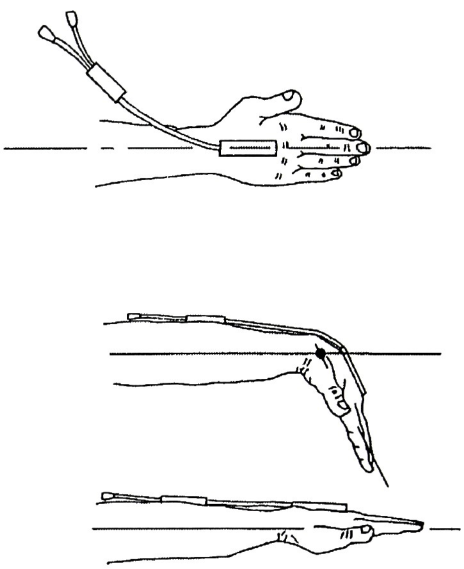

**Figure 3.3** Goniometer attachment

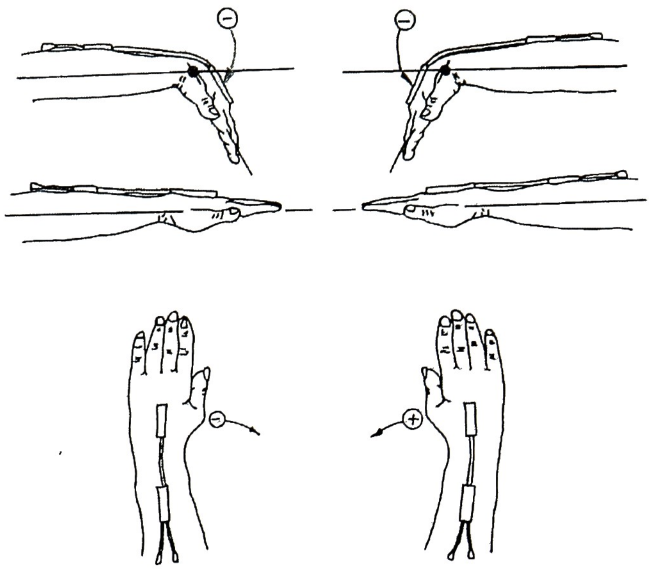

**Figure 3.4** Sign conventions for wrist position data

Goniometer data were collected and analyzed by DataLINK data acquisition system and management software (Biometrics Ltd, Gwent, UK). Data were collected at 50 Hz continuously for the thirty-minute testing period. All the data were displayed and saved in a laptop computer which was connected with this system. Joint angle data from each channel were filtered with a low-pass $6^{th}$ Butterworth filter using MATLAB. A five-hertz (5 Hz) cut-off frequency was used based on the frequency analysis and previous studies (Hansson et al., 1996; Serina et al., 1999). This filter attenuated the higher frequency noise while preserving the integrity of the wrist motion. After filtering, wrist positions were derived by sampling of angular data, and the angular velocities and accelerations were derived by differentiation and double- differentiation using 3-point first order central difference (Hansson et al., 1996).

$$v_i = (p_{i+1} - p_{i-1}) / 2 \times f_s \tag{3.1}$$

$$a_i = (v_{i+1} - v_{i-1}) / 2 \times f_s \tag{3.2}$$

Where $p_i$ = wrist position at sample *i*; $v_i$ = angular velocity at sample *i;* $a_i$ = angular acceleration at sample *i;* and $f_s$ = sampling rate. The absolute value of velocity and acceleration were derived and used for all further calculations.

The kinematic wrist motion measures for analysis consisted of the following statistics in the FE and RU planes:

- Mean, minimum, maximum and range* of wrist angle
- Mean, minimum, maximum and range* of wrist velocity
- Mean, minimum, maximum and range* of wrist acceleration

  * range = maximum – minimum

The minimum and maximum wrist positions are extreme wrist angles, and minimum and maximum wrist velocity and accelerations are respective peak values of velocity and acceleration with maximum and minimum indicating different directions of change.

### 3.4.2 Other Electrogoniometric Measurements

The repetitions, number of wrist motion pause and high risk wrist motion were calculated using the DataLINK management software. Two different methods were used to evaluate wrist motion repetition. The number of repetitions indicates the number of repeated cycles within a trace of wrist position data. A repetition was counted when a trace changed direction twice in succession. An example of a repetition is illustrated in Figure 3.5. In order to overcome the effects of noise, the change necessary to be taken as a change of direction can be set as the repetition threshold value. The trace must reverse direction for more than this value to be seen as a change of direction. In this study, the

threshold value was set at 4° based on the accuracy of the goniometer (Biometrics, 2002). As illustrated in Figure 3.5, the "bump" on the marked repetition trace was not considered as a change of direction because the range of the change was smaller than 4°.

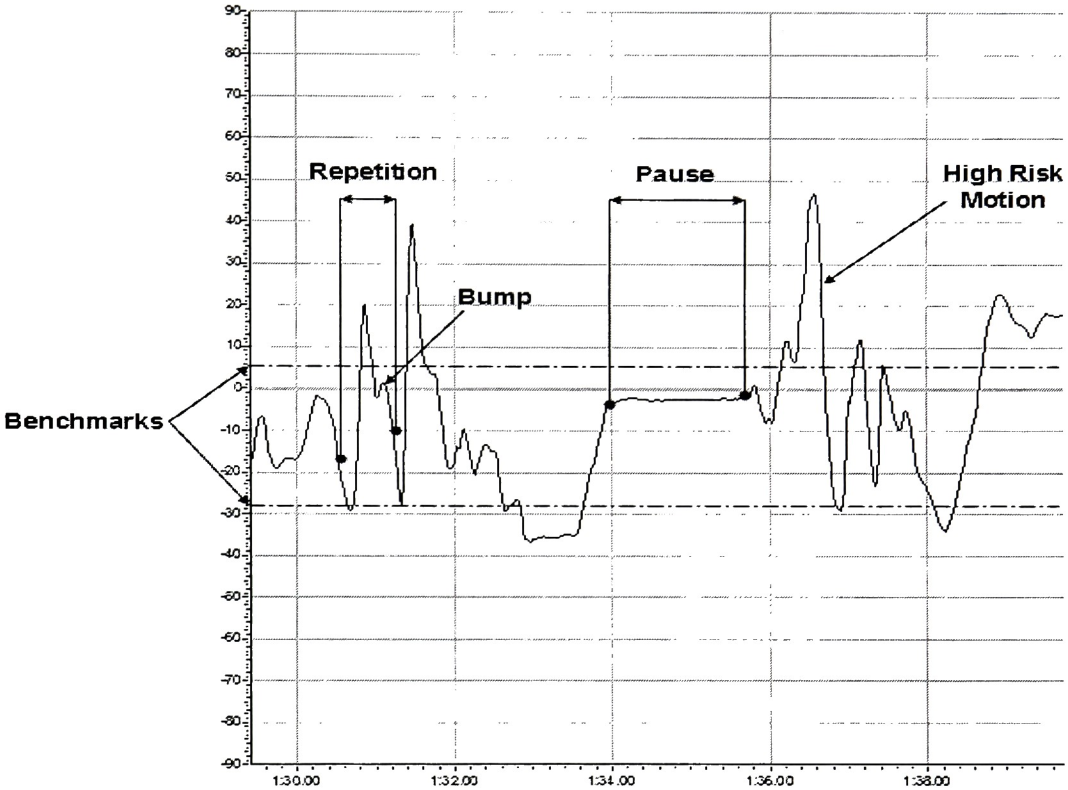


**Figure 3.5** Illustration of wrist repetition, pause and high risk values

Mean power frequency (MPF) was another measure of repetitiveness which has proven useful for complex and/or irregular work for which it is difficult or impossible to define repetitiveness based on observations (Hansson et al., 1996). Since MPF is the inverse of the mean cycle time, it corresponds to the established interpretation of repetitiveness as the inverse of the cycle time. It was calculated in order to compare the repetitiveness of sign language interpreting with other jobs that have been studied. Power

spectra of unfiltered position data were obtained using MATLAB to calculate MPF (Figure 3.6). MPF was calculated for a bandwidth of 0–5 Hz, as 99.5% of the total power was contained in this band for both wrist flexion and deviation (Hansson et al, 1996). The formula for calculating MPF is:

$$MPF = \sum(f_i \times p_i) / \sum p_i \qquad (3.3)$$

Where $f_i$ = frequency at sample $i$ and $p_i$ = power at sample $i$.

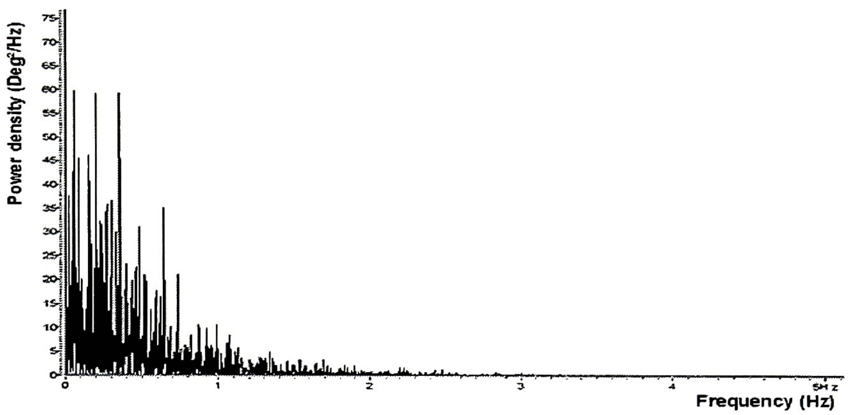


**Figure 3.6** A typical power spectra of wrist position during 11 minutes of interpreting task

Wrist motion was identified to be high risk when the trace moves over or under the marked upper and lower thresholds. Wrist motion data higher or lower than the marked benchmark values were counted as illustrated in Figure 3.5. The upper and lower limits were set as the maximum and minimum benchmark values of high risk industrial jobs as presented in Table 3.2 (Schoenmarklin and Marras, 1991). Similar to repetition, it is possible to set the minimum time allowed for a high risk motion – any movement of the trace over/under for less than the minimum time (0.5 sec) was ignored. The amount of time spent over and under the benchmark values was expressed by a percentage value

of the total time of the trace. In addition, the number of pauses of the wrists during interpreting was calculated. A pause was counted when the angular velocity of the wrist was below 1.0°/s for a continuous period of at least 0.5 second (Hansson et al, 1996), using the same technique for calculating high risk wrist motion.

**Table 3.2** Benchmark wrist motion values of high risk industrial job (Schoenmarklin and Marras, 1991)

| Plane | P(deg) | | V(deg/sec) | | A(deg/sec²) | |
|---|---|---|---|---|---|---|
| | Min | Max | Min | Max | Min | Max |
| RU | -18.96 | 4.69 | -115.1 | 115.7 | -2776 | 3077 |
| FE | -29.08 | 6.56 | -183.7 | 174.2 | -4927 | 4471 |

### 3.4.3 Electromyography (EMG) Measurement

Surface EMG of the upper trapezius muscle at the right shoulder was obtained using bipolar reusable electrodes (SX230, Biometrics Ltd, Gwent, UK). The electrodes have circular active areas with a diameter of 10 mm and an inter-electrode distance of 20 mm. Because of the large input impedance (>$10^{15}$ ohms), little or no skin preparation is needed, though skin was cleaned with alcohol before the electrodes were applied. Electrodes were placed above the descending part of the right trapezius muscle lateral of the middle of the line between C7 and the acromion in the direction of the muscle fibers, according to international guidelines (Mathiassen et al., 1995; Hermens et al., 2000). The electrode and its cable were affixed to the skin with double- and single-sided adhesive tape. A reference electrode was placed around the left ankle in contact with the bony prominence of the ankle. EMG data were recorded at 1000 Hz during the entire thirty-minute testing period using the same acquisition system as for electrogoniometric

measurements. EMG signals were hardware amplified (1000 gain), band-pass filtered (20 Hz --- 450 Hz) and AD converted. The root-mean-square (RMS) of the raw data was then calculated with a 100 ms time constant using the system software.

To facilitate comparison between individuals, EMG was normalized using a sub-maximal reference voluntary contraction (RVC) test. The RVC was obtained while the subjects were in a seated position, holding the right arm straight and horizontal in 90° abduction with the palm pointing downward. A 2.5 pounds weight was hung form the middle of the arm proximal to the elbow for 15 seconds. This reference test was repeated four times with one minute of rest in between each and was performed before the experiment. The average RVC value of the middle 10 seconds of the four trials was calculated to be the normalization reference (Mathiassen et al., 1995).

The $10^{th}$, $50^{th}$, and $90^{th}$ percentiles of the EMG amplitude distribution, mean power frequency (MPF) of the power spectrum and muscular rest were calculated which have been frequently used for post hoc analysis (Hansson, 2000; Gerard, 2002). Muscular rest was defined as the time when RMS values were below 10% of RVC for at least 1/8 second as a percentage of the total duration of the recording (Hansson, 2000). A decrease of MPF has been used for determining onset of muscle fatigue (Kumar, 1996). MPF was calculated using the same method as described in section 3.4.2.

### 3.4.4 Subjective Rating of Perceived Discomfort

A discomfort survey was prepared to monitor subjects' perception of discomfort. Rating of perceived discomfort (RPD) in upper extremities was measured using a modified 10-point scale developed by Borg (1982). The score values range from 0 for

"nothing at all" to 10 for "very, very strong." This scale can be used for whole body measurement or for specific body segments. Before the work, the subjects were instructed on how to rate the degree of discomfort. Subjects were asked to verbally rate their perceived discomfort as it related to four different areas (hands/fingers, wrists, arms/elbows and shoulders) on both of their upper extremities immediately after slow and fast segment of the interpretation task. A copy of the Borg scale is included in Appendix E.

Borg's Scale has been identified by many researchers as a useful tool to evaluate the perceived exertion of workload in manual work (Katharyn et al., 1994; Resnick, 1995) and patient handling tasks (Winkelmolen et al., 1994; Skotte et al., 2002). So far, it has not been used on sign language interpreters.

### 3.4.5 Heart Rate

Hear rate (HR) was measured with the Polar Vantage NV heart-rate monitor (Polar Electro Finland). HR values were recorded manually into an Excel worksheet every 15 seconds during the experiment. Mean HR was calculated afterwards. HR and Heart rate variability have shown a correlated relationship with psychological arousal and stress in previous studies (Thayer, 1970; Cox et al., 1983; King et al., 1983). HR has been reported to rise with other physiological indices of stress while HRV has typically been used to indicate changes of arousal. It has been implied that arousal and stress levels may change in unison, and therefore to monitor one allows the experimenter to infer changes in the other. Heart rate variability was not able to be obtained because the heart rate data were not continuous.

**3.5 Subjects**

Subjects included 12 full-time (at least 20 working hours per week) sign language interpreters from NTID with at least 5 years professional experience. Subjects were randomly assigned into stressed or non-stressed group with six people in each. The female/male ratios for the stressed and non-stressed group were 4/2 and 5/1 respectively. The average age, years of signing and interpreting were 39.2 (SD=12.1), 21.7 (SD=11.0) and 14.7 (SD=7.2) years, respectively. The average working hours per week was 25.7 (SD=3.9). The demographic data of two stress groups were matched. All subjects were right-handed for interpreting. Subjects were screened using the Nordic Questionnaire (Kuotinka et al., 1987) for current upper extremity musculoskeletal disorders and potential confounding disorders (Appendix B). Although several of the subjects had troubles (ache, pain, discomfort) during the last twelve months, all of them were healthy and free of ache, pain, and discomfort at the time of the experiment. Anyone who had troubles at the time of the experiment would not be included. Number of subjects reported troubles in different regions of upper extremity during the last twelve months is presented in Table 3.3.

**Table 3.3** Number of subjects reported ache, pain or discomfort during the last 12 months

| | Hands/Fingers | Wrists | Arms/Elbows | Shoulders |
|---|---|---|---|---|
| Right | 1 | 2 | 4 | 5 |
| Left | 1 | 0 | 0 | 4 |

## 3.6 Experimental Protocol

Subjects who met the prerequisites in section 3.5 were first informed of the purpose, methods and experimental procedures used in the study. An informed consent, which was approved by RIT and NTID Institutional Review Board (IRB) Committee, was read and signed by each subject (Appendix A). Demographic information (i.e., age, gender, sign/interpreting experience, working hours, etc.) was collected afterwards. The demographic questionnaire was included in the Appendix C. The subject was then asked to put on the heart rate monitor and to be seated. EMG surface electrodes and electrogoniometers were then fastened to the subject's right trapezius and both wrists, respectively. All the cables were arranged in a way that subjects could move their wrists freely with minimum interference. Each subject was then asked to fill out the SACL and RPD forms. Following calibration of the equipment, RVC EMG data were collected.

A curtain hanging from the ceiling was put between the subject and the equipment/investigator to minimize potential psychosocial influence on the subject. All the subjects were videotaped with a video camera about three meters in front of them. For the stressed group, two professional interpreters were seated behind the camera; for the non-stressed group, no one was observing behind the camera. The videotaped presentation was projected to the wall on the front-right side of the subjects for the convenience of them to see the speaker while interpreting. Pace version (normal→slow→fast; normal→fast→slow) for each subject was randomly selected.

When the subject was ready, data collection began and the subject started to interpret. After the warm-up and the first pace segment (during the transition period between slow and fast segment), the video was briefly paused and the subject was asked

to rate their perceived discomfort verbally. This process took about 10 to 15 seconds and then the data collection was resumed until the end of the presentation. Data collected during the transition period was removed for analysis. Immediately after the interpretation task, RPD and SACL information was collected again for each subject. Then the sensors were taken off the subject. Total testing session time was about one hour per subject. Each subject was paid $30 for his/her time and effort.

## 3.7 Data Analysis

Descriptive statistics were calculated for each dependent variable where appropriate. Two-way repeated measures analysis of variance (ANOVA) was used to determine the effect of pace, stress and their interaction on all the dependent variables. Paired t-test was used to compare demographic variables of the stressed and non-stressed group, and to compare variables of left and right hand. All variables were summarized using descriptive statistics and important findings were presented graphically. Pearson correlation test was used to investigate the relationship between demographic data and stress / arousal levels. Critical values for Pearson correlation coefficient was used to determine significance and was calculated based on the sample size. All variables had sample size of 12, thus the critical value was 0.5324 at significant level of 0.05 (Fisher, 1990). Significance was found if correlations exceeded critical values. P-values $< 0.05$ were considered significant for all dependent variables. Abbreviations of the variables used in the subsequent data analysis are summarized in Table 3.4.

**Table 3.4** Key to coding of variable names

| | |
|---|---|
| RU | radial/ulnar |
| FE | flexion/extension |
| R | right hand |
| L | left hand |
| P | wrist position angle |
| V | wrist velocity |
| A | wrist acceleration |
| Min | minimum position/velocity/acceleration |
| Max | maximum position/velocity/acceleration |
| Range | range of wrist motion |
| MPF | mean power frequency of power spectrum |
| SF | experimental condition of stressed-fast |
| SS | experimental condition of stressed-slow |
| NF | experimental condition of non-stressed-fast |
| NS | experimental condition of non-stressed-slow |
| SD | standard deviation |
| e.g. | |
| RU-L-V | Velocity of the left hand in radial/ulnar plane |

# CHAPTER 4

# RESULTS

## 4.1 SACL Score and Group Adjustment

Scores of stress and arousal of the two groups were obtained by subtracting the baseline score from the after-experiment score and the results are presented in Table 4.1. T-tests indicated that differences between stressed and non-stressed group were not significant for either stress ($p = 0.843$) or arousal ($p = 0.961$). This is further illustrated by Figures 4.1 and 4.2. Two subjects in the non-stressed group had stress scores that were higher than the average score of their stressed counterparts. In addition, half of the subjects in the stressed group showed lower scores than the average score of the non-stressed group. Based on these results, it was apparent that the experimental conditions did not produce the anticipated stratification in stress levels. Using the SACL scores, "stressed" and "non-stressed" groups were adjusted by switching the two subjects who had the highest scores in the original non-stressed group with the two in the original stressed group who had the lowest scores (circled in Figure 4.1). The new adjusted stressed group was consisted of the six subjects with the highest stress scores, and the lowest six were grouped as the non-stressed.

