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A Biomechanical Assessment of Early and Late Sign Language Learners: Impact on Work Style and Musculoskeletal Disorder Risk

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A Biomechanical Assessment of Early and Late Sign Language Learners: Impact on Work Style and Musculoskeletal Disorder Risk

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Abstract

American Sign Language (ASL) interpreters are a vital resource both for people who are deaf and people who are hearing. Interpreters face a combination of high cognitive and high physical demands while interpreting, placing them at an increased risk for upper extremity musculoskeletal disorders and burnout. Research has shown that individual differences exist in signing style, causing some interpreters to have a less physically demanding signing style than others. Anecdotal evidence suggests that interpreters who start signing at a young age may have a decreased likelihood for developing upper extremity musculoskeletal disorders due to the possible acquisition of a technique that minimizes strain on the body. The objectives of this study were to analyze the impact that learning to sign at a young age has on wrist kinematics while signing, as well as how wrist biomechanics are affected by the type of signing task being completed, casual conversation or formal interpreting.

Three subject groups were studied in this research: eight interpreters who are early signers, eight interpreters who are late signers, and nine students who are deaf and use ASL. The students observed the lecture task completed by the interpreters and then all the subjects actively participated in the conversation task. Biomechanical variables for position, velocity and acceleration were measured in both the flexion/extension and radial/ulnar deviation planes. It was found that sign language acquisition history or learning to sign at a young age did not significantly affect wrist kinematics. The signing task, however, did have a significant effect on kinematic data for both interpreter groups. The interpreting task resulted in wrist velocity that was 5%-15% greater, on average, than the conversation task. This study shows that interpreting poses higher biomechanical demands than everyday signing, and that learning to sign later in life does not put a person at a greater risk for upper extremity musculoskeletal disorders.

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Chapter 1

INTRODUCTION

Sign language interpreting is a critical resource for both people who are deaf and people who are hearing, as it facilitates communication between these two populations. American Sign Language (ASL) interpreters provide their services in many different settings such as medical, legal, religious, performing arts, and educational environments. Interpreters are a vital resource that society utilizes to facilitate communication between people who can hear and people who are deaf. Sign language interpreting comes with high cognitive and physical demands, however. It is well documented that this demanding task puts sign language interpreters at an elevated risk for upper extremity musculoskeletal disorders (MSDs) and burnout. A significant number of interpreters have to miss work or are working with pain due to the development of musculoskeletal disorders. In addition to interfering with sign language interpreters' careers and daily lives, injuries place more strain on the remaining interpreters who continue to support the same group of people who are deaf requiring their services. Any reduction in sign language interpreting resources, in turn, threatens the full participation and integration of people requiring their services.

Previous investigations into highly repetitive tasks in industry have shown that increased postural deviation, wrist velocity, and wrist acceleration are key factors associated with an elevated risk for musculoskeletal disorders. The profession of sign language interpreting has been shown to have high levels of all three risk factors. Furthermore, these biomechanical factors may be exacerbated by other conditions such as speaker pace, psychosocial aspects of the signing task, and a sign language interpreter's personal signing style. Previous research has

shown that differences in individual interpreting style do exist, and that some interpreters have a signing style that is less physically demanding. Anecdotal evidence suggests that interpreters who have used sign language throughout their lives may have a lower occurrence of upper extremity musculoskeletal disorders. Some examples of these interpreters are CODA (Children of Deaf Adults) or SODA (Siblings of Deaf Adults) individuals. Presumably, these individuals grew up in a household where sign language was used routinely and, consequently, they developed fluency in ASL early in their lives. While biomechanical comparisons between highly experienced and novice subjects have been made for other professions and activities, the topic remains unexplored for sign language interpreters.

The main focus of this proposed study was to evaluate the kinematic differences in interpreting style between groups of early signers and late signers. Three subject groups were studied in this research: interpreters who were early signers, interpreters who were late signers, and deaf non-interpreters who have used ASL throughout their lives. The goal of this work was to determine the extent to which these groups differ with respect to the wrist biomechanics produced when signing. The two groups of interpreters performed a routine interpreting task, such as they would perform as part of their job. In addition, the interpreters and the subjects who are deaf performed an informal conversation in ASL to assess whether task formality further differentiates the biomechanical differences between the groups. For all subjects, angular wrist position, velocity, and acceleration were measured to quantify differences in signing style.