**Table 4.1** Average SACL (SD) scores before adjusting

| Group | n | Stress | Arousal |
|---|---|---|---|
| Stressed | 6 | 6.83 (6.05) | 4.50 (6.09) |
| Non-stressed | 6 | 5.50 (14.6) | 4.33 (5.47) |

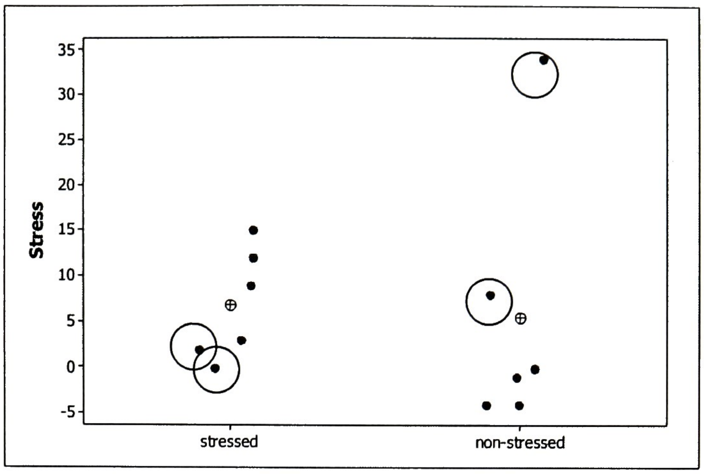


**Figure 4.1** Stress scores before adjusting (dots in the circle were switched ⊕ = mean value)

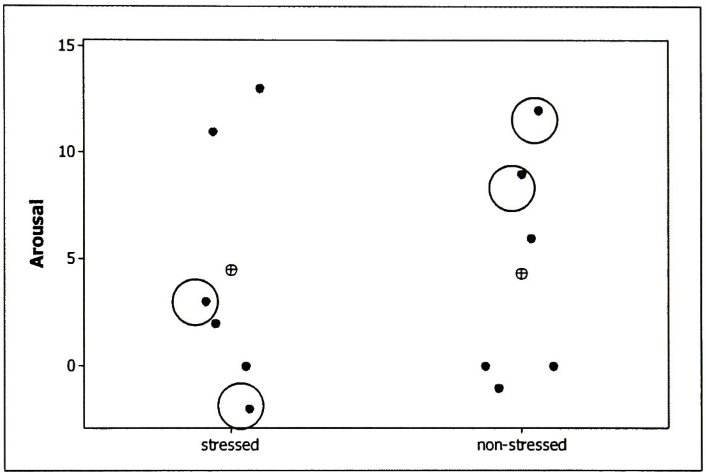


**Figure 4.2** Arousal scores before adjusting (dots in the circle were switched ⊕ = mean value)

Table 4.2 shows the SACL scores after adjusting. T-tests indicated that there were significant differences of both stress ($p = 0.023$) and arousal ($p = 0.031$) levels between the two groups after adjusting, with the stressed group having higher scores. Negative value in the table indicates that the average stress score after the experiment was lower than the baseline value. A distinct mean value difference of the two clusters of dots can be observed in the scatter plots of stress and arousal (Figures 4.3 and 4.4). All

the subsequent calculations and results have been based on these adjusted groups unless otherwise stated.

**Table 4.2** Average SACL (SD) scores after adjusting (* $p < 0.05$)

| Group | n | Stress | Arousal |
|---|---|---|---|
| Stressed | 6 | 13.50 (10.8)* | 7.83 (5.49)* |
| Non-stressed | 6 | -1.17 (2.40)* | 1.00 (2.97)* |

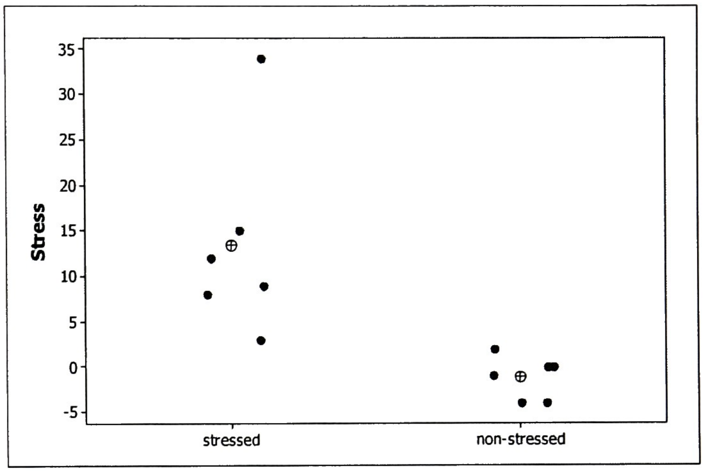


**Figure 4.3** Stress scores after adjusting (⊕ = mean value)

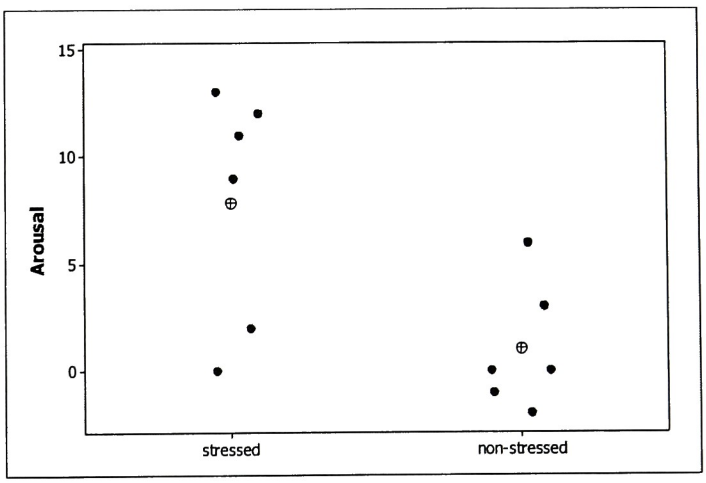


**Figure 4.4** Arousal scores after adjusting (⊕ = mean value)

## 4.2 Demographic Data

Descriptive statistics for demographic data were calculated for the adjusted groups. These statistics are presented in Table 4.3. The female/male ratio for the stressed and non-stressed group were 5/1 and 4/2, respectively. All subjects were right hand dominant. Paired t-tests were performed on age, years of signing, years of interpreting, and working hours per week, and no significant difference between the two groups was found. However, the average years of signing and interpreting of the stressed group were lower than those of the non-stressed group. Pearson correlation test was used to further explore the relationships of age, years of signing/interpreting, stress and arousal levels. Stress level was negatively correlated with both signing (p=0.011) and interpreting (p=0.021) experience. Predictably, positive correlation was also found between age and years of interpreting (p=0.009).

**Table 4.3** Demographic data

| | Stressed | | | Non-stressed | | |
|---|---|---|---|---|---|---|
| | Mean | SD | Range | Mean | SD | Range |
| Age (yrs) | 40.8 | 15.3 | 37.0 | 41.7 | 5.7 | 14.0 |
| Years of Signing | 18.3 | 8.8 | 26.0 | 28.0 | 9.0 | 24.5 |
| Years of Interpreting | 13.0 | 5.5 | 16.0 | 19.3 | 7.0 | 20.5 |
| Working Hours/Week | 25.1 | 4.2 | 10.0 | 26.3 | 4.1 | 10.0 |

**Table 4.4** Pearson linear correlation of demographic data (* P < 0.05)

| Variable | Correlation | P-value |
|---|---|---|
| Age – Signing | 0.302 | 0.316 |
| Age – Interpreting | 0.694 | 0.009* |
| Age – Stress | -0.425 | 0.148 |
| Age – Arousal | 0.469 | 0.106 |
| Stress – Signing | -0.676 | 0.011* |
| Stress – Interpreting | -0.630 | 0.021* |
| Arousal – Signing | -0.249 | 0.411 |
| Arousal – Interpreting | 0.061 | 0.843 |

## 4.3 Electrogoniometric Data

### 4.3.1 Wrist Motion

Wrist motion variables described in the previous chapter were calculated and descriptive statistic findings are presented in the following sections. Mean value of wrist position, velocity and acceleration of the groups before and after adjusting were compared (Tables 4.5 and 4.6). Absolute values were used to calculate mean velocity and acceleration. For the groups before adjusting, there was no significant effect of pace, stress, or pace×stress interaction on the mean values of wrist position. Significant differences of mean velocity and acceleration in the RU-R, FE-R and FE-L planes were found between the fast and slow pace. In the RU-L plane, the effect of pace on acceleration was close to being significant ($p=0.053$). However, such a difference was not found for the stress factor in any of the planes, nor for the interaction of pace and stress. As described in section 4.1, the stressed and non-stressed grouping for these results was based independent of the SACL scores. The next section groups subjects according to their actual SACL scores.

Table 4.6 shows the summary statistics that were statistically significant after the groups had been adjusted. Again, there was no significant effect of pace, stress, or pace×stress interaction on the mean position in any plane. Except mean RU-L-V ($p=0.072$), mean velocity and acceleration in all four planes (RU-R, RU-L, FE-R, and FE-L) were significantly affected by the change of pace. Stress factor was found to have a significant effect on RU-L-V, FE-L-V and FE-L-A. For RU-L-A, this effect was close to being significant ($p=0.063$). Interaction of pace and stress did not have noticeable effect on any of the variables.

**Table 4.5** Significant findings of mean wrist motion variables before adjusting (Refer to Table 3.4 for key coding)

| Variable | Pace | Stress | Interaction |
|---|---|---|---|
| Mean P | | | |
| RU - R | 0.796 | 0.825 | 0.787 |
| FE - R | 0.830 | 0.847 | 0.797 |
| RU - L | 0.573 | 0.900 | 0.764 |
| FE - L | 0.915 | 0.139 | 0.969 |
| Mean V | | | |
| RU - R | 0.015* | 0.187 | 1.000 |
| FE - R | 0.036* | 0.282 | 0.474 |
| RU - L | 0.109 | 0.518 | 0.639 |
| FE - L | 0.029* | 0.607 | 0.312 |
| Mean A | | | |
| RU - R | 0.007* | 0.265 | 0.908 |
| FE - R | 0.038* | 0.444 | 0.657 |
| RU - L | 0.053 | 0.452 | 0.543 |
| FE - L | 0.008* | 0.373 | 0.276 |

* Significant at the level of 0.05 level

**Table 4.6** Significant findings of mean wrist motion variables after adjusting (Refer to Table 3.4 for key coding)

| Variable | Pace | Stress | Interaction |
|---|---|---|---|
| Mean P | | | |
| RU - R | 0.787 | 0.161 | 0.960 |
| FE - R | 0.830 | 0.679 | 0.996 |
| RU - L | 0.572 | 0.702 | 0.970 |
| FE - L | 0.919 | 0.556 | 0.872 |
| Mean V | | | |
| RU R | 0.016* | 0.520 | 0.331 |
| FE - R | 0.042* | 0.988 | 0.570 |
| RU - L | 0.072 | 0.020* | 0.794 |
| FE - L | 0.008* | 0.002* | 0.447 |
| Mean A | | | |
| RU - R | 0.007* | 0.995 | 0.218 |
| FE - R | 0.037* | 0.446 | 0.511 |
| RU - L | 0.040* | 0.063 | 0.852 |
| FE - L | 0.003* | 0.008* | 0.538 |

* Significant at the level of 0.05 level

The main effects plots for mean velocity and acceleration were obtained for the adjusted groups and are presented in Figures 4.5 and 4.6. These figures show that pace had an obvious positive effect across all the variables, with faster pace resulting in higher mean velocity and acceleration than slow pace. Similarly, mean velocity and acceleration of the stressed group were higher than that of the non-stressed group for the left hand, as indicated by the P-values in Table 4.6. On the right hand, stress only had a moderate effect. In fact, acceleration in the FE-R plane decreased slightly as the level of stress increased, but this change was not statistically significant (p=0.446).

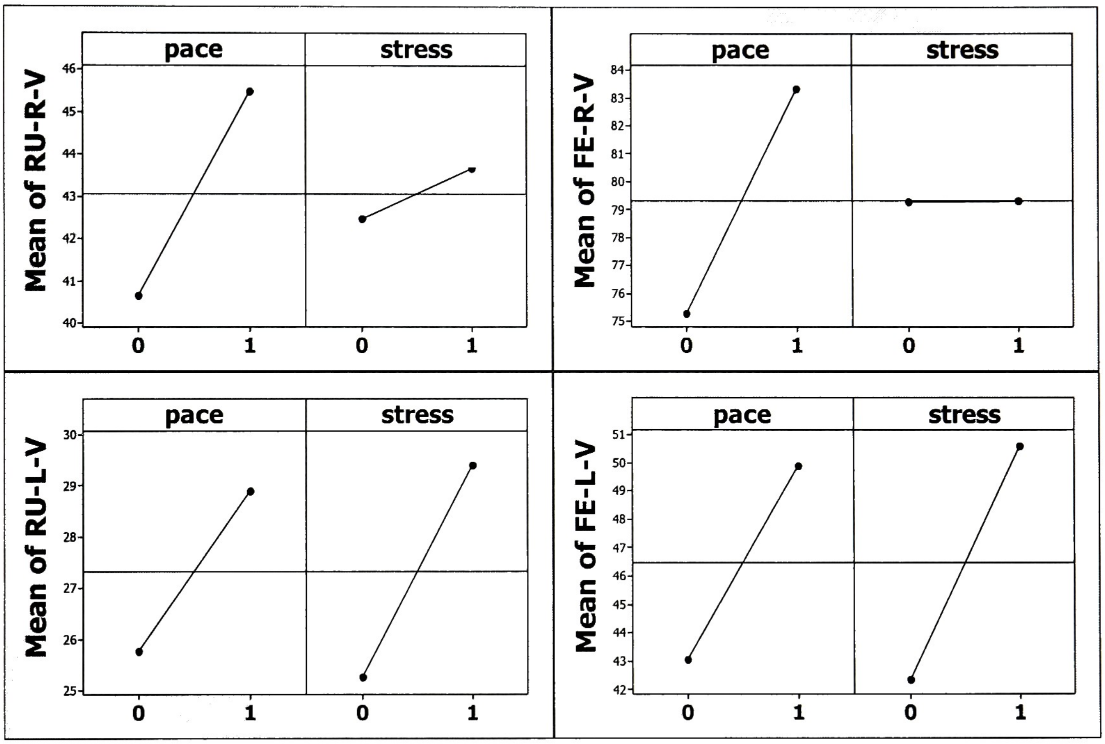


**Figure 4.5** Main effects plot for mean velocity in different planes after adjusting (0–slow/non-stressed 1–fast/stressed)

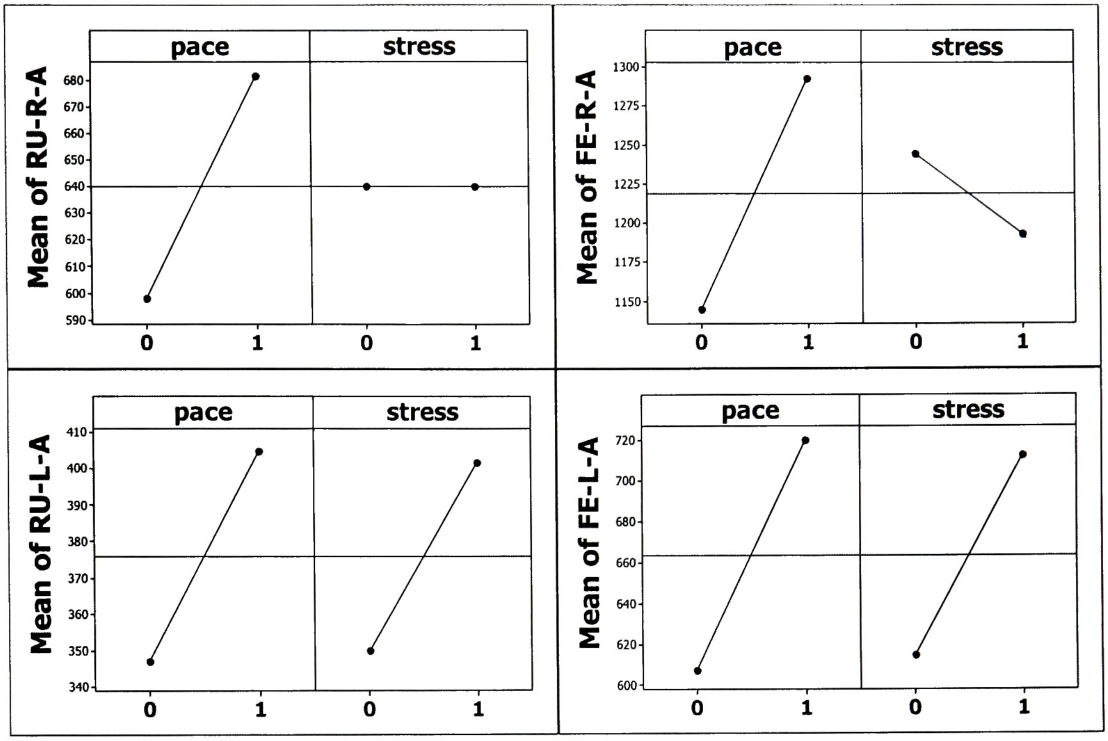


**Figure 4.6** Main effects plot for mean acceleration in different planes after adjusting (0–slow/non-stressed 1–fast/stressed)

Table 4.7 contains the increase of the mean velocity and acceleration from low to high pace/stress levels as a percentage of velocity and acceleration of the low level. The increases caused by pace were higher than 10% across all variables. For the left hand, the percent increases of the stressed group were about 15% to 20% greater than non-stressed group. Right hand had smaller percentage of changes, all of which were within 5%.

**Table 4.7** Increase of mean velocity and acceleration from low to high pace/stress levels

| Variable | Pace | Stress |
|---|---|---|
| Mean RU-R-V | 11.9% | 2.8% |
| Mean FE-R-V | 10.7% | 0.1% |
| Mean RU-L-V | 12.1% | 16.5% |
| Mean FE-L-V | 15.9% | 19.5% |
| Mean RU-R-A | 14.0% | -0.0% |
| Mean FE-R-A | 13.0% | -4.2% |
| Mean RU-L-A | 16.7% | 14.8% |
| Mean FE-L-A | 18.6% | 16.0% |

Descriptive statistics (mean, minimum, maximum and range) of wrist position under different experiment combinations are summarized in Tables 4.8 through 4.10 and illustrated in bar chart form in Figures 4.7 through 4.9. In Table 4.8, the negative sign indicates that wrist was flexed or radial for left hand/ulnar for right hand deviated as defined in the previous chapter. The mean position value of both hands in the RU plane was within ±2° while it was around – 12° in the FE-R plane and – 6° in the FE-L plane. There was less variability of the maximum, minimum and range statistics of wrist position among different planes than that of the mean statistics. The absolute values of minimum and maximum position ranged from around 30° to 40° in the RU plane and from around 55° to 65° in the FE plane. Mean velocity was the highest in the FE-R plane around 80°/s and the lowest in the RU-L plane around 27°/s, with RU-R and FE-L values in the middle. Minimum, maximum, and range of velocity followed the same trend as the means. Similarly, mean acceleration on FE-R and RU-L was the highest (1096°/$s^2$ ~1297°/$s^2$) and the lowest (323°/$s^2$ ~ 433°/$s^2$) among the four planes respectively, as were their respective minimum, maximum, and range values.

Within each bar chart, the mean or range was plotted as a function of different factor combinations (SF, SS, NF, and NS). The height of each bar represents the mean of all six subjects' data in that combination. The pictorial trend across all the position, velocity and acceleration values in Figure 4.7 through 4.12 was that values in the FE plane were higher than that in the RU plane, and values of the right hand were higher than that of the left hand.

Repeated ANOVA were performed on min, max and range of wrist position, velocity and acceleration as presented in Table 4.11. Variables that were significantly affected by pace, stress or pace×stress interaction are identified with an asterisk. Stress had a significant effect on min RU-R-P, min RU-L-P, min FE-L-V, max RU-L-A, range RU-L-P, range FE-L-P, range FE-L-V and range RU-L-A. Significant effect of pace was found only on max RU-L-A.

**Table 4.8** Summary statistics of the wrist position (degrees)
(Refer to Table 3.4 for key coding)

| Variable | Stressed | | Non-stressed | |
|---|---|---|---|---|
| | Fast | Slow | Fast | Slow |
| RU-R | | | | |
| Mean | -1.46 (4.64) | -1.92 (4.67) | 1.62 (5.38) | 0.95 (5.33) |
| Min | -42.55 (5.52) | -41.28 (7.73) | -32.29 (9.02) | -34.06 (8.52) |
| Max | 38.93 (3.76) | 40.02 (5.34) | 42.67 (6.29) | 42.29 (6.84) |
| Range | 81.48 (4.91) | 81.31 (8.64) | 74.97 (7.36) | 76.33 (9.56) |
| FE-R | | | | |
| Mean | -13.22 (7.46) | -12.32 (8.80) | -11.47 (11.49) | -10.53 (12.72) |
| Min | -64.77 (8.10) | -66.02 (9.52) | -64.30 (15.26) | -61.04 (14.83) |
| Max | 61.09 (4.91) | 62.06 (7.31) | 68.67 (13.94) | 69.08 (13.15) |
| Range | 125.87 (10.22) | 128.09 (10.57) | 132.97 (8.22) | 130.11 (7.43) |
| RU-L | | | | |
| Mean | 0.29 (2.07) | 1.25 (2.50) | 0.96 (5.08) | 1.79 (4.67) |
| Min | -37.42 (5.41) | -37.52 (3.42) | -32.15 (4.82) | -31.46 (4.34) |
| Max | 39.12 (8.72) | 37.78 (5.82) | 34.17 (7.91) | 33.52 (7.09) |
| Range | 76.54 (12.12) | 75.30 (5.67) | 66.31 (5.78) | 64.97 (5.51) |
| FE-L | | | | |
| Mean | -5.59 (7.99) | -4.63 (8.67) | -7.16 (9.24) | -7.38 (9.32) |
| Min | -62.67 (9.72) | -63.54 (10.20) | -55.98 (9.66) | -56.64 (9.01) |
| Max | 61.55 (10.33) | 62.67 (10.73) | 58.47 (10.12) | 55.48 (13.23) |
| Range | 124.22 (10.07) | 126.20 (10.02) | 114.46 (6.34) | 112.12 (8.63) |

**Table 4.9** Summary statistics of the wrist velocity (degrees/second)
(Refer to Table 3.4 for key coding)

| Variable | Stressed | | Non-stressed | |
|---|---|---|---|---|
| | Fast | Slow | Fast | Slow |
| RU-R | | | | |
| Mean | 47.0 (4.8) | 40.3 (4.4) | 44.0 (5.0) | 41.0 (3.6) |
| Min | -416.3 (48.4) | -386.9 (66.4) | -402.7 (62.1) | -389.6 (58.1) |
| Max | 443.0 (64.2) | 405.2 (39.5) | 403.7 (63.4) | 385.5 (56.2) |
| Range | 859.3 (95.4) | 792.1 (75.6) | 806.4 (108.7) | 775 (113.5) |
| FE-R | | | | |
| Mean | 84.4 (5.1) | 74.2 (7.8) | 82.2 (11.9) | 76.3 (10.2) |
| Min | -757.7 (99.6) | -756.8 (138.1) | -768.2 (100.7) | -755.0 (105.3) |
| Max | 729.5 (90.6) | 693.7 (80.2) | 803.7 (47.0) | 738.4 (88.5) |
| Range | 1487.1 (132.5) | 1450.5 (209.6) | 1572.0 (131.8) | 1493.4 (168.4) |
| RU-L | | | | |
| Mean | 31.2 (5.5) | 27.6 (3.0) | 26.6 (3.7) | 23.9 (3.4) |
| Min | -345.8 (70.3) | -339.7 (14.9) | -335.3 (54.5) | -322.8 (61.6) |
| Max | 325.3 (56.2) | 352.6 (43.3) | 324.4 (46.5) | 314.0 (83.3) |
| Range | 671.0 (120.3) | 692.3 (48.8) | 659.8 (86.4) | 636.8 (136.4) |
| FE-L | | | | |
| Mean | 53.1 (7.1) | 48.1 (3.2) | 46.7 (6.9) | 38.0 (4.8) |
| Min | -695.8 (84.3) | -664.8 (80.5) | -547.4 (61.5) | -548.4 (77.2) |
| Max | 639.1 (137.3) | 614.9 (90.2) | 614.4 (52.2) | 549.2 (102.1) |
| Range | 1334.9 (152.2) | 1279.8 (152.6) | 1161.8 (110.5) | 1097.6 (169.4) |

**Table 4.10** Summary statistics of the wrist acceleration (degrees/second$^2$)
(Refer to Table 3.4 for key coding)

| Variable | Stressed | | Non-stressed | |
|---|---|---|---|---|
| | Fast | Slow | Fast | Slow |
| RU-R | | | | |
| Mean | 699 (90) | 580 (60) | 664 (65) | 616 (51) |
| Min | -7464 (1359) | -6384 (1321) | -7358 (741) | -6899 (1483) |
| Max | 6906 (904) | 6028 (1233) | 6897 (829) | 6477 (967) |
| Range | 14371 (2051) | 12413 (2466) | 14255 (1267) | 13376 (2172) |
| FE-R | | | | |
| Mean | 1289 (113) | 1096 (155) | 1297 (192) | 1193 (182) |
| Min | -13018 (3122) | -12718 (2957) | -13857 (1929) | -13638 (3038) |
| Max | 12245 (2254) | 11285 (2720) | 13099 (2109) | 12337 (3349) |
| Range | 25263 (5218) | 24003 (5483) | 26955 (2823) | 25975 (6210) |
| RU-L | | | | |
| Mean | 433 (100) | 370 (40) | 376 (55) | 323 (45) |
| Min | -5408 (1286) | -4915 (367) | -4508 (793) | -4614 (1175) |
| Max | 5664 (651) | 4685 (561) | 4593 (882) | 4190 (1030) |
| Range | 11072 (1823) | 9600 (701) | 9102 (1570) | 8804 (2095) |
| FE-L | | | | |
| Mean | 759 (116) | 667 (36) | 681 (95) | 547 (54) |
| Min | -10546 (1513) | -10518 (1965) | -9833 (1910) | -8753 (1502) |
| Max | 10621 (2548) | 9457 (1805) | 9013 (1499) | 8065 (1754) |
| Range | 21167 (3801) | 19975 (3365) | 18846 (3358) | 16817 (3121) |

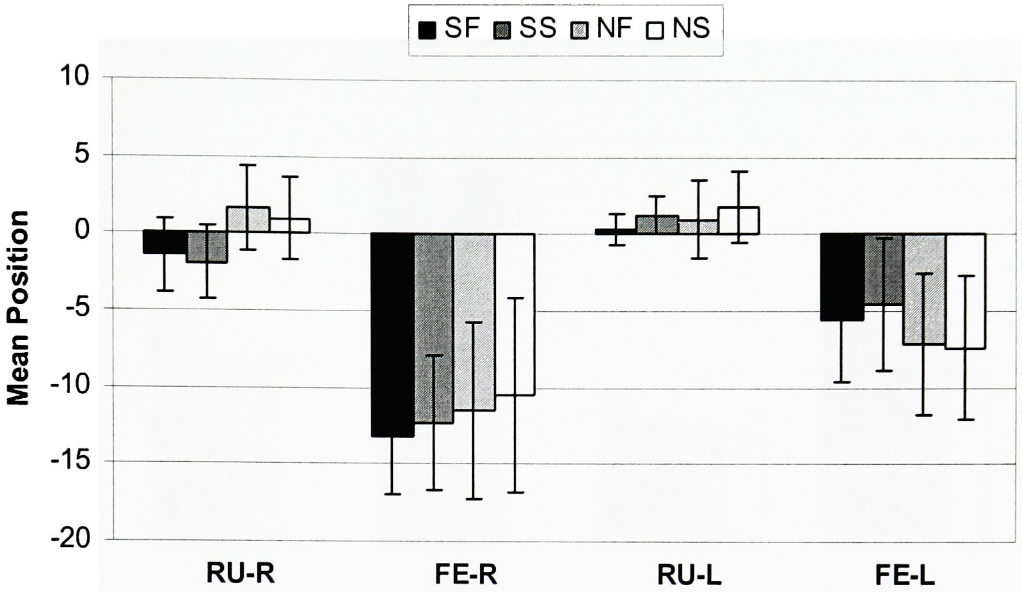


**Figure 4.7** Mean wrist position (deg) under different factor combinations

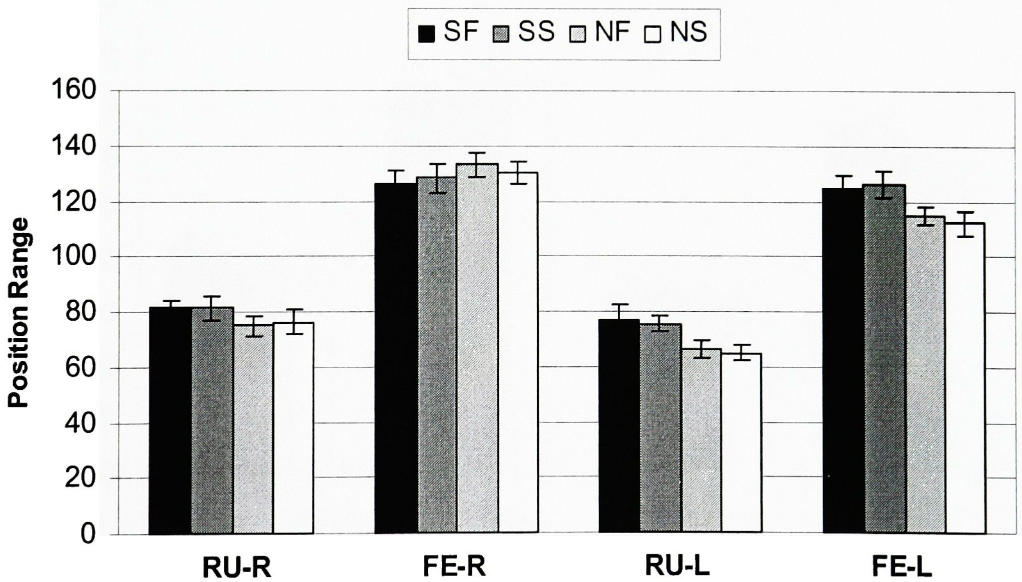


**Figure 4.8** Range of wrist position (deg) under different factor combinations

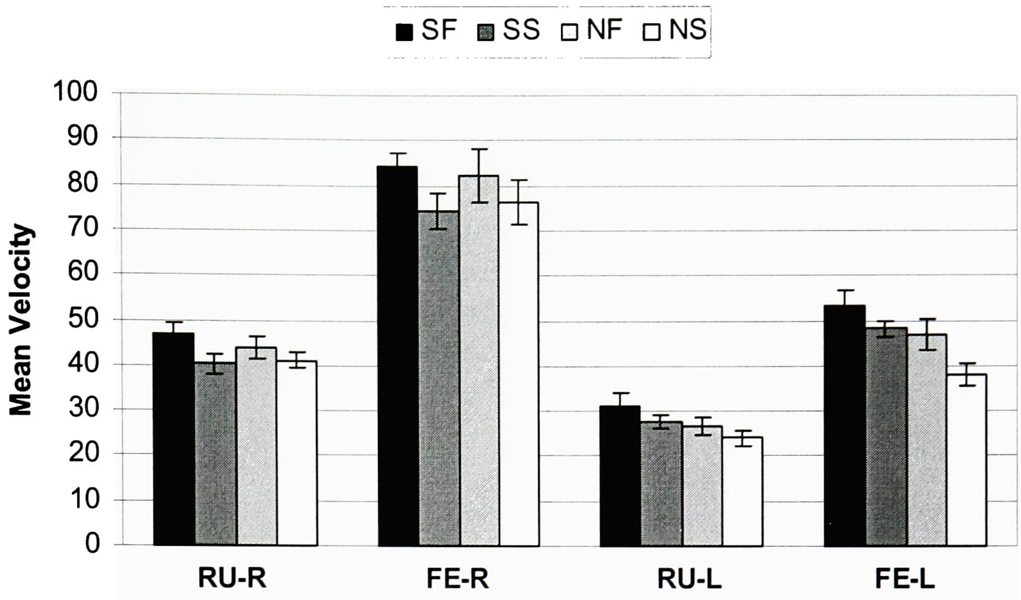


**Figure 4.9** Mean wrist velocity (deg/sec) under different factor combinations

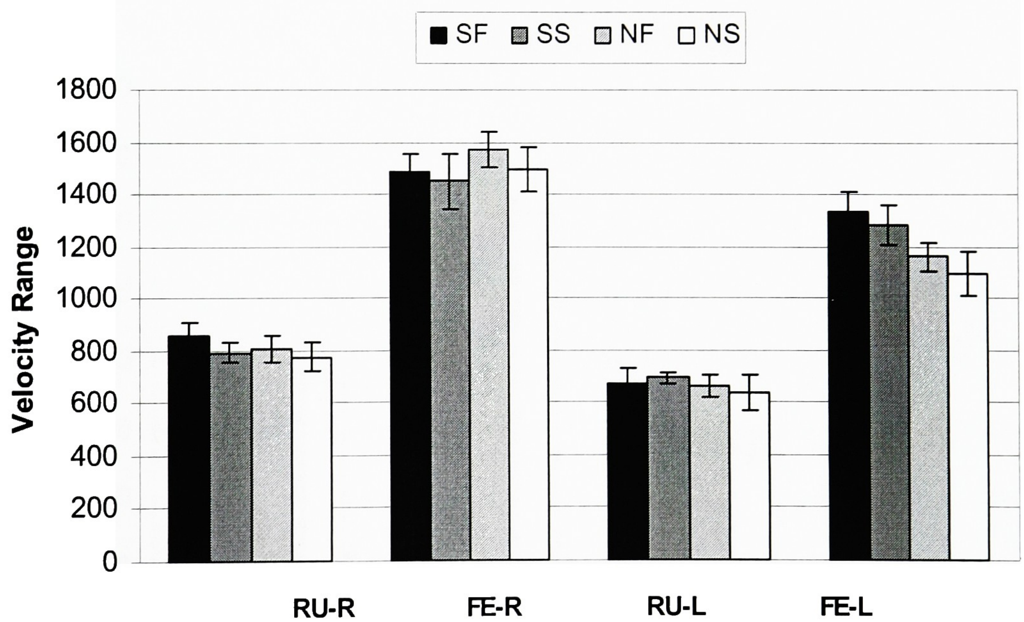


**Figure 4.10** Range of wrist velocity (deg/sec) under different factor combinations

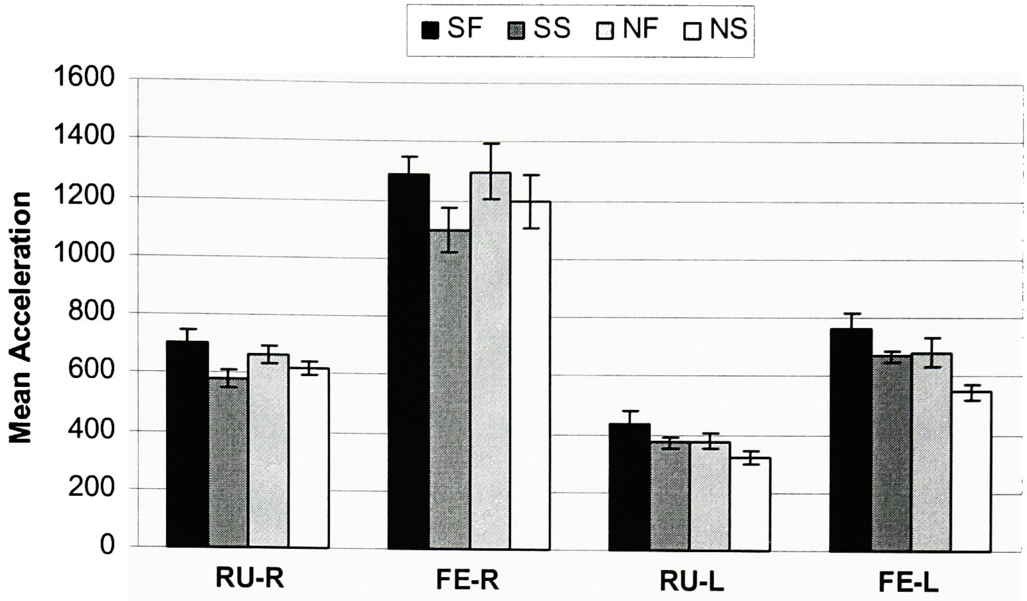


**Figure 4.11** Mean wrist acceleration (deg/sec$^2$) under different factor combinations

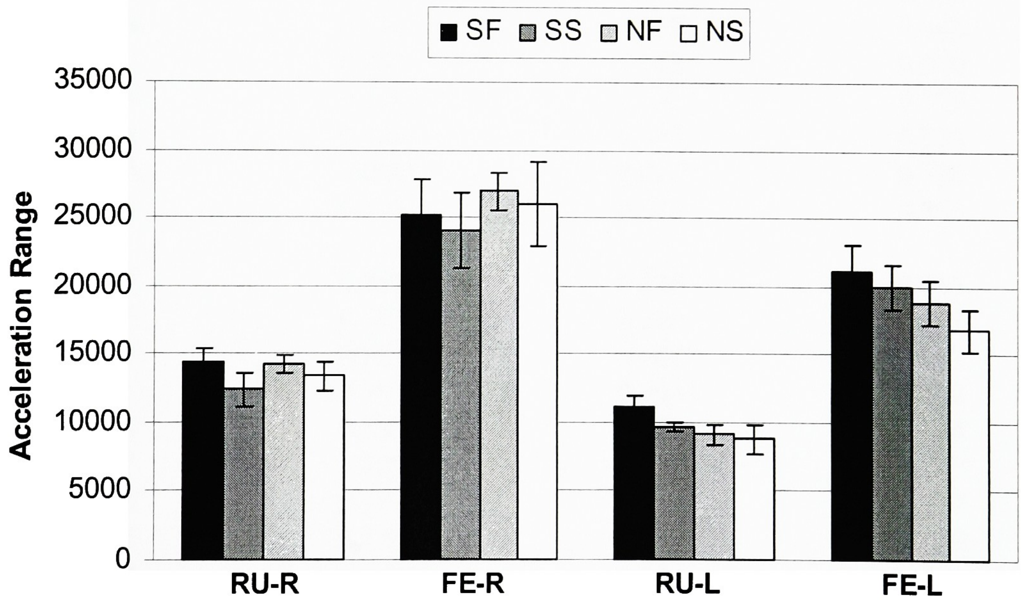


**Figure 4.12** Range of wrist acceleration (deg/sec$^2$) under different factor combinations

**Table 4.11** Significant findings of minimum, maximum and range of wrist motion

| Variable | Pace | Stress | Interaction |
|---|---|---|---|
| Min | | | |
| RU-R-P | 0.939 | 0.013* | 0.640 |
| FE-R-P | 0.843 | 0.595 | 0.659 |
| RU-L-P | 0.875 | 0.006* | 0.835 |
| FE-L-P | 0.848 | 0.100 | 0.979 |
| RU-R-V | 0.389 | 0.823 | 0.739 |
| FE-R-V | 0.880 | 0.924 | 0.894 |
| RU-L-V | 0.681 | 0.548 | 0.885 |
| FE-L-V | 0.636 | 0.000* | 0.614 |
| RU-R-A | 0.150 | 0.695 | 0.553 |
| FE-R-A | 0.823 | 0.451 | 0.972 |
| RU-L-A | 0.632 | 0.147 | 0.461 |
| FE-L-A | 0.444 | 0.096 | 0.467 |
| Max | | | |
| RU-R-P | 0.881 | 0.210 | 0.754 |
| FE-R-P | 0.876 | 0.109 | 0.950 |
| RU-L-P | 0.747 | 0.146 | 0.911 |
| FE-L-P | 0.839 | 0.273 | 0.658 |
| RU-R-V | 0.240 | 0.218 | 0.678 |
| FE-R-V | 0.131 | 0.079 | 0.649 |
| RU-L-V | 0.732 | 0.427 | 0.446 |
| FE-L-V | 0.287 | 0.282 | 0.620 |
| RU-R-A | 0.126 | 0.595 | 0.579 |
| FE-R-A | 0.436 | 0.389 | 0.928 |
| RU-L-A | 0.048* | 0.027* | 0.390 |
| FE-L-A | 0.197 | 0.073 | 0.893 |
| Range | | | |
| RU-R-P | 0.854 | 0.087 | 0.813 |
| FE-R-P | 0.933 | 0.239 | 0.507 |
| RU-L-P | 0.689 | 0.004* | 0.987 |
| FE-L-P | 0.961 | 0.004* | 0.558 |
| RU-R-V | 0.238 | 0.399 | 0.664 |
| FE-R-V | 0.399 | 0.351 | 0.757 |
| RU-L-V | 0.984 | 0.439 | 0.607 |
| FE-L-V | 0.334 | 0.008* | 0.940 |
| RU-R-A | 0.104 | 0.616 | 0.524 |
| FE-R-A | 0.596 | 0.389 | 0.947 |
| RU-L-A | 0.199 | 0.050* | 0.389 |
| FE-L-A | 0.262 | 0.064 | 0.768 |

* Significant at the level of 0.05 level

Wrist position data were compared to wrist range of motion (ROM) as wrist has different ROM in RU and FE planes. The range between 95$^{th}$ and 5$^{th}$ percentile of wrist position was calculated for each subject as a percentage of the 50$^{th}$ percentile female and male range of motion (Kroemer et al., 1997) and the average values of each experimental condition are presented in Table 4.12. Values of both left and right hand in the RU plane were close to or slightly over 70% of ROM, which were more than 20% higher than that in the FE plane. Significant differences between RU and FE plane ($p<0.001$) in both hands were found. In addition, difference between left and right hand was significant in both the FE plane ($p<0.001$) and in the RU plane ($p<0.01$).