The results of this study were intended to provide the data to support or refute the theory that early signers develop a signing technique that is inherently less risky than the technique of interpreters who were late signers. If such a finding is reached, this study also sought to identify

what specific aspects of the late signers' technique minimize their likelihood of developing an injury.

Chapter 2

LITERATURE REVIEW

2.1 Musculoskeletal Disorders in Industry

The U.S. Bureau of Labor Statistics (2006) defines work-related musculoskeletal disorders as injuries to the muscles, tendons, joints, cartilage, or spinal discs that do not occur due to acute traumas such as slips, trips, falls, or motor vehicle accidents. This refers specifically to disorders related to the overuse of muscles and joints due to an individual's work. Some examples of overuse syndromes that occur in work settings are carpal tunnel syndrome, brachial neuralgia, tendinitis, ulnar nerve entrapment, De Quevains Disease, and ganglion cysts. Overuse syndromes develop when a person repeatedly uses a particular muscle, tendon, or other soft tissue group without taking frequent enough rest breaks. This lack of adequate rest causes micro-traumas in the muscle tissues to form, and the body begins its inflammatory response in order to heal these micro-traumas (Sanderson, 1987). Once overuse syndromes develop, they require long periods of time to heal and will return again if the same work and pace is resumed. Musculoskeletal disorders result in time lost at work and can threaten an individual's livelihood.

Although the number of musculoskeletal disorders resulting in missed days from work in private industry went down by 9% in 2009, musculoskeletal disorders still accounted for 28% of all injuries resulting in days away from work. Most of these injuries occur in the upper extremity joints such as the shoulder and wrist. This statistic translates to a staggering 348,740 cases of missed days at work due to musculoskeletal disorders alone and not acute accidents (Bureau of Labor Statistics, 2009). The current number of injuries shows that although awareness about

safer work habits and training has helped employees in many industries to avoid overuse injuries, the problem still needs further research and attention.

The National Research Council has identified that both physical and psychosocial factors play a role in creating work related upper extremity disorders. Some physical factors that they identified were manual material handling, repetition of work, force, the interaction between repetition and force, the interaction between repetition and a cold environment, and vibration. Psychosocial factors attributed to musculoskeletal disorder development include high perceived job demands, job stress, pain coping style, and low perceived job support (National Research Council, 2001). These factors are eliminated from or reduced in work tasks whenever possible, but sometimes this cannot be done. Studying each industry specifically can help to discover what specific aspects of work tasks in that industry contribute most to upper extremity disorders.

2.2 Musculoskeletal Disorders in Sign Language Interpreters

It is well understood that American Sign Language interpreters are at an increased risk for many upper extremity musculoskeletal disorders. During the 1988-1989 academic year at the National Technical Institute for the Deaf, 45% of the employed sign language interpreters were either completely disabled from interpreting or had to reduce their workload due to upper extremity pain from interpreting (DeCaro, Feuerstein, & Hurwitz, 1992). In the following year, 60% of the full time interpreters at NTID were diagnosed with either work related tendonitis or nerve entrapment disorders (Feuerstein & Fitzgerald, 1992). In a larger population during that same time period in 1987, a survey of the Southern California Registry of Interpreters for the

Deaf (SCRID) found that approximately 44% of members had some type of overuse syndrome (Sanderson, 1987). This has been a prevalent job risk in all SLI populations.

Bringing awareness to this problem has helped encourage professional organizations for sign language interpreters such as the Registry of Interpreters for the Deaf (RID) and institutions to focus on overuse syndrome reduction, but more recent studies show that the problem still exists. In 2000, a random selection of 250 certified interpreters were surveyed about their experiences with pain and discomfort during and after interpreting. Out of the 145 interpreters who responded, 119 or 82% had experienced some form of disabling pain or discomfort as a result of sign language interpreting. About a third of the instances of pain were in the wrist or hand (Scheuerle, Guilford, & Habal, 2000).