**Table 4.12** Wrist motion range of SLI as a percentage of ROM (%)

| Plane | SF | SS | NF | NS |
|---|---|---|---|---|
| RU-R | 79.4 (7.9) | 79.1 (10.0) | 82.7 (9.5) | 80.9 (7.9) |
| RU-L | 76.0 (10.5) | 79.1 (11.5) | 70.7 (10.5) | 75.0 (13.8) |
| FE-R | 48.8 (6.9) | 50.6 (7.9) | 52.5 (6.6) | 50.4 (5.9) |
| FE-L | 42.3 (5.2) | 45.0 (7.6) | 43.4 (6.7) | 39.8 (5.7) |

### 4.3.2 High Risk Wrist Motion, Wrist Pause and Repetition

High risk wrist motion in Table 4.13 was defined as the time when position, velocity and acceleration were over the maximum or below the minimum value of the high risk industrial jobs (Table 3.2) as a percentage of the total recording time. The percentage of high risk position fell in the range from 36.1% to 50.5% with most of the values higher than 40%. Except FE-R, high risk velocities in other planes were below 10%. High risk acceleration variables were generally small, around 0.2% to 3.9%.

When wrist velocity was below 1°/s for at least 0.5 second, it was identified as a "pause" period (Hansson et al, 1996). Total time of pause as a percentage of total recording time was found to be the highest in the RU-L plane (7.7% ~ 9.9%), and the lowest in the FE-R plane (3.0% ~ 4.4%).

A repetition was defined as a piece of wrist position trace having two direction changes in succession as illustrated in Figure 3.4. Repetition in Table 4.13 was the total number of repetitions during the eleven-minute fast/slow sessions. The order of the repetitions from the highest to the lowest was FE-R (705~820), RU-R (505~595), FE-L (398~521) and RU-L (290~381). This order was the same for MPF values. MPF ranged from 0.48 Hz to 0.67 Hz for the right hand and from 0.34 Hz to 0.53 Hz for the left hand.

As shown in Table 4.13, among the 12 high risk variables, only velocity and acceleration in FE-L plane were significantly influenced by pace and stress. Higher level of pace and stress led to higher percentage of high risk values (Table 4.13).

Pace had a significant effect on almost all variables of pause, repetition and MPF (except FE-R), while only repetition on the left hand and FE-L MPF were significantly affected by stress. Figure 4.13 to 4.17 illustrate their relationship showing that compared with slow pace, fast pace resulted in lower pause percentage and higher repetition. Stressed group had lower pause percentage and higher repetition on the left hand than the non-stressed group, while opposite but moderate change was observed on the right hand. There was no significant interaction effect for any of the variables.

**Table 4.13** Summary statistics of the high risk wrist motion, pause, repetition and MPF (Refer to Table 3.4 for key coding)

| Variable | Stressed | | Non-stressed | |
|---|---|---|---|---|
| | Fast | Slow | Fast | Slow |
| High risk P (%) | | | | |
| RU-R | 44.9 (12.3) | 44.7 (11.9) | 50.5 (5.8) | 49.8 (8.0) |
| FE-R | 43.3 (10.1) | 46.5 (9.3) | 46.2 (7.6) | 45.3 (6.2) |
| RU-L | 40.8 (7.3) | 44.2 (6.1) | 42.4 (16.6) | 45.2 (14.9) |
| FE-L | 36.1 (11.5) | 38.0 (8.5) | 39.5 (7.3) | 36.7 (11.0) |
| High risk V (%) | | | | |
| RU-R | 10.5 (2.6) | 8.2 (2.1) | 9.3 (2.5) | 8.5 (2.0) |
| FE-R | 14.0 (1.9) | 11.7 (1.9) | 13.4 (3.4) | 12.2 (2.8) |
| RU-L | 5.1 (2.0) | 4.5 (1.5) | 4.4 (1.6) | 3.7 (1.5) |
| FE-L | 6.5 (1.6) | 6.2 (0.6) | 5.6 (1.4) | 3.7 (1.2) |
| High risk A (%) | | | | |
| RU-R | 2.4 (1.4) | 1.4 (0.6) | 1.8 (0.9) | 1.8 (0.7) |
| FE-R | 3.8 (1.1) | 2.8 (1.2) | 3.9 (1.8) | 3.5 (1.6) |
| RU-L | 0.7 (0.6) | 0.4 (0.3) | 0.4 (0.3) | 0.2 (0.2) |
| FE-L | 1.1 (0.5) | 0.9 (0.3) | 0.8 (0.4) | 0.4 (0.2) |
| Pause (%) | | | | |
| RU-R | 4.5 (0.6) | 6.0 (1.5) | 4.4 (0.7) | 5.7 (1.0) |
| FE-R | 3.0 (0.4) | 4.4 (1.1) | 3.0 (0.8) | 4.0 (1.2) |
| RU-L | 7.7 (1.4) | 9.5 (1.5) | 9.1 (1.1) | 9.9 (0.7) |
| FE-L | 5.6 (0.8) | 7.3 (1.4) | 7.0 (1.6) | 8.2 (1.4) |
| Repetition | | | | |
| RU-R | 595 (60) | 505 (47) | 586 (55) | 534 (39) |
| FE-R | 820 (63) | 705 (105) | 825 (104) | 757 (100) |
| RU-L | 381 (64) | 331 (27) | 341 (54) | 290 (27) |
| FE-L | 521 (77) | 444 (31) | 469 (67) | 398 (42) |
| MPF (Hz) | | | | |
| RU-R | 0.57 (0.05) | 0.48 (0.05) | 0.51 (0.06) | 0.49 (0.06) |
| FE-R | 0.67 (0.09) | 0.56 (0.09) | 0.60 (0.08) | 0.59 (0.08) |
| RU-L | 0.41 (0.07) | 0.36 (0.04) | 0.39 (0.05) | 0.34 (0.04) |
| FE-L | 0.53 (0.09) | 0.46 (0.06) | 0.44 (0.08) | 0.39 (0.05) |

**Table 4.14** Significant findings of repetition, pause and high risk motion (Refer to Table 3.4 for key coding)

| Variable | Pace | Stress | Interaction |
|---|---|---|---|
| High risk P | | | |
| RU-R | 0.911 | 0.198 | 0.954 |
| FE-R | 0.740 | 0.815 | 0.555 |
| RU-L | 0.540 | 0.794 | 0.954 |
| FE-L | 0.910 | 0.800 | 0.561 |
| High risk V | | | |
| RU-R | 0.115 | 0.654 | 0.437 |
| FE-R | 0.109 | 0.975 | 0.619 |
| RU-L | 0.321 | 0.264 | 0.975 |
| FE-L | 0.034* | 0.003* | 0.133 |
| High risk A | | | |
| RU-R | 0.186 | 0.755 | 0.257 |
| FE-R | 0.232 | 0.520 | 0.664 |
| RU-L | 0.206 | 0.114 | 0.666 |
| FE-L | 0.046* | 0.016* | 0.575 |
| Pause | | | |
| RU-R | 0.003* | 0.678 | 0.827 |
| FE-R | 0.005* | 0.596 | 0.627 |
| RU-L | 0.017* | 0.093 | 0.371 |
| FE-L | 0.015* | 0.056 | 0.707 |
| Repetition | | | |
| RU-R | 0.003* | 0.640 | 0.384 |
| FE-R | 0.028* | 0.467 | 0.540 |
| RU-L | 0.014* | 0.042* | 0.979 |
| FE-L | 0.005* | 0.048* | 0.885 |
| MPF | | | |
| RU-R | 0.017* | 0.211 | 0.120 |
| FE-R | 0.085 | 0.580 | 0.141 |
| RU-L | 0.029* | 0.312 | 0.962 |
| FE-L | 0.050* | 0.013* | 0.756 |

* Significant at the level of 0.05 level

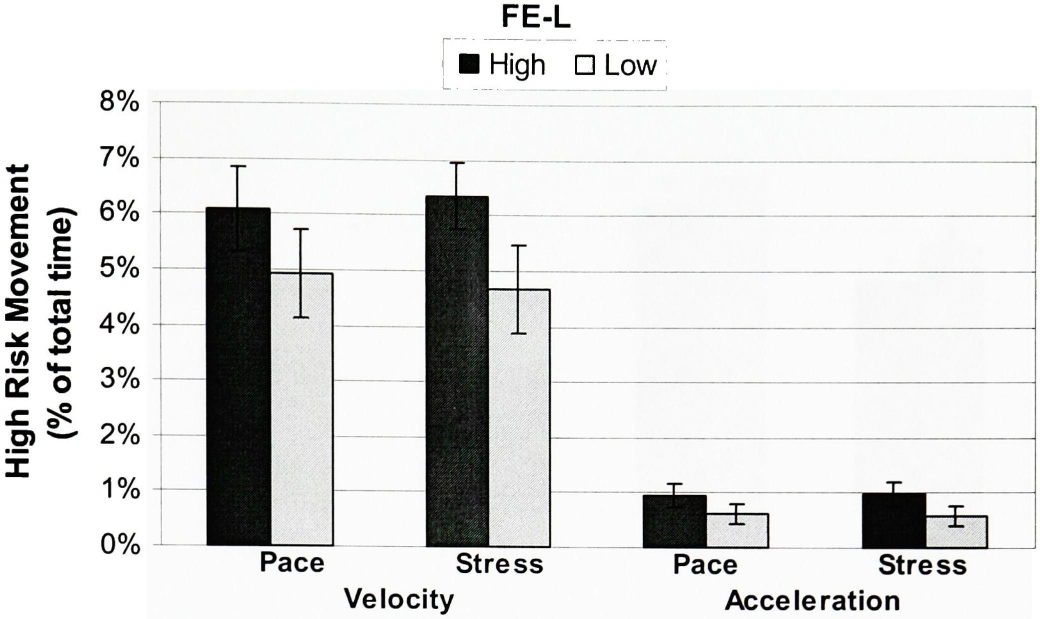


**Figure 4.13** High risk velocity and acceleration in the FE-L plane

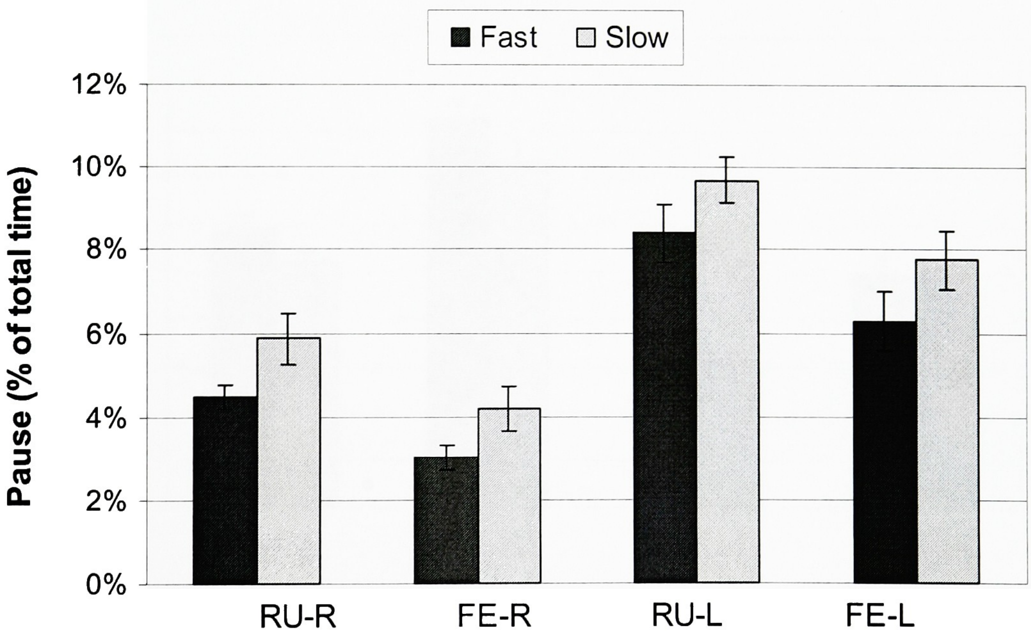


**Figure 4.14** Pause of wrist motion in different planes as a function of pace level

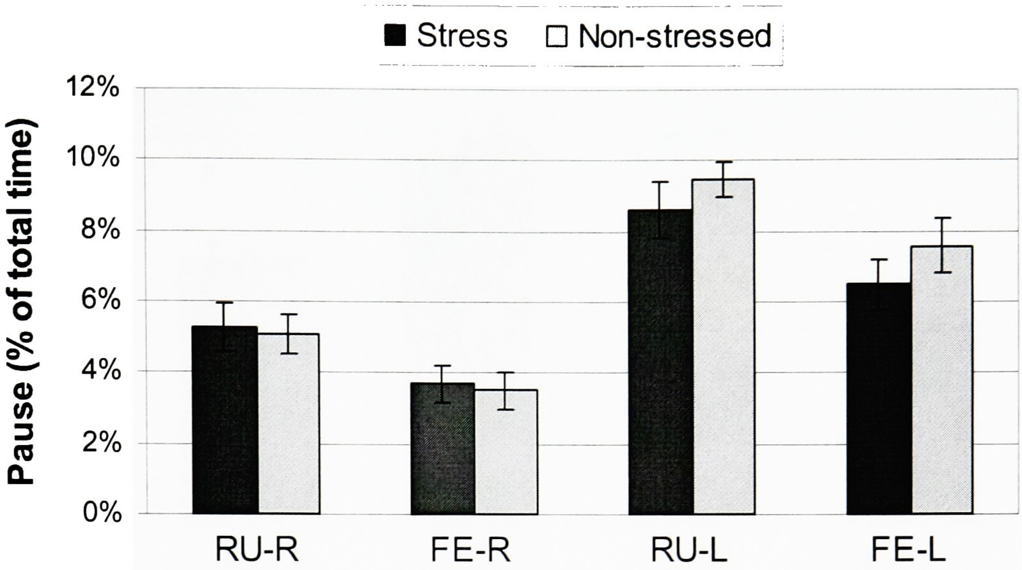


**Figure 4.15** Pause of wrist motion in different planes as a function of stress level

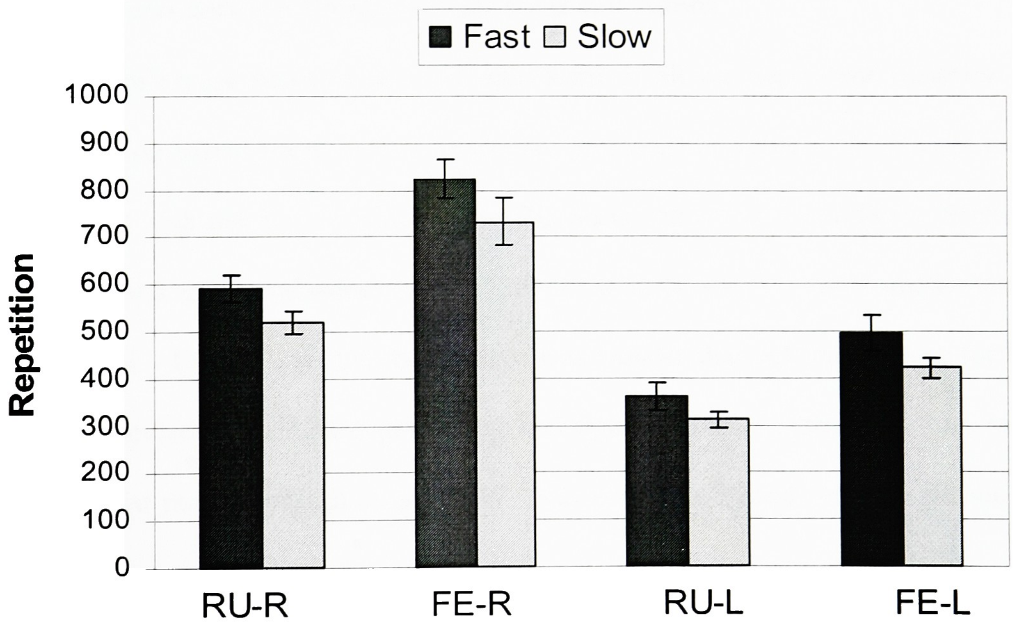


**Figure 4.16** Repetition of wrist motion in different planes as a function of pace level

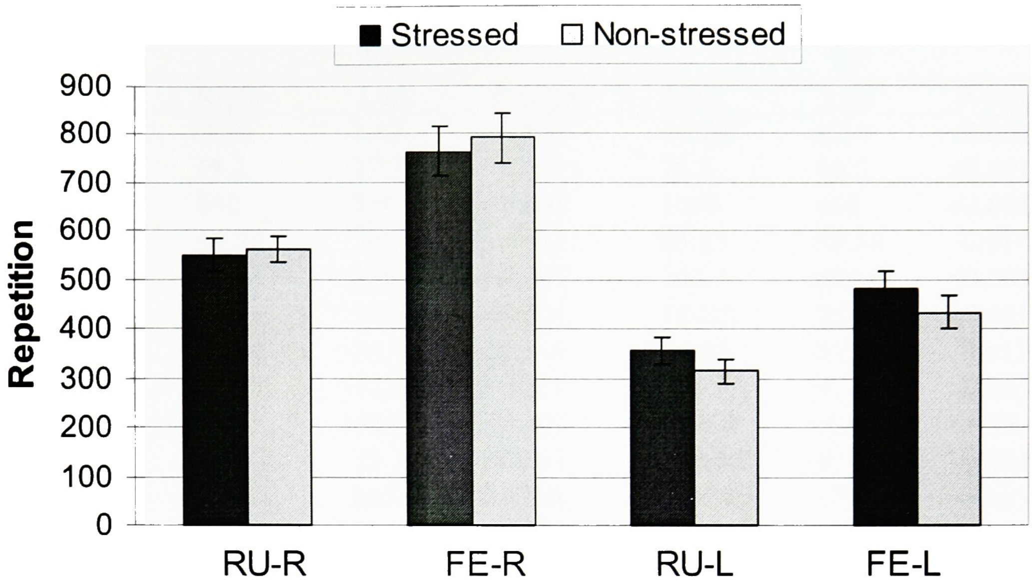


**Figure 4.17** Repetition of wrist motion in different planes as a function of stress level

### 4.3.3 Differences between Dominant/Non-dominant Hands

The difference between left and right hand of all the dependent variables was calculated using paired t-test and the results are presented in Table 4.15. Except mean, max, min and high risk wrist position in the RU plane, there was a significant difference between left and right hand values of all the other variables with a P-value smaller than or close to 0.001. Except that right hand pause was smaller than left hand pause for both flexion and deviation, right hand (dominant) had higher values of mean, min, max, range, high risk wrist motion, repetition and MPF than that of left hand for both flexion and deviation.

**Table 4.15** Comparison of the left and the right hand kinetic variables

| Variable | RU | | | FE | | |
|---|---|---|---|---|---|---|
| | Right | Left | P-value | Right | Left | P-value |
| Mean P | -0.20 | 1.07 | 0.430 | -11.88 | -6.19 | <0.001 |
| Mean V | 43.1 | 27.3 | <0.001 | 79.3 | 46.5 | <0.001 |
| Mean A | 640 | 376 | <0.001 | 1219 | 663 | <0.001 |
| Max P | 40.98 | 36.15 | 0.053 | 65.23 | 59.54 | 0.014 |
| Max V | 409.3 | 329.1 | <0.001 | 741.3 | 604.4 | <0.001 |
| Max A | 6577 | 4783 | <0.001 | 12242 | 9289 | <0.001 |
| Min P | -37.54 | -34.63 | 0.146 | -64.03 | -59.71 | 0.012 |
| Min V | -398.9 | -335.9 | <0.001 | -759.4 | -614.1 | <0.001 |
| Min A | -7027 | -4861 | <0.001 | -13308 | -9913 | <0.001 |
| Range P | 78.52 | 70.78 | <0.001 | 129.26 | 119.25 | =0.001 |
| Range V | 808.2 | 665.0 | <0.001 | 1500.8 | 1218.5 | <0.001 |
| Range A | 13604 | 9645 | <0.001 | 25549 | 19202 | <0.001 |
| High risk P | 0.475 | 0.432 | 0.232 | 0.453 | 0.376 | 0.002 |
| High risk V | 0.091 | 0.044 | <0.001 | 0.128 | 0.055 | <0.001 |
| High risk A | 0.019 | 0.004 | <0.001 | 0.035 | 0.008 | <0.001 |
| Pause | 5.17 | 9.03 | <0.001 | 3.61 | 7.02 | <0.001 |
| Repetition | 555 | 336 | <0.001 | 777 | 458 | <0.001 |
| MPF | 0.51 | 0.37 | <0.001 | 0.60 | 0.45 | <0.001 |

## 4.4 Electromyography Data

EMG statistics are summarized in Table 4.16 and include the $10^{th}$, $50^{th}$, $90^{th}$ percentile EMG, MPF of the EMG power spectrum, and muscle rest. Stressed group had smaller $10^{th}$ but slightly larger $50^{th}$ percentile EMG values than non-stressed group. The $90^{th}$ percentile value of the stressed group was about 11% higher than the non-stressed group. MPF under the four experimental conditions (SF, SS, NF and NS) were close to each other, around 67 Hz. Muscular rest was defined as the time when RMS values were below 10% of RVC for at least 1/8 second as a percentage of the total duration of the recording (Hansson, 2000). Rest time was longer for the stressed than the non-stressed subjects. However, no significant effect was found of pace and stress, or pace×stress interaction ($p > 0.1$) on any of the electromyography variables.

**Table 4.16** Right Trapezius EMG statistics in different experimental conditions

| Variable | SF | SS | NF | NS |
|---|---|---|---|---|
| EMG (% of RVC) | | | | |
| $10^{th}$ | 19.4 | 20.7 | 22.8 | 23.0 |
| $50^{th}$ | 48.2 | 47.9 | 46.8 | 46.7 |
| $90^{th}$ | 88.1 | 87.4 | 77.8 | 76.6 |
| MPF (Hz) | 67.9 | 65.1 | 68.6 | 66.8 |
| Rest (%) | 5.3 | 5.8 | 2.7 | 3.4 |

## 4.5 Subjective Rating of Perceived Discomfort

RPD was measured after each pace session (fast and slow). Six out of twelve subjects did not feel any kind of discomfort at all (RPD = 0) for either sessions. Four people in the stressed group and two in the non-stressed group reported at least minor discomfort. The ratings summarized in Table 4.17 were obtained by averaging the scores for different body regions from all six subjects in each group. Stressed subjects reported discomfort for all four regions (Hands/Fingers, Wrists, Arms/Elbows and Shoulders) of upper extremity with the highest score on right shoulder (1.3). Non-stressed group reported lower scores and only the hands/fingers and shoulder regions received non-zero scores. Moreover, there was no change of the RPD over the two measurements for the non-stressed group while there was an increase from the first to the second RPD for the stressed group. For example, RPD increased from 0.3 to 1.3 on right shoulder and stayed at 0.3 for the stressed and non-stressed group, respectively.

**Table 4.17** Average RPD score for stressed and non-stressed subjects

| Body Region | Hand | Stressed | | Non-stressed | |
|---|---|---|---|---|---|
| | | First | Second | First | Second |
| Hands/Fingers | L | 0 | 0.5 | 0 | 0 |
| | R | 0 | 0.8 | 0.2 | 0.2 |
| Wrists | L | 0 | 0 | 0 | 0 |
| | R | 0.1 | 0.2 | 0 | 0 |
| Arms/Elbows | L | 0.3 | 0.3 | 0 | 0 |
| | R | 0.1 | 0.8 | 0 | 0 |
| Shoulders | L | 0 | 0 | 0 | 0 |
| | R | 0.3 | 1.3 | 0.3 | 0.3 |

## 4.6 Heart Rate

Heart rate in Table 4.18 is the average heart rate of the six subjects under each experimental condition. The average heart rates for the stressed group were 90.9 (fast pace) and 91.3 (slow pace) beats/min. For the non-stressed group the average heart rates were 89.8 (fast pace) and 86.1 (slow pace) beats/min. Although non-stressed group had smaller heart rate than that of the stressed group, these differences were not statistically significant for different pace and stress levels ($p>0.1$).

**Table 4.18** Average HR in different experimental conditions

| Experiment Condition | HR |
|---|---|
| SF | 90.9 (14.2) |
| SS | 91.3 (14.6) |
| NF | 89.8 (12.4) |
| NS | 86.1 (10.6) |

# CHAPTER 5

# Discussion

## 5.1 Independent Variables

The objective of this study was to evaluate the impact of different pace and stress levels on biomechanical responses of sign language interpreters. Fast and slow paced speeches were obtained by creating a 115% and 85% paced version of the original videotape. High and low stress conditions were assigned and it was assumed that subjects would feel more stressed in the stressed condition than in the non-stressed condition. However, SACL scores were not significantly different between the original groups, indicating that the original stressed group was not more stressed than the original non-stressed group (Table 4.1, Figures 4.1 and 4.2).

The stress factor was harder to control than the pace factor. The pace factor was objective and can be precisely specified and regulated, while the stress factor was subjective. Perception of stress and arousal can be affected by many factors, such as experience, age, gender, personality, health condition, mood, etc. (Cox, 1985). Psychosocial factors at work (demands and factors such as job control and social support), together with the personal capacity to cope with such factors, may influence work-related stress (Bongers et al., 1993). Thus different people may perceive stress and arousal differently even if they are in the same environmental situation. This individual difference was reflected in the large variation of the stress and arousal scores obtained from the participants of this experiment (Table 4.2).

Pearson correlation test (Table 4.4) showed that stress level was negatively correlated with both signing and interpreting experience. Their relationships are illustrated in Figure 5.1. The two subjects in the original non-stressed group who had the highest stress values were also two of the youngest and the least experienced among all the subjects. Their average age, years of signing, and years of interpreting were 24, 5.5 and 5.0 years, respectively. This result was not surprising because experience can help people learn how to cope with stressful working conditions. Based on demand-control theory (Dean et al., 2001), young interpreters have less control of the stress effects (how to cope with stressful situations) than more experienced interpreters, which may contribute to their higher stress levels. The two subjects with the lowest stress scores in the original stressed group had average age, years of signing, and years of interpreting of 46, 32.8 and 25.8 years, respectively. One subject explained that the experimental conditions were not particularly stressful since he had previously interpreted in much more stressful situations such as police investigation.

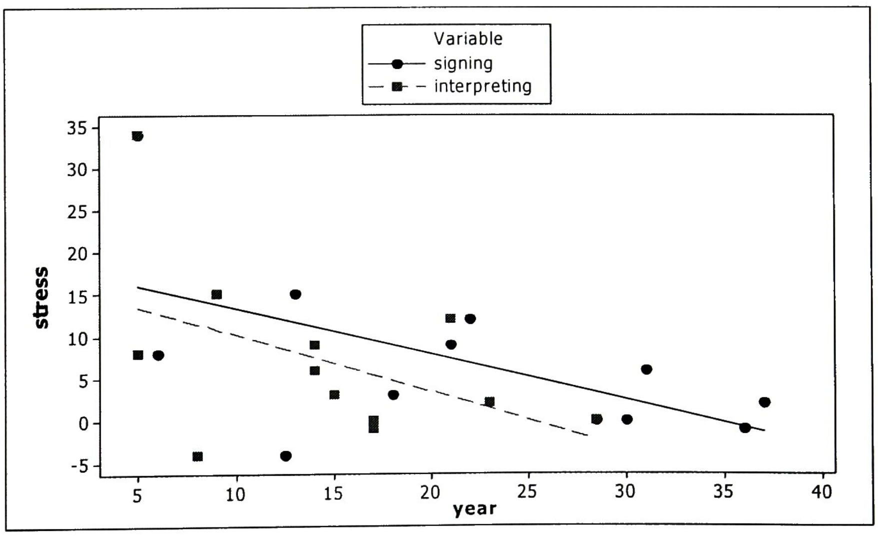


**Figure 5.1** Negative correlations of stress and signing/interpreting experience

The switch of the two subjects between the stressed and the non-stressed groups was necessary and justifiable. First of all, there were no statistically significant demographic differences (age, years of signing/interpreting and working hours per week) between the two groups after switching as described in chapter four. So any possible confounding effects on the results caused by subjects' demographic differences are minimal. Secondly, switching resulted in a significant difference of the stress/arousal levels between the two groups. The original stressed group was not more stressed than the non-stressed group. By switching subjects, the stressed group was then statistically more stressed than the non-stressed group, thus the high and low levels of the stress factor were validated. It should be noted that the name "non-stressed" does not mean that subjects in this group were not stressed at all. The name "stressed" and "non-stressed" were used to imply the significantly different psychological states of the two groups, which actually mean "more stressed" and "less stressed," rather than "stressed" and "not stressed."

The stress scores after adjusting was 13.5 for the stressed and -1.17 for the non-stressed group. Negative value shows that subjects in the non-stressed group felt slightly less stressed during the experiment than the baseline measurement, and that, conversely, the stressed group felt more stressed than baseline. Baseline measurement was obtained after all the sensors were attached to the subject, which may cause stress on subjects even before the actual measurement. After the warm-up period, subjects may have gotten used to the sensors and felt more relaxed. For the non-stressed subjects, this was evident by their negative stress score. For the stressed subjects, this effect was not comparable to the feeling of stress, which led to an increased stress score. Anecdotally, subjects from

the stressed group indicated that they had more worries about missing words/sentences and interpretation of unfamiliar terms than did the non-stressed group.

Increase in self-reported stress and decrease in self-reported arousal has been reported after a prolonged and monotonous repetitive task (Cox, 1983). This was not the case for sign language interpreting in this study. Both the stress and arousal levels had an increase for the stressed group (stress =13.5, arousal = 7.8). The arousal level for the non-stressed group, although small (arousal=1.0), also increased. The increased arousal score indicated that subjects were not only stressed, but also stimulated. Sign language interpreting is highly repetitive in terms of hand activity and wrist movement, but it is by no means monotonous. Instead, it has high mental demands as new information comes out very quickly and interpreters have to translate that verbal information simultaneously into sign language. The fact that American Sign Language (ASL) has its own grammar, syntax and semantics different from English (Wilcox et al., 1991) even adds more challenges to this job.

Contrary to initial assumptions, some subjects in this study felt that the slow pace segment was harder to interpret than the fast one because subjects had to wait constantly during the slow segment to grasp the complete meaning of sentences. During the fast segment, the flow of information came faster with very few pauses, making it easier to grasp the main idea of the material. Again, demand-control theory may help to explain this phenomenon: because the rate of information was less in the slow segment than in the fast one, although the demands were similar, subjects felt more stressed in the slow segment.

There are many other factors that could be stressors for sign language interpreting besides what has been described in this study. These factors include unfamiliarity of the interpreting materials, stage interpreting, audience, and interpreting under urgent situations. Future research should investigate and identify what other possible stressors are and how they affect the biomechanical responses of interpreters.

## 5.2 Wrist Motion

### 5.2.1 Mean Values

Mean wrist position data were not affected by either pace or stress factor (Tables 4.5 and 4.6). This was not surprising considering that ASL has its own standardized signs and wrist motions as a formal language. The sign for each word is the same in different conditions. Although differences do exist among individuals, it is not likely to be significant enough to influence the average wrist position.

The pace effect was not influenced by the group adjustment because it was a within-subject variable. Pace factor had a significant effect on mean wrist velocity and acceleration with fast pace resulting in higher values of mean wrist kinetic values than slow pace (Tables 4.5 and 4.6). This result was consistent with the initial hypothesis and was straightforward to understand as wrists had to move faster in the fast segment than in the slow one to keep up with the speaker's pace. It also suggested that a pace increase of 30% (115% - 85%) can lead to a significant increase of velocity and acceleration. In addition, this increase applied to both RU and FE planes of both hands, suggesting an overall faster wrist movement when pace increases.

The effect of stress was much more complex than the effect of pace. Before adjusting, stress did not have a significant effect on any of the mean wrist velocity and acceleration variables. After switching two subjects according to their actual SACL scores, it was found that mean velocity and acceleration of the left wrist, but not the right wrist, were significantly higher for the stressed group than the non-stressed group. Before further discussion, it is necessary to introduce some background of ASL. In ASL, special emphasis (the equivalent of underlining a word in a written document) can be given by producing a sign faster and sharper than normally or by switching the dominant hand with which the sign is performed (Wilbur, 1979). For a right-handed person, the right is the dominant hand and the left is passive. Signs are performed by either one hand or both hands. One-handed signs are performed with only the dominant hand, and two-handed signs often involve the dominant hand performing an action while the passive hand remains relatively still. If a right-handed person uses her/his left hand (or vice versa), it places special emphasis on that word.

One explanation of the increased use of the left hand among stressed subjects could be that when the left hand would normally be held still, stressed subjects moved both of their hands instead of just one, perhaps for emphasis. For example, it was possible that they performed symmetrical movements in both hands when only the dominant hand is needed. Because all the subjects were right-handed, the high velocity and acceleration of left hand may suggest that subjects in the stressed group used a more emphatic tone than those who were less stressed. As mentioned earlier, subjects in the stressed group expressed more concern about accuracy than less stressed ones, which may have led to more emphasis in signing. Further analysis of the relationship between

hand movement characteristics and language accuracy/efficiency is needed, but is beyond the scope of this study.

### 5.2.2 Minimum, Maximum and Range Variables

There was a lack of significance of pace factor effect on any of the maximum, minimum and range variables expect Max RU-L-A (Table 4.11). This indicates that for the most part, 30% (115%-85%) change of the speaker's pace does not influence the maximum range of wrist motion and does not result in higher peak movement velocities and accelerations. It was observed in the videotapes that even in the slow segment subjects still used ballistic wrist movements. Wrist movements were observed to have more pauses in the slow segment and in the fast segment. However, a long pause was often followed by a sprint of movement. Minimum and range of wrist position was affected by the stress factor as indicated with asterisks in Table 4.11. The overall trend was that the stressed group had greater extreme wrist position values than the non-stressed group. Only 4 out of 24 velocity and acceleration variables were affected by stress and all of them were on the left hand. As described in section 5.1, subjects were prone to have more left wrist motion when they were stressed, which lead to higher maximum and minimum values of the left hand movements than the non-stressed group. However, it should be noted that maximum and minimum variables only represent a transient status of wrist motion rather than reflecting the characteristic of the whole recording period.

### 5.2.3 Comparison of Wrist Motion with Other Occupations

One of the objectives of this study was to compare the wrist motion statistics with other occupations that have been studied in a similar manner. The comparison of wrist motion results is summarized in Table 5.1. Results of this study were calculated by averaging the data from each of the six subjects in all four experimental conditions (SF, SS, NF and NS) for the corresponding variables. In a study of wrist motion in industrial jobs, Marras (1991) found that FE acceleration and FE velocity were the best two parameters to discriminate between low and high risk groups, while wrist position variables predicted risk level poorly, where risk was defined by recorded occupational injuries and illnesses. Mean acceleration values of high and low CTD risk groups were suggested as preliminary benchmarks to establish safety levels of wrist motion in industry.

**Table 5.1** Comparison of wrist motion results with other occupations
P = position (deg) V = velocity (deg/sec) A = acceleration (deg/sec$^2$)

| | Task | Variable | | RU | | | FE | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | P | V | A | P | V | A |
| Marras & Schoenmarklin (1991) | Industrial jobs | Mean | Low risk | -7.62 | 17.0 | 301 | -10.09 | 28.7 | 494 |
| | | | High risk | -6.73 | 25.9 | 494 | -12.02 | 42.2 | 824 |
| | | Min | Low risk | -16.51 | -79.3 | -1755 | -23.58 | -121.2 | -2788 |
| | | | High risk | -18.96 | -115.1 | -2776 | -29.08 | -183.7 | -4927 |
| | | Max | Low risk | 1.12 | 77.3 | 1759 | 4.35 | 120.3 | 2588 |
| | | | High risk | 4.69 | 115.7 | 3077 | 6.56 | 174.2 | 4471 |
| Marklin & Monroe (1998) | Meat packing industry | Mean | | n.a. | 30 | 578 | n.a. | 45 | 844 |
| | | Peak | | n.a. | 156 | 3593 | n.a. | 239 | 4895 |
| Serina et al. (1999) | Typing | Mean | R | 18.6 | 11 | 127 | 19.9 | 25 | 317 |
| | | | L | 14.7 | 12 | 141 | 23.4 | 23 | 295 |
| | | Peak | R | n.a. | 82 | 940 | n.a. | 164 | 2058 |
| | | | L | n.a. | 94 | 966 | n.a. | 188 | 2444 |
| Stål et al. (1999) | Machine milking | Mean | R | 2 | 16 | n.a. | -15 | 28 | n.a. |
| | | | L | -4 | 14 | n.a. | -8 | 20 | n.a. |
| | | Peak | R | -12 | 76 | n.a. | -46 | 147 | n.a. |
| | | | L | -22 | 71 | n.a. | -37 | 114 | n.a. |
| Kristensen et al. (2002) | Deboning of poultry | Mean | | 8 | 18 | 377 | -17 | 36 | 191 |
| | | Peak | | 18 | 60 | 1469 | -36 | 127 | 729 |
| This study | Sign language interpreting | Mean | R | -0.81 | 43.1 | 640 | -11.89 | 79.3 | 1219 |
| | | | L | 1.07 | 27.3 | 376 | -6.15 | 46.5 | 664 |
| | | Min | R | -37.55 | -398.9 | -7026 | -64.03 | -759.4 | -13308 |
| | | | L | -34.64 | -335.9 | -4861 | -59.71 | -614.1 | -9913 |
| | | Max | R | 40.98 | 409.4 | 6577 | 65.22 | 741.3 | 12242 |
| | | | L | 36.15 | 329.1 | 4783 | 59.54 | 604.4 | 9289 |

The comparison of sign language interpreting (SLI) with industrial jobs (Marras et al., 1991) is illustrated in Figures 5.2 through 5.5. It was found that mean velocities of SLI were higher than both low and high risk industrial jobs. Mean velocity of the left hand was slightly higher than that of high risk industrial jobs, and the right hand mean velocities were almost twice that of high risk industrial jobs in both RU and FE planes. Mean acceleration of the left hand was higher than the low risk industrial jobs but lower than the high risk ones. SLI had the highest mean accelerations on the right hand, which were 1.3 and 1.5 times of that of high risk industrial jobs in the RU and FE planes, respectively. Max/Min velocity and acceleration values of SLI on both hands were much higher than that of high risk industrial jobs. Max/Min velocities of SLI were about three times as large as that of the high risk industrial jobs, and this ratio ranged from 1.5 to 2.7 for Max/Min accelerations. Other tasks listed in Table 5.1 include mean packing, typing, machine milking and deboning of poultry, all of these which have smaller velocity and acceleration values than SLI. This result suggested that wrist movements of SLI were more ballistic than other tasks in terms of both how fast they move (velocity) and how fast they change the speed (acceleration).