Further work in reducing pain and overuse injuries in sign language interpreters is essential to allowing the safe fulfillment of a career and livelihood for interpreters as well as allowing deaf and hard of hearing individuals to get the services that they need. Other means exist to allow individuals who are deaf or hard of hearing to acquire spoken information, such as C-print, a speech to text technology developed at the National Technical Institute for the Deaf (NTID) which allows captionists to provide text versions of spoken word to individuals via comuters and display monitors (C-Print Development and Training, 2012). Technology such as C-print helps to take some of the burden off of interpreters but in no way replaces the need for interpreters or sufficiently mitigates the effects of the shortage of ASL interpreters. In the 2011 fiscal year, 21,068 hours of real-time captioning hours were provided to students at NTID, while 98,032 interpreting hours were provided (2011 NTID Annual Report, 2011). Technology like C-print is more readily available at a technologically advanced institution like NTID, so the amount of captioning hours that are performed in comparison to interpreting is likely much lower on a

national level. The interpreter shortage is still a very relavant concern. Dean and Pollard (2001) suggest that the national shortage of ASL interpreters may in part result from cumulative trauma disorders and burnout. Interpreters are susceptible to most cumulative trauma disorders of the upper extremities, but in a 1992 survey performed at Rochester Institute of Technology, the most prevalent disorder found was wrist and shoulder tendinitis (Feuerstein & Fitzgerald, 1992).

Classroom interpreting in particular can be very demanding and laden with highly repetitive motion, and the association between classroom ASL interpreters and musculoskeletal disorders has been established by DeCaro, Feuerstein, and Hurwitz (1992). In a study of wrist and forearm motion of classroom interpreters, Shealy, Feuerstein, & Latko (1991) determined that during a typical 50 minute assignment, an interpreter carries out 13,600 movements or 270 movements per minute. This drastically exceeds the recommendations proposed by Shoenmarklin and Marras (1993) that an individual in a highly repetitive job should not perform more than 13,000 hand movements over an 8 hour day. In a separate study performed by Qin, Marshall, Mozrall, and Marschark (2008), wrist velocity and acceleration data were collected on several sign language interpreters. In this study, values for the dominant right hand also exceeded high risk limits for velocity and acceleration defined by Shoenmarklin and Marras (1993).

These statistics describe the extremely demanding wrist motion involved in sign language interpreting, and it is important to note the differences between interpreting and everyday signing. Sign language interpreting carries a set of demands that are not present in casual conversational ASL use. The main source of difference between casual signing and sign language interpreting is the occupational stress present for sign language interpreters. Interpreters have to deal with the stress related to presenting something to an audience, even if that audience is only one person. Interpreters take on the responsibility for allowing effective

communication to occur for individuals, which could be extremely important communication such as that involved in a school lesson or a court trial. Other demands are present that relate to an interpreter's role and lack of ability to control his or her work task. Due to the nature of their work, interpreters are not fully in control of their signing speed. Rather, they are forced to keep up with the speed of the lecturer or other individual whose spoken words are being interpreted. Feuerstein and Fitzgerald (1992) compare sign language interpreting to a paced assembly line because of this characteristic. In casual signing, a person can respond to another individual at a pace that is comfortable for him. Interpreters also generally have no control over the topics they have to sign about and the language that they have to use, unlike someone who is carrying out a conversation. This can lead to interpreters having to discuss topics that are unfamiliar to them, another factor that contributes to occupational stress. These demands and low ability to counter them make sign language interpreting a high risk occupation for burnout (Dean & Pollard, 2001).

2.3 Risk Factors

To aid in the analysis of upper extremity disorders, risk factors can be categorized into three areas: biomechanical factors, psychosocial factors, and individual factors (Bernard, 1997). Interaction occurs within and between categories, leading perhaps to burnout or musculoskeletal injury. This categorization technique can be applied to the study of musculoskeletal disorders in sign language interpreters.

2.3.1 Biomechanical Factors

Biomechanical exposures relate to the motions that an interpreter carries out during a job as well as the forces that act on the interpreter's upper extremities while signing. Specifically,

these factors are force, posture, and repetitive motion (Shealy, Feuerstein, & Latko, 1991). Signing is a unique task due to the fact that no external forces are acting on the hands and arms; only the weight and inertia of the extremities themselves must be supported, so velocity and acceleration contribute significantly to the biomechanical response.