The fact that no significant interaction effect was found whatsoever indicated that pace and stress factors act independently of each other. The biomechanical responses caused by one factor in different levels of the other factor were not significantly different. For example, the difference of results between fast and slow pace in stressed group was not statistically different than that in the non-stressed group.

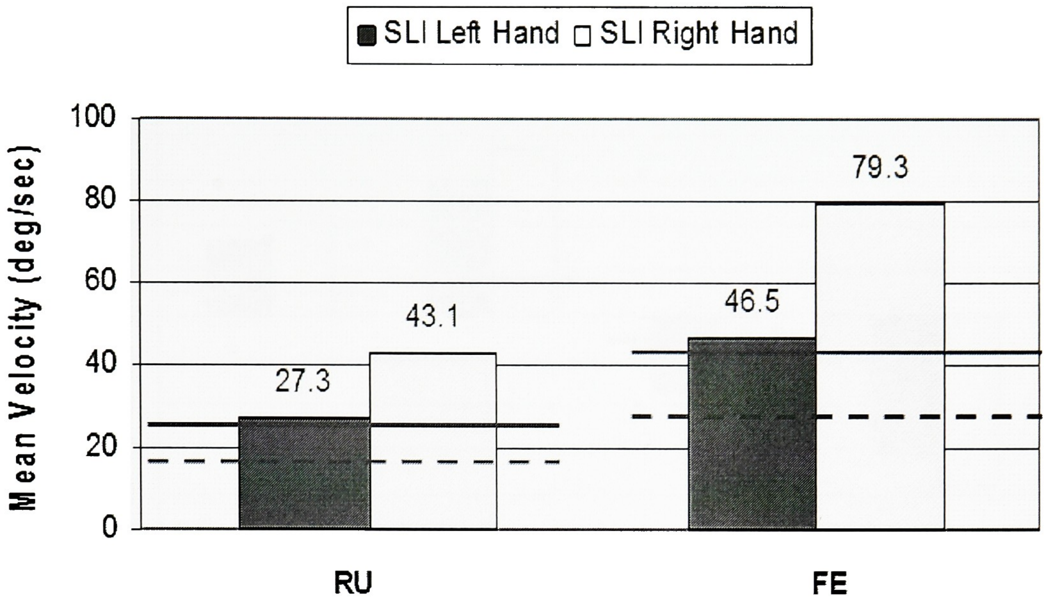


**Figure 5.2** Mean velocity of SLI comparing to the benchmarks of industrial jobs
Solid line (—) = high risk    Dashed line (- - -) = low risk

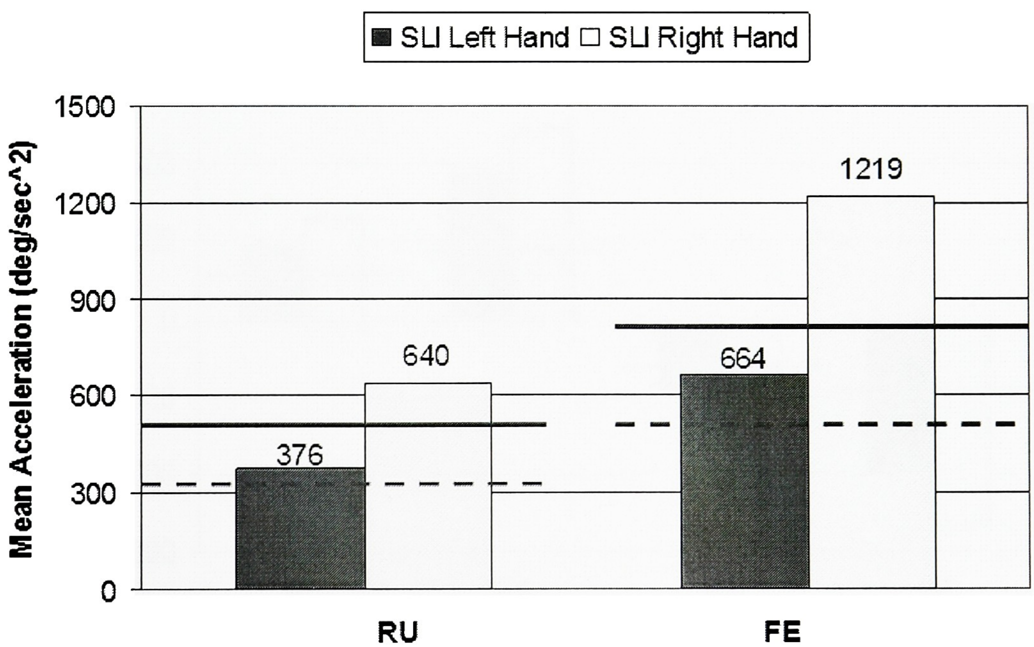


**Figure 5.3** Mean acceleration of SLI comparing to the benchmarks of industrial jobs
Solid line (—) = high risk    Dashed line (- - -) = low risk

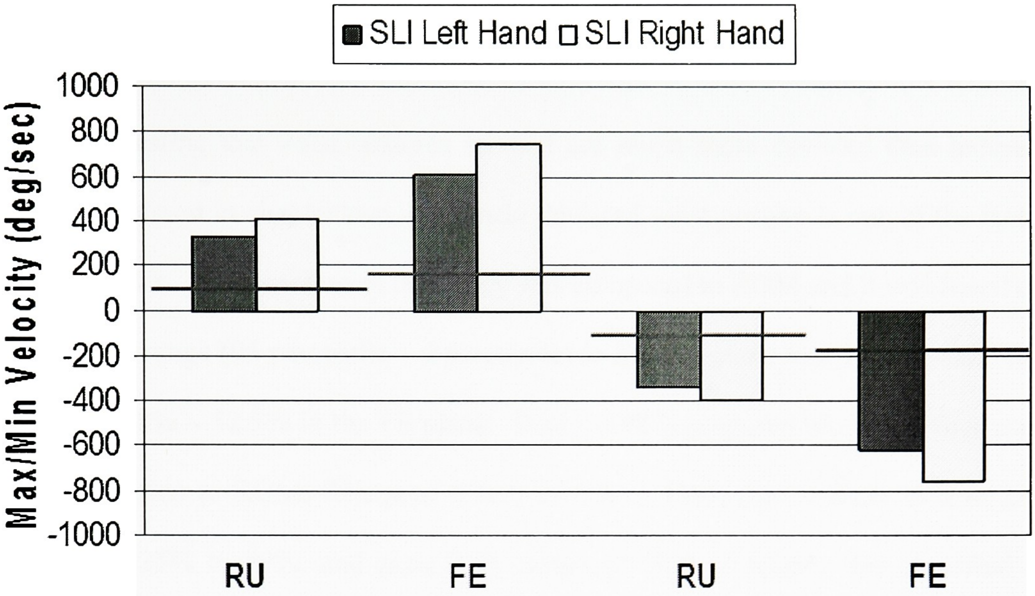


**Figure 5.4** Max/Min velocity of SLI comparing to the benchmarks of industrial jobs
Solid line (—) = high risk

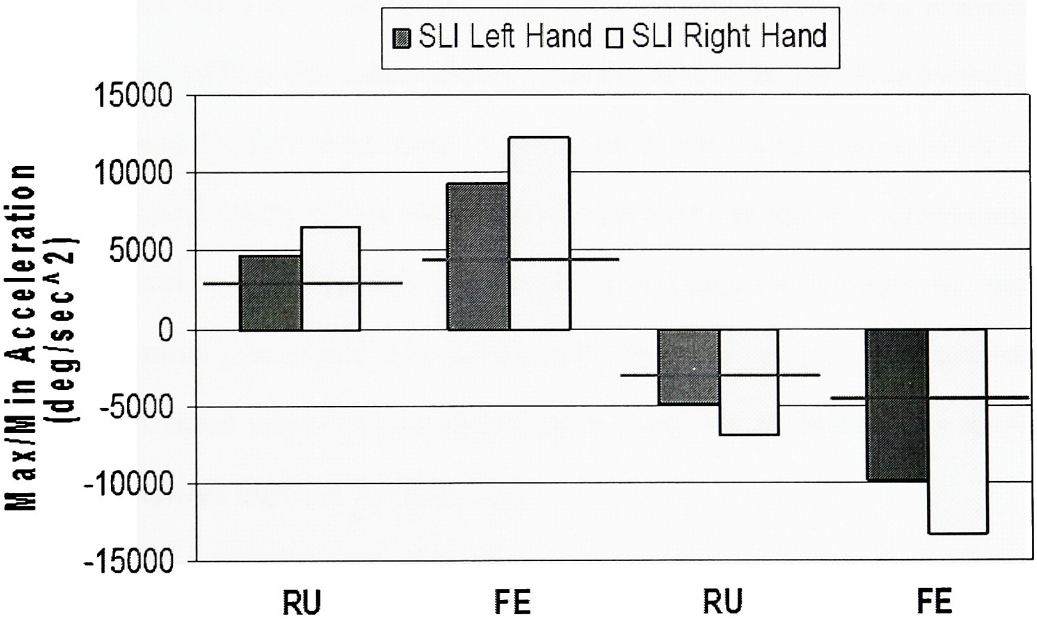


**Figure 5.5** Max/Min acceleration of SLI comparing to the benchmarks of industrial jobs
Solid line (—) = high risk

### 5.2.4 High Risk Wrist Motion, Wrist Pause and Repetition

High risk wrist positions of SLI as a percentage of total recording time was close to 50%, suggesting that wrist postures for SLI are much more deviated than industrial jobs. As discussed in chapter two, extremely deviated wrist posture is one of the factors that cause RMIs. Wrist motion of this study was compared to ROM and it was found that wrist position range (95 percentile – 5 percentile) in the RU plane was 70.7% – 82.7% of ROM and 39.8% – 52.5% in the FE plane. Drury (1987) proposed the use of four zones of risk in relation to ROM. His zone 0 is from 0% to 10%, zone 1 from 10% to 25%, zone 2 from 25% to 50%, and zone 3 in excess of 50% of ROM. He classified the respective exposures to risks as none, low, moderate, and severe. For SLI, results of this study indicated that wrist motion was within the range of severe risk in the RU plane and moderate/severe risk in the FE plane.

The time when wrist movements were faster than the most ballistic movements (<Min or > Max) of high risk industrial jobs was about 10% of the total time for the right hand, and around 5% for the left hand. Changes of velocity (acceleration) which were faster than the peak values of high risk industrial tasks were less than 4% of total time. It indicated that although the Max/Min accelerations of SLI were much higher than that of high risk industrial jobs (Table 5.1), it happened very infrequently. As suggested by Marras (1991), mean values of acceleration and velocity are the best two variables to discriminate between high and low RMI risks.

Table 5.2 summarizes the studies that have investigated wrist motion pause and MPF using the same methods as described in chapter three. In this study the results showed that sign language interpreters had very few pauses and possibilities to rest

wrists/hands during interpreting (≤ 6% for the right hand and <10% for the left hand). Compared to other occupational groups (Figure 5.6), pauses for SLI were similar to machine milking (Stål et al., 1999), except that machine milking does not have much difference between the left and right hands. This is probably because milking requires the use of both hands almost equally while SLI distinguishes dominant and non-dominant hand. Industrial quality control of earplugs (Arvidsson et al., 2003) in a manufacturing company was reported to have higher RMI symptoms among the operators than other industrial workers. Operators perform quality control of more than 20,000 earplugs per half-hour. Tasks such as industrial quality control and deboning of poultry require continuous hand/wrist movements with almost no rest because their speeds are often controlled by automated system, such as machines and conveyers. For computer aided design, the left hand was observed to move only half of the time. However, pause percentage of the right hand was similar to SLI. Sign language interpreters have chances to pause when the speaker pauses or slows down. With these pauses, interpreters may put their hands on their laps or just hold them in the air.

Another factor that causes RMIs is repetitiveness. In the study where Frølund Thomsen et al. (2002) showed an increased risk of CTS for repetitive non-forceful work, MPF as a measurement of repetitiveness was 0.53–0.79 Hz. In this study, the repetitiveness of the right hand (Table 5.2) was within this range and was lower than this range on the left hand. Repetitiveness of SLI was at the same level as other highly repetitive work with a high prevalence of upper extremity musculoskeletal disorders, such as milking, poultry processing, and industrial jobs (Figure 5.7). In a study of female industrial workers (Hansson et al., 2000), it was reported that 0.53 Hz corresponded to a

prevalence of upper extremity musculoskeletal disorders in wrists/hands of 55% and 0.40 Hz to 32%. Feuerstein et al. (1992) has reported a repetition of 4.5 Hz of SLI. However, this number was obtained from a single subject by observation analysis and did not distinguish different hands and motion planes. The highest repetition (FE-R) was around 800 for the total eleven minutes, which was more than one repetition per second.

**Table 5.2** Comparison of wrist pause and MPF with other occupations

| Task | | | | Pause (%) | MPF (Hz) |
|---|---|---|---|---|---|
| Arvidsson et al. (2003) | Industrial quality control | RU | R | 3.1 | 0.57 |
| | | | L | 2.3 | 0.52 |
| | | FE | R | 2.0 | 0.55 |
| | | | L | 1.7 | 0.41 |
| Byström et al. (2002) | Computer-aided design | RU | R | 7.8 | 0.19 |
| | | | L | 50 | 0.16 |
| | | FE | R | 5.7 | 0.31 |
| | | | L | 40 | 0.19 |
| Kristensen et al. (2002) | Deboning of poultry | RU | Mechanical | 0.16 | 0.59 |
| | | | Manual | 0.59 | 0.39 |
| | | FE | Mechanical | 0.03 | 0.60 |
| | | | Manual | 0.23 | 0.51 |
| Hansson et al. (2000) | Laminate industry | | R | 5.4 | 0.42 |
| | | | L | 4.9 | 0.41 |
| Stål et al. (1999) | Machine milking | RU | R | 7.6 | 0.47 |
| | | | L | 7.8 | 0.39 |
| | | FE | R | 4.9 | 0.50 |
| | | | L | 5.6 | 0.42 |
| This study | Sign language interpreting | RU | R | 5.2 | 0.51 |
| | | | L | 9.0 | 0.38 |
| | | FE | R | 3.6 | 0.61 |
| | | | L | 7.0 | 0.46 |

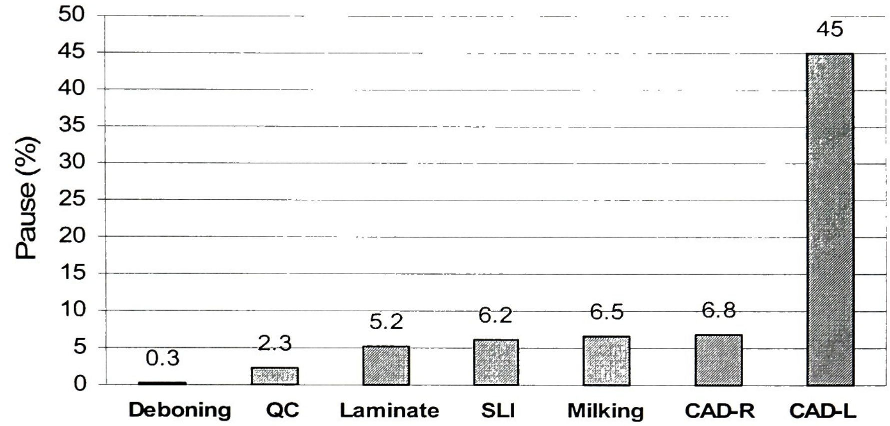


**Figure 5.6** Pause (%) for different occupations (Refer to Table 5.2)

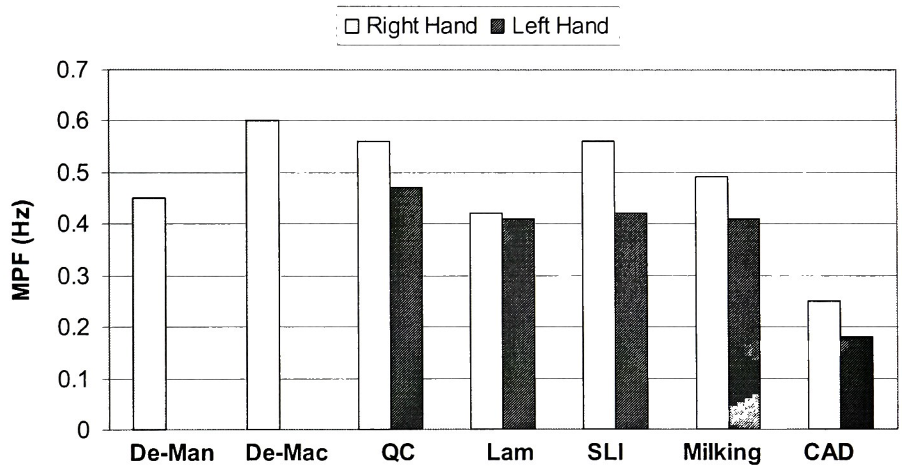


**Figure 5.7** MPF for different occupations (Refer to Table 5.2)

The occurrence of high risk wrist motion, repetition, and MPF data were consistent with the wrist motion data. High wrist velocity and acceleration corresponded to high percentage of high risk movements, more repetition/high MPF and fewer pauses, and vice versa.

Differences in the kinetic variables between SLI and other occupations may be due to the inherent characteristics of different jobs. Compared to most industrial tasks, e.g. assembly job and meat processing, SLI involves more deviated wrist positions, faster movements and more frequent changes of wrist positions and movements. It was reported that the duration of a sign is normally less than a second (Wilbur, 1979). The repetitiveness data of this study also suggested less than a second per repetition on the right hand and less than two second per repetition on the left during interpreting. Ballistic wrist movements are common in interpreting in order to perform highly deviated wrist motions in a very short time.

Right hand had higher values (fewer pauses) of almost all the dependent variables than left hand (Table 4.15), suggesting that the dominant hand is more risky to RMIs than the non-dominant hand. This is consistent with the information (Marschark, 2005) that sign language interpreters at NTID had more problems on their dominant than the non-dominant hand, and that the dominant hand tended to have problems earlier than the non-dominant hand.