Stress on the body occurs largely due to the postures and motions that an interpreter must use to make recognizable signs. An interpreter's hand is frequently held in a fully pronated position with the wrist in ulnar deviation or extension while the elbow is flexed greater than 90 degrees. The combination of these postures is attributed to a higher risk of upper extremity disorders (Shealy, Feuerstein, & Latko, 1991). In a study of interpreters from the National Technical Institute of the Deaf at RIT, several other biomechanical factors were attributed to increased upper extremity pain and fatigue while interpreting: fewer rest breaks during signing, more hand and wrist deviations from neutral, more frequent excursions from an optimal work envelope, and more rapid finger and hand movements while interpreting (Feuerstein & Fitzgerald, 1992).

2.3.2 Psychosocial Factors

Further demand is placed on SLIs due to the psychosocial factors involved with interpreting. Dean and Pollard (2001) use demand control theory to explain why interpreters are at such a high risk for injury and burnout. Linguistic, environmental, interpersonal, and intrapersonal demands are all placed on interpreters. Interpreters must deal with a certain level of anxiety regarding their knowledge of the language and their ability to sign clearly. Interpreters can also be affected by environmental factors such as uncomfortable temperatures or disruptive noises. Furthermore, interpreters are influenced by the other people involved in the interpreting task including those utilizing their services. Stress can arise from issues such as

trouble hearing the individuals who are speaking or trouble understanding a person's accent or vocabulary. Additionally, each interpreter has to manage his or her own personal factors, both physical and psychological, which can be related to the task itself or any other part of the interpreter's life. While high demand alone does not immediately lead to problems for interpreters, the fact that they also possess low decision latitude to respond to the demands of their role puts them at high risk for burnout or injury (Dean & Pollard, 2001).

Though conventional logic might associate psychological stress with only cognitive loading, research suggests that psychosocial factors may have an effect on the biomechanics of the task. In a study by Qin, Marshall, Mozrall, and Marschark (2008), a group of SLIs interpreted a pre-recorded lecture while being subjected to several factors meant to induce stress including a fast paced lecture and two supervisors being present in the room while taking notes. Subjects were also told that a video of the interpreting session would be played at a national interpreting conference. Subjects who experienced stress also produced an increase in non-dominant wrist velocity of between 14.8% and 19.5% compared to interpreters who did not experience stress. The study provided evidence that psychosocial stress can have a physical effect on an individual, which can increase the risk of developing a musculoskeletal disorder.

2.3.3 Individual Factors

Aside from biomechanical and psychosocial risk factors, people have their own set of individual risk factors that affect their likelihood for developing upper extremity disorders. People of certain sex, age, and anthropometry are at a higher likelihood for musculoskeletal injuries. Interpreters who are female, older than 40, pregnant, have small wrists, or who have previous wrist fractures are all at an elevated individual risk for an upper extremity disorder (Stedt, 1989). The gender factor is especially important to consider in this case because of the

high ratio of females to males in the field of sign language interpreting. DeCaro, Feuerstein, and Hurwitz observed approximately 85% female interpreters in their study (1992). This is still the trend as can be seen in a more recent study by Scheuerle, Guilford, & Habal (2000) in which a survey of interpreters found that 82% of the 145 respondents were female.

Many other factors come into play when looking at individual signing style. Personal interpreting work style has been shown to cause differing levels of fatigue and pain. In Beyond Biomechanics, Feuerstein (1996) defines work style as an individual pattern of cognitions, behaviors, and physiological reactivity that co-occur while performing job tasks. This interaction can contribute to the development or reoccurrence of work-related musculoskeletal symptoms. Feuerstein and Fitzgerald's investigation of sign language interpreters at RIT showed that interpreters experiencing pain utilized a different work style than interpreters not reporting pain. Some interpreters create greater deviations from neutral while signing than others do. Interpreters also sign with varying levels of wrist and finger acceleration. These factors are both associated with greater pain and fatigue (Feuerstein & Fitzgerald, 1992).

The National Research Council created a model which describes three potential ways that individual work style can influence the musculoskeletal response to work. First, individuals perform job tasks differently, creating variation in the biomechanical loading of their joints. Further differences arise in the unique tolerances that each person has to the strain and fatigue caused by biomechanical loading. Third, people may experience pain from musculoskeletal strain differently due to the variations in behavioral and cognitive responses (National Research Council, 2001). All of these elements play into a person's individual response to the demands of interpreting.

Several research attempts have been made to reduce the individual factors contributing to musculoskeletal disorder development in SLIs. Feuerstein, Marshall, Shaw, and Burrell (2000) created a multicomponent intervention to reduce the factors that lead to upper extremity disorders through a series of work organization and work style changes. Eleven training sessions were held over a 10-week period. These training sessions emphasized topics such as predisposing medical factors for developing musculoskeletal disorders, overexertion during work, ergonomic risk factors, work organization factors, and individual psychosocial stressors which may increase a person's risk for MSDs. The study revealed a 69% reduction in the number of cases reporting upper extremity problems in the three years after the intervention. This is further evidence that individual factors can play a significant role in the progression of upper extremity disorders in SLIs. Similar results were seen in an intervention technique performed by Delisle, Durand, Imbeau, and Lariviere (2006). Five group meetings were held over a period of nine weeks where information about MSDs and their risk factors were presented and videos of interpreters were analyzed. A decrease in pain frequency and average pain intensity was seen in four of the seven interpreters. The fact that more improvement was not realized was attributed to the fact that interpreting style is developed through years of signing and is very difficult to change once a style is learned.

This learned signing style is influenced by all of an individual's experiences with sign language and with other people who sign. It has been hypothesized that an individual's early life experiences with learning to sign can highly influence their work style throughout their life. Specifically, it has been suggested that interpreters who grow up as a CODA, SODA or with some other significant exposure to sign language from an early age will develop a signing style that allows those interpreter to sign with less pain and fewer biomechanical problems.

2.4 The Experience Effect

The possible experience effect for CODA interpreters may result from the early age that CODAs learn to sign when their parents sign regularly at home. It is also thought to occur because a "more natural" technique is taught by parents who are deaf, or because of a number of other factors. This was hypothesized by Podhorodecki and Spielholz during an electromyographic study of sign language interpreters in 1993. They suggested that perhaps learning to sign at an earlier age allows one to sign with "more natural body mechanics." Podhorodecki and Spielholz (1993) conducted a study of 33 people who were either deaf or sign language interpreters from the New York Society for the Deaf's Interpreter and Deaf Registry. In this study both early signing and late signing interpreters (referred to in this study as native and non-native signers) were observed. Of the 33 subjects, 24 were non-native interpreters, 6 were deaf and were native signers, and 3 were native signing hearing interpreters. At the time of the study, 16 subjects reported pain in the upper extremities, with none of these subjects being native signers. When supramaximal motor and sensory nerve conduction studies were performed, findings suggestive of cumulative trauma syndromes were seen in five subjects, three of whom were deaf native signers. However, none of them complained of any symptoms. More detailed studies into the effect that being CODA has on an interpreter's signing style and risk level for developing a cumulative trauma disorder have not been performed, but research into the experience effect in other professions, such as musicians, suggests that early exposure to activities involving fine motor control can result in better biomechanical technique.

The demands of being a professional musician closely relate to many of the demands of sign language interpreting. Both involve complex arm, hand, and finger movements that have to be carried out repeatedly and at a prescribed pace or tempo. These two tasks also both bring

with them the psychosocial demands that come along with a performance environment: the anticipation and reaction of the audience, the personal expectations and confidence in one's abilities, and the various other environmental factors that may be present. In a study by Parlitz, Peschel, & Altenmuller (1998), the effects of training and expertise were analyzed through ten expert piano players and ten novices. The expert group consisted of pianists who started playing at the average age of six and who practice for about four hours a day. Subjects in the amateur group started playing anywhere between the ages of five and twenty and practice for less than an hour a day. F-scan sensor-matrix-foil was placed under the piano keys and mean pulse per touch and mean touch-duration for several exercises for each subject were measured. Duration was measured, because once a piano string has been activated, it creates no further sound by holding down the key longer, so this is a useless and inefficient exertion. Just as upper extremity disorders are associated with signing, they are attributed to an inefficient use of force exerted while playing the piano (Parlitz, Peschel, & Altenmuller, 1998).