Although the above analysis suggests that SLI involves more ballistic wrist movement and more deviated wrist position comparing to industrial jobs, the following two differences between SLI and industrial jobs should be noted when evaluating their overall RMI risks. First, SLI and industrial jobs have different work/rest cycles. The average working hours per week in this study (25.7 hours, SD=3.9) is typical for educational sign language interpreters. Normally, classes are less than 120 minutes and two interpreters alternate with each other every half an hour during each class. So interpreters have breaks during and between interpreting sessions. However, industrial

workers normally work eight hours per day (40 hours/week) continuously. This may increase RMI risk on industrial jobs. Another difference is that most of the industrial jobs require exertion of handgrip forces while SLI is a non-forceful job. As described in chapter two, forceful exertion is one of the three biomechanical factors (repetition, deviated posture and force) which cause RMIs. The combination of forceful handgrip with repetitive motion may pose additional risk to industrial workers.

## 5.3 Other Measurements

No significant difference between high and low levels of pace and stress factor was found on normalized EMG data of upper trapezius muscle. However, the $50^{th}$ and $90^{th}$ percentile EMG of the stressed group was slightly higher than the non-stressed group (Table 4.16). MPF was within the 50-80 Hz range of unfatigued muscle, which may be because the total recording time was not long enough to generate fatigue on trapezius muscle. No effect of pace or stress on HR was found in this study. HR was slightly higher than the 75 beats/min normal resting values (Marieb, 1999), indicating a somewhat high stress/arousal state of subjects as a whole. It was found that stress had an influence on subjective perception of discomfort, though on an absolute scale, discomfort was very small (Table 4.18). The stressed group reported more discomfort and the non-stressed group and right shoulder is the most common place for discomfort. As discomfort may be considered a cumulative effect, it was not surprising to have a lack of discomfort over the relatively short experimental period.

## 5.4 Limitations

Certain Factors affected the results of this study, such as issues regarding measurement system, methods used for data collection and calculation, and possible confounding influences on subjective psychosocial perception. Some of the most relevant sources of errors and/or limitations are listed below.

- Stress factor was measured and validated by a single subjective metric. HR and HR variability can be used as a supplementary metric of psychological status. However, HR data did not show significant differences between different experimental conditions. It is ideal to get a resting HR measurement before the experiment and compare the relative change of HR in different conditions. It is somewhat difficult to get a good baseline HR as subjects get stimulated once they arrived and HR rose before actual recording.
- There is not a standardized data processing method for wrist motion as there is for EMG data. Different filters, smoothing and calculation methods were used in various studies and could have influences on the results. Marras et al. (1991) used self-designed filters incorporated to their measurement equipment and other researchers (Serina et al., 1999; Hansson et al., 1996) used post-hoc computer analysis to process the data. This study used the latter one. When comparing to other studies, the potential differences caused by different measurements and calculations methods should be considered.
- Lack of significant findings of EMG and discomfort ratings may due to the limited time frame of this study. Sign language interpreters normally work at least 20 hours per week. Fatigue and discomfort are cumulative effects of

repeated exertions of hours, days, weeks or longer. So half an hour recording may be too short to obtain any significant findings of muscle fatigue and the perception of discomfort.

## 5.5 Future Research

- Use multiple evaluation metrics to measure stress and arousal levels, e.g. continuous HR/HR variability, skin conductance, and blood pressure. These psychophysical measures were used in studies and reported to be correlated with stress (Wahlström et al., 2002; Thayer, 1970). One or more measurement together with SACL can be used at a time.
- The experimental environment and the stressors used in this study may be somewhat different than the real working environment. Although it is not believed to have much difference on the performance of subjects, future research should look at more complicated real working conditions than the experimental settings.
- There are many factors that may influence the biomechanical responses of sign language interpreters and their perception of stress/arousal. Future research is needed to investigate what other factors are besides the ones used in this study and how they influence the performance of interpreters.
- Incorporate interpreting accuracy analysis into the biomechanical analysis of SLI. This study investigated the biomechanical characteristics of SLI without considering the potential tradeoff between interpreting accuracy and biomechanical characteristics. Thus their relationship remains unknown.

- Another limiting factor could be the sample size of the study. Although a sample size of 12 subjects was employed, a larger sample size would help reduce variability and increase the power. In addition, a subject group with more homogeneous demographic data would reduce more potential confounding factors.
- Longitudinal research is needed to study the effect of various factors on biomechanical responses of sign language interpreters in relation to RMIs. Although SLI has been identified for more than a decade as one of the jobs that have a high prevalence of RMIs, studies which investigated biomechanical responses quantitatively were sparse.

# CHAPTER 6

# Conclusion

This study investigated the effect of pace and psychosocial stress on the biomechanical responses of sign language interpreters in a quantitative manner. In addition, kinematic variables of SLI were compared with other occupations identified as high risk jobs of RMIs. A total of twelve professional sign language interpreters participated in this study with half an hour interpreting task for each subject.

The general founding was that biomechanical responses in both hands were significantly affected by pace, while only the left hand was significantly affected by stress. Pace was found to have a significant effect on the mean velocity, acceleration, wrist pauses and repetitiveness of both hands. Fast pace resulted in higher velocity, acceleration, more repetitions and fewer pauses than slow pace. However, significant stress effects on mean velocity, acceleration and extreme position (Min, Max and Range) were found only in the left hand with the stressed group having higher values than the non-stressed group. High risk velocity/acceleration in the FE plane and repetitiveness of the left hand were significantly higher in the stressed group than the non-stressed group. No interaction effect was found indicating that pace and stress factor worked independently from each other. Right (dominant) hand was found to have much higher wrist motion (fewer pauses) values than the left (non-dominant) hand.

Marras (1991) reported that FE acceleration and FE velocity were the best two parameters to discriminate between low and high risk groups for industrial jobs. Wrist velocity of both hands and wrist acceleration of the right hand of SLI were higher than

the high risk industrial benchmarks. Acceleration of the left hand was between the high and low risk industrial benchmarks. It was also found that wrists were more deviated than high risk industrial jobs. In addition, the repetitiveness of SLI was within the high risk range of CTS for repetitive non-forceful work (Frølund Thomsen et al., 2002) and was similar to other occupations with high prevalence of upper extremity musculoskeletal disorders.

It was evident from the foregoing results that SLI is a high risk occupation of upper extremity RMIs, regardless of different pace and stress conditions. This study provided evidence and support for the high prevalence of RMIs among sign language interpreters from the biomechanical perspective which filled in the void of such studies. In addition, the relationship between pace/stress and biomechanical responses of wrist motion were investigated which provided useful information to control these variables in order to reduce biomechanical stress on sign language interpreters.

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## Appendix A: Consent Form

Title of Project: Effects of job-related factors on the biomechanics of sign language interpreting

Investigator(s): Dr. Matthew M. Marshall and Jin Qin

I understand that I am being asked to voluntarily participate in a study at Rochester Institute of Technology that involves evaluating the biomechanics of sign language interpreting. The purpose of this study is to how characteristics of the interpreting task affect the biomechanics of the wrist and the muscle activity of the upper back.

The goal of this research is to gain a better understanding of the factors that lead to cumulative trauma disorders so that steps may be made in the future to reduce or eliminate the prevalence of these disorders among sign language interpreters. The results may also be extended to other occupations that require higher levels of upper extremity exertion.

This study involves having a surface electrode placed over the trapezius muscle in my upper back and electrogoniometers placed over both my wrists. These instruments will be connected by a cable to a computer for data collection. The investigator will demonstrate and describe the instruments prior to placing them on my arms and back. Once the sensors are attached, I will perform an interpreting task for 30 minutes, during which time the instrumentation will remain on my arms and back. The sign language interpreting task will consist of pre-recorded material. The pace of the material will vary throughout the session. The interpreting session will be videotaped for future observational analysis.

The risks of the study are minimal. The cables extending from the instrumentation to the portable computer might interfere with my work activities, although every attempt will be made to minimize this potential problem. I understand that my participation in this study is voluntary and I may stop at any time, without penalty. I am under no pressure to participate.

I will receive payment of $30 for participating in this study. I realize that I am voluntarily participating in this project and can withdraw from participation at any time. I have read (or have explained) the information given above. I understand the meaning of this instrumentation. Project personnel have offered to answer any questions I may have concerning the study and have provided complete answers to all my questions. I hereby consent to participate in this study. One copy of this document will be kept together with our research records on this study at RIT. As a participant I will receive a copy to keep if I request it.

Name: Date:

Witness: Date:

## Appendix B: Screening Questionnaire

### Nordic Questionnaire

Please answer the following questions, circling one of the following, where appropriate. You may skip any question you feel uncomfortable answering.

| | | To be answered only by those who have had trouble | |
|---|---|---|---|
| Have you at any time during the last 12 months had trouble (ache, pain, discomfort) in: | | Have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble? | Have you had trouble at any time during the last 7 days? |
| **Hands/Fingers:** | | | |
| 1. no | 2. yes, in right hand/fingers<br>3. yes, in left hand/fingers<br>4. yes, in both hands/fingers | 1. no 2. yes | 1. no 2. yes |
| **Wrists:** | | | |
| 1. no | 2. yes, in right wrist<br>3. yes, in left wrist<br>4. yes, in both wrists | 1. no 2. yes | 1. no 2. yes |
| **Arms/Elbows:** | | | |
| 1. no | 2. yes, in right arm/elbow<br>3. yes, in left arm/elbow<br>4. yes, in both arms/elbows | 1. no 2. yes | 1. no 2. yes |
| **Shoulders:** | | | |
| 1. no | 2. yes, in right shoulder<br>3. yes, in left shoulder<br>4. yes, in both shoulders | 1. no 2. yes | 1. no 2. yes |

## Appendix C: Demographic Data

Name:

Gender: Female Male

Age:

Dominant hand: right-handed left-handed

How long have you been signing?

How long have you been interpreting?

How many hours do you work (interpreting) per week?

## Appendix D: Stress-Arousal Checklist

The words shown below describe different feelings and moods. Please use this list to describe your feelings at this moment:

1. If the word *definitely* describes your feelings, circle the double plus (++).
2. If the word *more or less* describes your feelings, circle the plus (+).
3. If you do not understand the word, or you *can not decide* whether or not it describes how you feel, circle the question mark (?).
4. If the word *does not describe* the way you feel, circle the minus (−).

| | Adjective | Definitely Feel ++ | Feel Slightly + | Not Sure ? | Definitely Do Not Feel — |
|---|---|---|---|---|---|
| 1 | Tense | | | | |
| 2 | Worried | | | | |
| 3 | Apprehensive | | | | |
| 4 | Bothered | | | | |
| 5 | Uneasy | | | | |
| 6 | Dejected | | | | |
| 7 | Up-tight | | | | |
| 8 | Jittery | | | | |
| 9 | Nervous | | | | |
| 10 | Distressed | | | | |
| 11 | Peaceful | | | | |
| 12 | Relaxed | | | | |
| 13 | Cheerful | | | | |
| 14 | Contented | | | | |
| 15 | Pleasant | | | | |
| 16 | Comfortable | | | | |
| 17 | Calm | | | | |
| 18 | Restful | | | | |
| 19 | Active | | | | |
| 20 | Energetic | | | | |
| 21 | Vigorous | | | | |
| 22 | Alert | | | | |
| 23 | Lively | | | | |
| 24 | Activated | | | | |
| 25 | Stimulated | | | | |
| 26 | Drowsy | | | | |
| 27 | Tired | | | | |
| 28 | Idle | | | | |
| 29 | Sluggish | | | | |
| 30 | Sleepy | | | | |

## Appendix E: Ratings of Perceived Discomfort

Referring to the following scales, please rate the discomfort level at each region listed below (decimal number could be used e.g. 4.5)

| | | |
|---|---|---|
| 0 | Not at all | |
| 0.5 | Very, very light | (just noticeable) |
| 1 | Very light | |
| 2 | Light | |
| 3 | Moderate | |
| 4 | Somewhat strong | |
| 5 | Strong | (heavy) |
| 6 | | |
| 7 | Very strong | |
| 8 | | |
| 9 | | |
| 10 | Very, very strong | (almost max) |

**Hands/Fingers:**

left right

**Wrists:**

left right

**Arms/Elbows:**

left right

**Shoulders:**

left right

# Appendix F: Results of Statistical Analysis

## Significant Main effects on Wrist Motion Variables

### Two-way ANOVA: mean RU-R-V versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 140.215 | 140.215 | 6.94 | 0.016 |
| stress | 1 | 8.652 | 8.652 | 0.43 | 0.520 |
| Interaction | 1 | 20.039 | 20.039 | 0.99 | 0.331 |
| Error | 20 | 404.325 | 20.216 | | |
| Total | 23 | 573.231 | | | |

S = 4.496   R-Sq = 29.47%   R-Sq(adj) = 18.89%

### Two-way ANOVA: mean FE-R-V versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 390.02 | 390.023 | 4.72 | 0.042 |
| stress | 1 | 0.02 | 0.018 | 0.00 | 0.988 |
| Interaction | 1 | 27.63 | 27.628 | 0.33 | 0.570 |
| Error | 20 | 1652.75 | 82.638 | | |
| Total | 23 | 2070.42 | | | |

S = 9.091   R-Sq = 20.17%   R-Sq(adj) = 8.20%

### Two-way ANOVA: mean RU-L-V versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 58.594 | 58.594 | 3.62 | 0.072 |
| stress | 1 | 103.834 | 103.834 | 6.41 | 0.020 |
| Interaction | 1 | 1.135 | 1.135 | 0.07 | 0.794 |
| Error | 20 | 324.026 | 16.201 | | |
| Total | 23 | 487.588 | | | |

S = 4.025   R-Sq = 33.55%   R-Sq(adj) = 23.58%

### Two-way ANOVA: mean FE-L-V versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 279.55 | 279.552 | 8.53 | 0.008 |
| stress | 1 | 408.62 | 408.623 | 12.47 | 0.002 |
| Interaction | 1 | 19.75 | 19.747 | 0.60 | 0.447 |
| Error | 20 | 655.52 | 32.776 | | |
| Total | 23 | 1363.44 | | | |

S = 5.725   R-Sq = 51.92%   R-Sq(adj) = 44.71%

### Two-way ANOVA: mean RU-R-A versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 42143 | 42143.0 | 9.09 | 0.007 |

| | | | | | |
|---|---|---|---|---|---|
| stress | 1 | 0 | 0.2 | 0.00 | 0.995 |
| Interaction | 1 | 7515 | 7515.4 | 1.62 | 0.218 |
| Error | 20 | 92705 | 4635.3 | | |
| Total | 23 | 142364 | | | |

S = 68.08   R-Sq = 34.88%   R-Sq(adj) = 25.11%

### Two-way ANOVA: mean FE-R-A versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 132269 | 132269 | 4.97 | 0.037 |
| stress | 1 | 16084 | 16084 | 0.60 | 0.446 |
| Interaction | 1 | 11922 | 11922 | 0.45 | 0.511 |
| Error | 20 | 532693 | 26635 | | |
| Total | 23 | 692968 | | | |

S = 163.2   R-Sq = 23.13%   R-Sq(adj) = 11.60%

### Two-way ANOVA: mean RU-L-A versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 20074 | 20074.0 | 4.84 | 0.040 |
| stress | 1 | 16094 | 16094.3 | 3.88 | 0.063 |
| Interaction | 1 | 149 | 148.5 | 0.04 | 0.852 |
| Error | 20 | 82872 | 4143.6 | | |
| Total | 23 | 119188 | | | |

S = 64.37   R-Sq = 30.47%   R-Sq(adj) = 20.04%

### Two-way ANOVA: mean FE-L-A versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 76569 | 76568.8 | 11.49 | 0.003 |
| stress | 1 | 57918 | 57918.4 | 8.69 | 0.008 |
| Interaction | 1 | 2613 | 2612.5 | 0.39 | 0.538 |
| Error | 20 | 133309 | 6665.4 | | |
| Total | 23 | 270409 | | | |

S = 81.64   R-Sq = 50.70%   R-Sq(adj) = 43.31%

## Repetition

### Two-way ANOVA: RU R versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 30317.0 | 30317.0 | 11.60 | 0.003 |
| stress | 1 | 590.0 | 590.0 | 0.23 | 0.640 |
| Interaction | 1 | 2072.0 | 2072.0 | 0.79 | 0.384 |
| Error | 20 | 52289.5 | 2614.5 | | |
| Total | 23 | 85268.6 | | | |

S = 51.13   R-Sq = 38.68%   R-Sq(adj) = 29.48%

### Two-way ANOVA: FE R versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 50142 | 50142.0 | 5.61 | 0.028 |
| stress | 1 | 4902 | 4902.0 | 0.55 | 0.467 |
| Interaction | 1 | 3480 | 3480.0 | 0.39 | 0.540 |
| Error | 20 | 178615 | 8930.7 | | |
| Total | 23 | 237139 | | | |

S = 94.50   R-Sq = 24.68%   R-Sq(adj) = 13.38%

### Two-way ANOVA: RU L versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 15301.5 | 15301.5 | 7.19 | 0.014 |
| stress | 1 | 10004.2 | 10004.2 | 4.70 | 0.042 |
| Interaction | 1 | 1.5 | 1.5 | 0.00 | 0.979 |
| Error | 20 | 42583.3 | 2129.2 | | |
| Total | 23 | 67890.5 | | | |

S = 46.14   R-Sq = 37.28%   R-Sq(adj) = 27.87%

### Two-way ANOVA: FE L versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 33078 | 33078.4 | 10.14 | 0.005 |
| stress | 1 | 14455 | 14455.0 | 4.43 | 0.048 |
| Interaction | 1 | 70 | 70.0 | 0.02 | 0.885 |
| Error | 20 | 65232 | 3261.6 | | |
| Total | 23 | 112835 | | | |

S = 57.11   R-Sq = 42.19%   R-Sq(adj) = 33.52%

## Pause

### Two-way ANOVA: RU R versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 11.6204 | 11.6204 | 11.24 | 0.003 |
| stress | 1 | 0.1837 | 0.1837 | 0.18 | 0.678 |
| Interaction | 1 | 0.0504 | 0.0504 | 0.05 | 0.827 |
| Error | 20 | 20.6750 | 1.0338 | | |
| Total | 23 | 32.5296 | | | |

S = 1.017   R-Sq = 36.44%   R-Sq(adj) = 26.91%

### Two-way ANOVA: FE R versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 8.1667 | 8.16667 | 9.87 | 0.005 |
| stress | 1 | 0.2400 | 0.24000 | 0.29 | 0.596 |
| Interaction | 1 | 0.2017 | 0.20167 | 0.24 | 0.627 |
| Error | 20 | 16.5500 | 0.82750 | | |
| Total | 23 | 25.1583 | | | |

S = 0.9097   R-Sq = 34.22%   R-Sq(adj) = 24.35%

### Two-way ANOVA: RU L versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 9.8817 | 9.88167 | 6.80 | 0.017 |
| stress | 1 | 4.5067 | 4.50667 | 3.10 | 0.093 |
| Interaction | 1 | 1.2150 | 1.21500 | 0.84 | 0.371 |
| Error | 20 | 29.0500 | 1.45250 | | |
| Total | 23 | 44.6533 | | | |

S = 1.205   R-Sq = 34.94%   R-Sq(adj) = 25.18%

### Two-way ANOVA: FE L versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 12.7604 | 12.7604 | 7.12 | 0.015 |
| stress | 1 | 7.3704 | 7.3704 | 4.11 | 0.056 |
| Interaction | 1 | 0.2604 | 0.2604 | 0.15 | 0.707 |
| Error | 20 | 35.8483 | 1.7924 | | |
| Total | 23 | 56.2396 | | | |

S = 1.339   R-Sq = 36.26%   R-Sq(adj) = 26.70%

## High Risk V/A

### Two-way ANOVA: FE-L-V versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 0.0008097 | 0.0008097 | 5.18 | 0.034 |
| stress | 1 | 0.0017137 | 0.0017137 | 10.97 | 0.003 |
| Interaction | 1 | 0.0003840 | 0.0003840 | 2.46 | 0.133 |
| Error | 20 | 0.0031256 | 0.0001563 | | |
| Total | 23 | 0.0060329 | | | |