The piano force study found that in order to achieve the same tempo and loudness, amateurs applied significantly more and longer force to the keys. Expert finger force remained below 2 N while amateur force in some fingers was over 20 N. Expert mean touch duration was 0.3 seconds compared to the amateur mean touch duration of 0.5 seconds, a difference that was found to be statistically significant (Parlitz, Peschel, & Altenmuller, 1998). This large gap between expert and amateur data suggests that the amateurs have developed a much less biomechanically demanding work style for playing the piano.

In another study, Wales (2007) looked at six expert and six amateur violinists and studied a basic bowing task. Violin playing is another profession where musculoskeletal disorders are numerous and threatening to one's career. The amateurs involved in the study had to have been

playing for at least two years, and the experts needed to have been playing for at least seven years with orchestra experience. The bowing task consisted of five bowing cycles of one full down-bow followed by one full up-bow. A down bow is performed by resting the hair of the bow on the violin strings near the frog end of the bow where the hand contacts the bow. The bow is then drawn along the string to the tip of the bow. An up bow consists of the opposite movement on the strings. This was repeated on each of the four strings moving from G to E. Muscle activity was examined for each subject, and novice muscle activity was higher during all bowing activities. Novice muscle activity was also more irregular across each of the strings. Researchers also observed that the less experienced violinists have a much shorter or even nonexistent relaxation phase after a bow direction change and that there was less of an agonist-antagonist relationship between the biceps and triceps of novices. Both muscles were engaged the whole time for less experienced subjects, while an antagonist relationship between the biceps and triceps was observed for the expert musicians. Whether biomechanical differences between experts and novices in both of these studies results from the age when the individuals started learning the task, from all the years of practice, or for other reasons is not completely clear, but it is apparent that work style differences do exist between the groups. This work seeks to address the same question for sign language interpreters.

Chapter 3

METHODOLOGY

3.1 Experimental Objective

The primary objective of this study was to assess whether the acquisition of ASL fluency early in life results in a signing style that is inherently less risky than when fluency is achieved later in life. A secondary objective was to see if observed biomechanical differences are further pronounced by the formality of the signing task. An experiment was conducted using electrogoniometry to evaluate whether or not the three populations of early signing interpreters, late signing interpreters, and ASL fluent people who are deaf show a difference in wrist deviation from the neutral position and a difference in wrist velocity and acceleration. In this experiment, early signing interpreters were classified as individuals who learned ASL before graduating from high school. Most of the early signing subjects in this study were CODA or SODA, but some learned ASL in high school classes or from friends who were deaf. The late signing group in this study included the interpreters who learned sign language as part of a college program or in a separate interpreter training program. The separation of interpreters into the two groups was determined by the availability of interpreters at the time of the study.

3.1.1 Hypotheses

Based on the experimental objective, the following hypotheses were proposed.

1. Individuals with early acquisition of sign language (*early signers*) will display decreased wrist kinematic data while signing the same task compared to those who achieved fluency later in life (*late signers*).
2. For a fixed task, late signers will exhibit greater variation in wrist kinematic data within the population than will be experienced by early signers.
3. SLI subjects, regardless of their ASL acquisition, will display increased wrist kinematic data during the formal signing task as opposed to during the informal task.
4. In addition to late signing interpreters displaying greater wrist kinematics than early signing interpreters in both tasks, late signing interpreters will display a greater difference between tasks.
5. For the casual task, the wrist kinematic data for early signing interpreters will resemble the wrist kinematic data for the subjects who are deaf in the study.

3.2 Experimental Overview

To achieve the objectives of this research, a laboratory study was conducted using a mixed experimental design. Both early signing and late signing interpreters were included in this study, as well as a group of students who are deaf. A between subjects design was utilized to study the biomechanical differences between the early and late signers. The experiment consisted of two tasks, a formal interpreting task and an informal conversation task which are

described in detail in sections 3.6.4 and 3.6.5. The tasks allowed for style differences between early and late signing interpreters to be studied. Both interpreter groups completed the formal and informal tasks, but the group who was deaf only participated actively in the informal conversation task as these subjects were not professional interpreters. A within-subjects design was implemented here to evaluate whether biomechanics for interpreting are different from biomechanics during casual conversation. Electrogoniometry was used to assess wrist posture and wrist kinematics.

The experimental design is illustrated in Figure 3.1 below. The two independent variables used in this design were sign language acquisition history (the sign language factor) and the type of signing task executed (the setting factor). The dependent variables studied were wrist flexion/extension, wrist radial/ulnar deviation, wrist kinematics (velocity and acceleration) for each plane of wrist deviation, percent pause of wrist motion, range of wrist motion, and the standard deviation of mean wrist motion. These variables are described thoroughly in the following sections. Each independent variable combination shown in Figure 3.1 was studied except for the combination of subjects who are deaf in the formal setting.

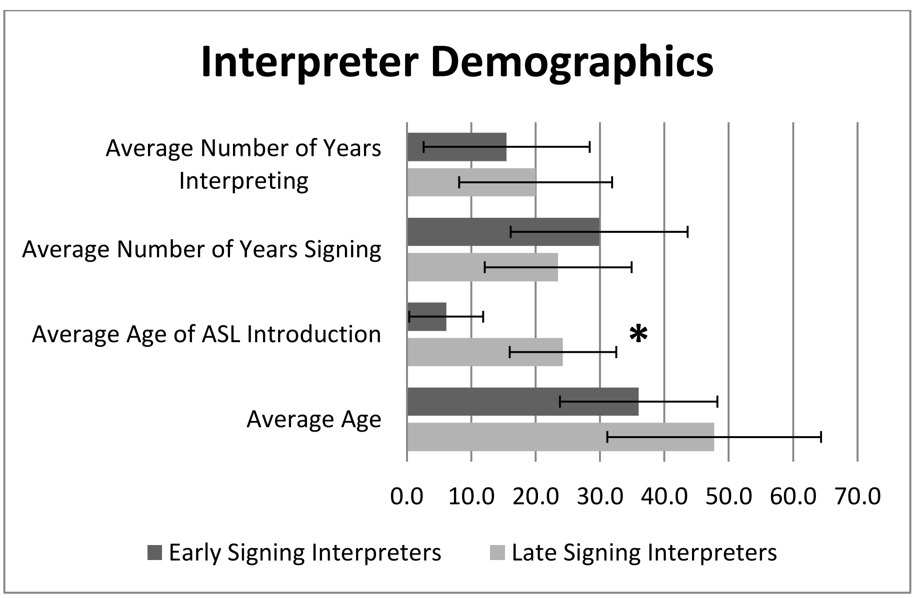
		Sign Language Acquisition Factor		
		Early Signing Interpreter	**Late Signing Interpreter**	**Person who is Deaf**
Task Factor	**Formal (Lecture Interpretation)**	**X**	**X**	
	Informal (Casual Conversation)	**X**	**X**	**X**

Figure 3.1: Experimental Design

3.3 Subjects

3.3.1 Interpreters

Subjects for the interpreting groups were recruited from the employed interpreters at the National Technical Institute for the Deaf (NTID) at RIT and through the Genessee Valley Region Registry of Interpreters for the Deaf (GVRRID). Interpreter subjects with varying levels of sign language and interpreting history were recruited for the experiment. A questionnaire targeting ASL acquisition information was filled out by each potential subject. This questionnaire allowed appropriate subjects to be chosen for the two groups: early and late signers and can be found in Appendix A. Each group contained eight interpreters. The average age at the time of the study for subjects in the early and late signing groups was 36.0 (SD=12.2) and 47.8 (SD=16.6) respectively. All but one interpreter in the study were right hand dominant. The female/male ratio for the early group was 6/2, and the female/male ratio for the late group was 5/3.



*Significant at an alpha level of 0.05

Figure 3.2: Interpreter Demographics

The age range for when ASL was first used in the early signing group was 0-15 with an average age of 6.1 (SD=5.7). The age range for first ASL use in the late signing group was 17-42 with an average age of 24.3 (SD=8.3). The average number of years signing and number of years interpreting professionally for the early group were 29.9 (SD=13.8) and 15.5 (12.9) respectively. The average number of years signing and number of years interpreting professionally for the late group were 23.5 (SD=11.4) and 20.0 (SD=11.9) respectively. Figure 3.2 above shows a comparison of the demographic data for the two groups of interpreters. Analysis of variance was performed on interpreter age, age when the subject started signing, number of years signing, and number of years interpreting. No significant difference was found between the subject groups except for the variable of when the subjects started signing. This should be statistically different for this experiment, as the possible differences between the groups are under investigation. These results are presented in Table 3.1. Although some interpreters had experienced pain or injuries from interpreting in the past, no interpreters who were experiencing pain at the time of the study were included in the experiment.