S = 0.01250   R-Sq = 48.19%   R-Sq(adj) = 40.42%

### Two-way ANOVA: FE-L-A versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 0.0000601 | 0.0000601 | 4.51 | 0.046 |
| stress | 1 | 0.0000927 | 0.0000927 | 6.97 | 0.016 |
| Interaction | 1 | 0.0000043 | 0.0000043 | 0.32 | 0.575 |
| Error | 20 | 0.0002663 | 0.0000133 | | |
| Total | 23 | 0.0004234 | | | |

S = 0.003649   R-Sq = 37.12%   R-Sq(adj) = 27.68%

## Main Effects on Electromyography Data

### Two-way ANOVA: 10th versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| pace | 1 | 0.000363 | 0.0003635 | 0.02 | 0.900 |
| stress | 1 | 0.004834 | 0.0048337 | 0.21 | 0.648 |
| Interaction | 1 | 0.000193 | 0.0001927 | 0.01 | 0.927 |
| Error | 20 | 0.449688 | 0.0224844 | | |
| Total | 23 | 0.455078 | | | |

S = 0.1499   R-Sq = 1.18%   R-Sq(adj) = 0.00%

### Two-way ANOVA: 50th versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 0.000029 | 0.0000290 | 0.00 | 0.979 |
| stress | 1 | 0.000958 | 0.0009576 | 0.02 | 0.880 |
| Interaction | 1 | 0.000005 | 0.0000049 | 0.00 | 0.991 |
| Error | 20 | 0.822037 | 0.0411019 | | |
| Total | 23 | 0.823029 | | | |

S = 0.2027   R-Sq = 0.12%   R-Sq(adj) = 0.00%

### Two-way ANOVA: 90th versus pace, stress

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| pace | 1 | 0.00050 | 0.0005042 | 0.01 | 0.939 |
| stress | 1 | 0.06623 | 0.0662340 | 0.78 | 0.388 |
| Interaction | 1 | 0.00004 | 0.0000350 | 0.00 | 0.984 |
| Error | 20 | 1.69781 | 0.0848905 | | |
| Total | 23 | 1.76458 | | | |

S = 0.2914   R-Sq = 3.78%   R-Sq(adj) = 0.00%

## Hear Rate

### Paired T-Test and CI: HR-fast, HR-slow

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| HR1 | 12 | 90.3667 | 12.7095 | 3.6689 |
| HR2 | 12 | 88.6650 | 12.4746 | 3.6011 |
| Difference | 12 | 1.70167 | 3.35985 | 0.96991 |

95% CI for mean difference: (-0.43308, 3.83641)
T-Test of mean difference = 0 (vs not = 0): T-Value = 1.75   P-Value = 0.107

### Paired T-Test and CI: HR-stressed, HR-non-stressed

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| HR3 | 12 | 91.0842 | 13.7385 | 3.9660 |
| HR4 | 12 | 87.9475 | 11.1631 | 3.2225 |
| Difference | 12 | 3.13667 | 19.44122 | 5.61220 |

95% CI for mean difference: (-9.21570, 15.48903)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.56   P-Value = 0.587

## Stress and Arousal

### Original groups

#### Two-Sample T-Test and CI: stress1, stress 2

```
Two-sample T for stressed vs non-stressed

              N  Mean  StDev  SE Mean
stressed      6  6.83   6.05      2.5
non-stressed  6   5.5   14.6      6.0


Difference = mu (stressed) - mu (non-stressed)
Estimate for difference:  1.33333
95% CI for difference:  (-14.48877, 17.15544)
T-Test of difference = 0 (vs not =): T-Value = 0.21  P-Value = 0.843  DF = 6
```

#### Two-Sample T-Test and CI: arousal 1, arousal 2

```
Two-sample T for stressed vs non-stressed

              N  Mean  StDev  SE Mean
stressed      6  4.50   6.09      2.5
non-stressed  6  4.33   5.47      2.2


Difference = mu (stressed)   mu (non-stressed)
Estimate for difference:  0.166667
95% CI for difference:  (-7.390804, 7.724138)
T-Test of difference = 0 (vs not =): T-Value = 0.05  P-Value = 0.961  DF = 9
```

### Adjusted Groups

#### Two-Sample T-Test and CI: stress1, stress2

```
Two-sample T for stressed vs non-stressed

              N   Mean  StDev  SE Mean
stressed      6   13.5   10.8      4.4
non-stressed  6  -1.17   2.40     0.98


Difference = mu (stressed)   mu (non-stressed)
Estimate for difference:  14.6667
95% CI for difference:  (3.0342, 26.2992)
T-Test of difference = 0 (vs not =): T-Value = 3.24  P-Value = 0.023  DF = 5
```

#### Two-Sample T-Test and CI: arousal1, arousal2

```
Two-sample T for stressed vs non-stressed

              N  Mean  StDev  SE Mean
stressed      6  7.83   5.49      2.2
non-stressed  6  1.00   2.97      1.2
```

```
Difference = mu (stressed)   mu (non-stressed)
Estimate for difference:  6.83333
95% CI for difference:  (0.80728, 12.85939)
T-Test of difference = 0 (vs not =): T-Value = 2.68  P-Value = 0.031  DF = 7
```

## Demographic Data after Adjusting

### 1: stressed group   2: non-stressed group

### Paired T-Test and CI: age1, age2

```
             N      Mean      StDev   SE Mean
age1         6   40.8333    15.2501    6.2258
age2         6   41.6667     5.7155    2.3333
Difference   6 -0.833333  15.144856  6.182862


95% CI for mean difference: (-16.726885, 15.060218)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.13  P-Value = 0.898
```

### Paired T-Test and CI: sign1, sign2

```
             N      Mean     StDev  SE Mean
sign1        6   18.3333    8.8015   3.5932
sign2        6   28.0000    9.0056   3.6765
Difference   6  -9.66667  15.35470  6.26853


95% CI for mean difference: (-25.78043, 6.44710)
T-Test of mean difference = 0 (vs not = 0). T-Value = -1.54  P-Value = 0.184
```

### Paired T-Test and CI: interpret1, interpret2

```
             N      Mean    StDev  SE Mean
interpret1   6   13.0000   5.4772   2.2361
interpret2   6   19.2500   6.9839   2.8512
Difference   6  -6.25000  7.53492  3.07612


95% CI for mean difference: (-14.15741, 1.65741)
T-Test of mean difference = 0 (vs not = 0): T-Value = -2.03  P-Value = 0.098
```

### Paired T-Test and CI: hour1, hour2

```
             N      Mean    StDev  SE Mean
hour1        6   25.0833   4.2475   1.7341
hour2        6   26.3333   4.1433   1.6915
Difference   6  -1.25000  6.59356  2.69181
95% CI for mean difference: (-8.16951, 5.66951)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.46  P-Value = 0.662
```

## Comparison between right and left hands

### Paired T-Test and CI: mean FE-R-P, FE-L-P

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| p2 | 24 | -11.8847 | 9.6863 | 1.9772 |
| p4 | 24 | -6.1865 | 8.3096 | 1.6962 |
| Difference | 24 | -5.69817 | 4.84932 | 0.98986 |

95% CI for mean difference: (-7.74586, -3.65048)
T-Test of mean difference = 0 (vs not = 0): T-Value = -5.76 P-Value = 0.000

### Paired T-Test and CI: mean RU-R-V, RU-L-V

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| mean v1 | 24 | 43.0588 | 4.9923 | 1.0190 |
| v3 | 24 | 27.3267 | 4.6043 | 0.9398 |
| Difference | 24 | 15.7321 | 4.0179 | 0.8202 |

95% CI for mean difference: (14.0355, 17.4287)
T-Test of mean difference = 0 (vs not = 0): T-Value = 19.18 P-Value = 0.000

### Paired T-Test and CI: mean FE-R-V, FE-L-V

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| v2 | 24 | 79.3071 | 9.4878 | 1.9367 |
| v4 | 24 | 46.4763 | 7.6993 | 1.5716 |
| Difference | 24 | 32.8308 | 9.4181 | 1.9225 |

95% CI for mean difference: (28.8539, 36.8078)
T-Test of mean difference = 0 (vs not = 0): T-Value = 17.08 P-Value = 0.000

### Paired T-Test and CI: mean RU-R-A, RU-L-A

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| mean a1 | 24 | 639.954 | 78.675 | 16.059 |
| a3 | 24 | 375.796 | 71.987 | 14.694 |
| Difference | 24 | 264.158 | 67.324 | 13.742 |

95% CI for mean difference: (235.730, 292.587)
T-Test of mean difference = 0 (vs not = 0): T-Value = 19.22 P-Value = 0.000

### Paired T-Test and CI: mean FE-R-A, FE-L-A

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| a2 | 24 | 1218.71 | 173.58 | 35.43 |
| a4 | 24 | 663.46 | 108.43 | 22.13 |
| Difference | 24 | 555.254 | 169.843 | 34.669 |

95% CI for mean difference: (483.536, 626.972)
T-Test of mean difference = 0 (vs not = 0): T-Value = 16.02 P-Value = 0.000

**Paired T-Test and CI: min FE-R-P, FE-L-P**

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| min p2 | 24 | -64.0317 | 11.6589 | 2.3799 |
| min p4 | 24 | -59.7058 | 9.6609 | 1.9720 |
| Difference | 24 | -4.32583 | 7.75756 | 1.58351 |

95% CI for mean difference: (-7.60156, -1.05010)
T-Test of mean difference = 0 (vs not = 0): T-Value = -2.73  P-Value = 0.012

**Paired T-Test and CI: min RU-R-V, RU-L-V**

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| min v1 | 24 | -398.883 | 56.419 | 11.516 |
| min v3 | 24 | -335.896 | 51.658 | 10.545 |
| Difference | 24 | -62.9875 | 63.1801 | 12.8966 |

95% CI for mean difference: (-89.6661, -36.3089)
T-Test of mean difference = 0 (vs not = 0): T-Value = -4.88  P-Value = 0.000

**Paired T-Test and CI: min FE-R-V, FE-L-V**

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| min v2 | 24 | -759.425 | 104.621 | 21.356 |
| min v4 | 24 | -614.121 | 98.879 | 20.184 |
| Difference | 24 | -145.304 | 116.242 | 23.728 |

95% CI for mean difference: (-194.389, -96.220)
T-Test of mean difference = 0 (vs not = 0): T-Value = -6.12  P-Value = 0.000

**Paired T-Test and CI: min RU-R-A, RU-L-A**

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| min a1 | 24 | -7026.58 | 1252.50 | 255.66 |
| min a3 | 24 | -4861.46 | 976.19 | 199.26 |
| Difference | 24 | -2165.13 | 1472.32 | 300.54 |

95% CI for mean difference: (-2786.83, -1543.42)
T-Test of mean difference = 0 (vs not = 0): T-Value = -7.20  P-Value = 0.000

**Paired T-Test and CI: min FE-R-A, FE-L-A**

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| min a2 | 24 | -13307.6 | 2656.1 | 542.2 |
| min a4 | 24 | -9912.7 | 1781.4 | 363.6 |
| Difference | 24 | -3394.96 | 2501.36 | 510.59 |

95% CI for mean difference: (-4451.19, -2338.73)
T-Test of mean difference = 0 (vs not = 0): T-Value = -6.65  P-Value = 0.000

## Paired T-Test and CI: max FE-R-P, FE-L-P

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| max p2 | 24 | 65.2267 | 10.6205 | 2.1679 |
| max p4 | 24 | 59.5404 | 10.8056 | 2.2057 |
| Difference | 24 | 5.68625 | 10.41436 | 2.12582 |

95% CI for mean difference: (1.28865, 10.08385)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.67 P-Value = 0.014

## Paired T-Test and CI: max RU-R-V, RU-L-V

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| max v1 | 24 | 409.329 | 57.040 | 11.643 |
| max v3 | 24 | 329.071 | 57.319 | 11.700 |
| Difference | 24 | 80.2583 | 76.8768 | 15.6924 |

95% CI for mean difference: (47.7961, 112.7205)
T-Test of mean difference = 0 (vs not = 0): T-Value = 5.11 P-Value = 0.000

## Paired T-Test and CI: max FE-R-V, FE-L-V

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| max v2 | 24 | 741.333 | 83.735 | 17.092 |
| max v4 | 24 | 604.392 | 99.435 | 20.297 |
| Difference | 24 | 136.942 | 101.486 | 20.716 |

95% CI for mean difference: (94.088, 179.795)
T-Test of mean difference = 0 (vs not = 0): T-Value = 6.61 P-Value = 0.000

## Paired T-Test and CI: max RU-R-A, RU-L-A

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| max a1 | 24 | 6577.17 | 998.34 | 203.79 |
| max a3 | 24 | 4783.08 | 931.01 | 190.04 |
| Difference | 24 | 1794.08 | 1177.19 | 240.29 |

95% CI for mean difference: (1297.00, 2291.17)
T-Test of mean difference = 0 (vs not = 0): T-Value = 7.47 P-Value = 0.000

## Paired T-Test and CI: max FE-R-A, FE-L-A

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| max a2 | 24 | 12241.6 | 2559.3 | 522.4 |
| max a4 | 24 | 9289.0 | 2039.0 | 416.2 |
| Difference | 24 | 2952.63 | 2780.78 | 567.62 |

95% CI for mean difference: (1778.41, 4126.84)
T-Test of mean difference = 0 (vs not = 0): T-Value = 5.20 P-Value = 0.000

### Paired T-Test and CI: range RU-R-P, range RU-L-P

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| diff p1 | 24 | 78.5208 | 7.8711 | 1.6067 |
| diff p3 | 24 | 70.7800 | 8.9901 | 1.8351 |
| Difference | 24 | 7.74083 | 7.46402 | 1.52359 |

95% CI for mean difference: (4.58905, 10.89261)
T-Test of mean difference = 0 (vs not = 0): T-Value = 5.08  P-Value = 0.000

### Paired T-Test and CI: range FE-R-P, range FE-L-P

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| diff p2 | 24 | 129.260 | 8.992 | 1.835 |
| diff p4 | 24 | 119.249 | 10.349 | 2.112 |
| Difference | 24 | 10.0113 | 12.3196 | 2.5147 |

95% CI for mean difference: (4.8092, 15.2133)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.98  P-Value = 0.001

### Paired T-Test and CI: range RU-R-V, range RU-L-V

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| diff v1 | 24 | 808.217 | 98.117 | 20.028 |
| diff v3 | 24 | 664.967 | 98.758 | 20.159 |
| Difference | 24 | 143.250 | 113.833 | 23.236 |

95% CI for mean difference: (95.183, 191.317)
T-Test of mean difference = 0 (vs not = 0): T-Value = 6.16  P-Value = 0.000

### Paired T-Test and CI: range FE-R-V, range FE-L-V

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| diff v2 | 24 | 1500.77 | 159.24 | 32.50 |
| diff v4 | 24 | 1218.51 | 167.80 | 34.25 |
| Difference | 24 | 282.258 | 184.593 | 37.680 |

95% CI for mean difference: (204.311, 360.205)
T-Test of mean difference = 0 (vs not = 0): T-Value = 7.49  P-Value = 0.000

### Paired T-Test and CI: range RU-R-A, range RU-L-A

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| diff a1 | 24 | 13603.6 | 2063.6 | 421.2 |
| diff a3 | 24 | 9644.5 | 1764.6 | 360.2 |
| Difference | 24 | 3959.17 | 2286.61 | 466.75 |

95% CI for mean difference: (2993.62, 4924.72)
T-Test of mean difference = 0 (vs not = 0): T-Value = 8.48  P-Value = 0.000

### Paired T-Test and CI: range FE-R-A, range FE-L-A

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| diff a2 | 24 | 25549.0 | 4876.4 | 995.4 |
| diff a4 | 24 | 19201.8 | 3584.9 | 731.8 |
| Difference | 24 | 6347.21 | 4783.52 | 976.43 |

95% CI for mean difference: (4327.30, 8367.11)
T-Test of mean difference = 0 (vs not = 0): T-Value = 6.50 P-Value = 0.000

## Repetition

### Paired T-Test and CI: RU R, RU L

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| RU R | 24 | 555.125 | 60.888 | 12.429 |
| RU L | 24 | 335.750 | 54.330 | 11.090 |
| Difference | 24 | 219.375 | 49.051 | 10.012 |

95% CI for mean difference: (198.663, 240.087)
T-Test of mean difference = 0 (vs not = 0): T-Value = 21.91 P-Value = 0.000

### Paired T-Test and CI: FE R, FE L

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| FE R | 24 | 776.708 | 101.540 | 20.727 |
| FE L | 24 | 457.958 | 70.042 | 14.297 |
| Difference | 24 | 318.750 | 87.567 | 17.874 |

95% CI for mean difference: (281.774, 355.726)
T-Test of mean difference = 0 (vs not = 0): T-Value = 17.83 P-Value = 0.000

## Pause

### Paired T-Test and CI: RU R, RU L

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| RU R | 24 | 5.17083 | 1.18926 | 0.24276 |
| RU L | 24 | 9.03333 | 1.39336 | 0.28442 |
| Difference | 24 | -3.86250 | 1.23387 | 0.25186 |

95% CI for mean difference: (-4.38352, -3.34148)
T-Test of mean difference = 0 (vs not = 0): T-Value = -15.34 P-Value = 0.000

### Paired T-Test and CI: FE R, FE L

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| FE R | 24 | 3.60833 | 1.04587 | 0.21349 |
| FE L | 24 | 7.02083 | 1.56371 | 0.31919 |
| Difference | 24 | -3.41250 | 1.12610 | 0.22986 |

```
95% CI for mean difference: (-3.88801, -2.93699)
T-Test of mean difference = 0 (vs not = 0): T-Value = -14.85  P-Value = 0.000
```

## High Risk P

### Paired T-Test and CI: RU R, RU L

```
             N      Mean     StDev   SE Mean
RU R        24  0.474958  0.096163  0.019629
RU L        24  0.431629  0.114251  0.023321
Difference  24  0.043329  0.172771  0.035267


95% CI for mean difference: (-0.029626, 0.116284)
T-Test of mean difference = 0 (vs not = 0): T-Value = 1.23  P-Value = 0.232
```

### Paired T-Test and CI: FE R, FE L

```
             N      Mean     StDev   SE Mean
FE R        24  0.453246  0.079580  0.016244
FE L        24  0.375825  0.092049  0.018789
Difference  24  0.077421  0.108378  0.022122


95% CI for mean difference: (0.031657, 0.123185)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.50  P-Value = 0.002
```

## High Risk V

### Paired T-Test and CI: RU R, RU L

```
             N      Mean     StDev   SE Mean
RU R        24  0.091004  0.023505  0.004798
RU L        24  0.043917  0.016259  0.003319
Difference  24  0.047088  0.018001  0.003674


95% CI for mean difference: (0.039486, 0.054689)
T-Test of mean difference = 0 (vs not = 0): T-Value = 12.81  P-Value = 0.000
```

### Paired T-Test and CI: FE R, FE L

```
             N      Mean     StDev   SE Mean
FE R        24  0.127954  0.025932  0.005293
FE L        24  0.055008  0.016196  0.003306
Difference  24  0.072946  0.026295  0.005367


95% CI for mean difference: (0.061843, 0.084049)
T-Test of mean difference = 0 (vs not = 0): T-Value = 13.59  P-Value = 0.000
```

## High Risk A

### Paired T-Test and CI: RU R, RU L

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| RU R | 24 | 0.018583 | 0.009375 | 0.001914 |
| RU L | 24 | 0.004085 | 0.003691 | 0.000753 |
| Difference | 24 | 0.014499 | 0.007819 | 0.001596 |

95% CI for mean difference: (0.011197, 0.017801)
T-Test of mean difference = 0 (vs not = 0): T-Value = 9.08 P-Value = 0.000

### Paired T-Test and CI: FE R, FE L

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| FE R | 24 | 0.034942 | 0.014265 | 0.002912 |
| FE L | 24 | 0.007793 | 0.004291 | 0.000876 |
| Difference | 24 | 0.027149 | 0.013528 | 0.002761 |

95% CI for mean difference: (0.021437, 0.032861)
T-Test of mean difference = 0 (vs not = 0): T-Value = 9.83 P-Value = 0.000