Variable	F-statistic	P-value
Interpreter Age	2.59	0.13
Age When Started Signing	25.97	0.00*
Years Signing	1.02	0.33
Years Interpreting	0.53	0.48

*Significant at an alpha level of 0.05

Table 3.1 – Analysis of Variance of Demographic Data

3.3.2 Students

A group of nine college aged students who are deaf or hard of hearing (DHH) and who use sign language participated in this study for the purpose of data comparison with the hearing interpreter groups. All subjects in this group were students at the National Technical Institute for the Deaf at the time of the study, and none were professional interpreters. The group had a female/male ratio of 3/6, and all subjects in this group were right handed. This group possessed a wide range of number of years using sign language from 4 to 22 with an average of 11.8 (SD=7.2) years of signing experience.

The original intent was to pair each of eight student subjects with both an early and a late signing interpreter in order to study how the students interact with early vs. late signing interpreters. During the process of scheduling subjects, it was determined that making sure this setup occurred was not essential to the objectives of this research and would have significantly delayed the study. Each student was still paired with two interpreters when possible, and in the end nine student subjects participated in the study.

3.4 Independent Variables

3.4.1 Sign Language Acquisition History

The first independent variable was sign language acquisition history. Subjects were considered to be at one of three levels making them early signing interpreters, late signing interpreters, or subjects who are deaf. Early signers were defined as people who grew up signing at a young age before coming to college. This generally occurred because a subject was a CODA or SODA. Late signers were defined as those who started signing after high school. This

generally occurred as part of an interpreter training program. Participants were selected for the deaf subject group if they were deaf or hard of hearing and used sign language but were not professional interpreters. When subjects were recruited for this study, they were asked about their sign language acquisition history and were placed into one of the groups based on their responses. Participants were selected based on the availability of remaining spots in each of the subject groups.

3.4.2 Signing Task

Signing task was another independent variable used to study the different effect that conversational signing versus interpreting has on wrist kinematics. Two levels of task were included in the study: formal and informal. A pre-recorded lecture was used as the stimulus for the formal task. The lecture was conducted by Professor Benjamin Karney at UCLA on April 1, 2009. It is the introductory lecture for a course titled *Communication and Conflict in Couples and Families*, and it is available for free use online. For this study, only the first 20 minutes of the lecture were used and were played on a computer screen for each of the interpreter subjects. No interpreter received any prior information on the lecture before arriving to participate in the study. Each interpreter was told to interpret the lecture to the student he or she was paired with as if they were in a classroom with the lecture occurring live. Data were only collected for the interpreter subjects during this task.

The second task was an informal conversation task, where each interpreter participated in a 10 minute conversation with the student for whom he or she had just interpreted the lecture. During this task, wrist position data were collected from both the interpreter and student subjects. In an attempt to make this task somewhat consistent across subjects while still keeping it informal, a series of open ended discussion questions were provided for each group of subjects

on a computer screen to guide the conversation. These questions are included in Appendix B. Subjects were told to spend as little or as much time on each question as they felt was appropriate, and the conversation was stopped after 10 minutes.

3.5 Dependent Variables

3.5.1 Wrist Position and Kinematic Variables

Wrist flexion/extension (FE) and radial/ulnar deviation (RU) were studied in both tasks (Figure 3.3). Both variables were recorded using biaxial electrogonimoters (SG 65, Biometrics Ltd, Gwent, UK) which are described in detail is section 3.6.3. The position data were later differentiated to obtain wrist velocity and acceleration. In the results presented in the following chapters, zero degree angles represent the neutral wrist position. Positive angles (+) represent wrist extension, and negative angles (-) represent wrist flexion for both wrists. Since the goniometric sensors are not right or left wrist specific, the signs for radial and ulnar deviation differ for each wrist. For the left wrist, radial deviation is represented by negative (-) angles, and ulnar deviation is represented by positive (+) angles. The signs for radial/ulnar deviation are opposite for the right wrist (Figure 3.4).

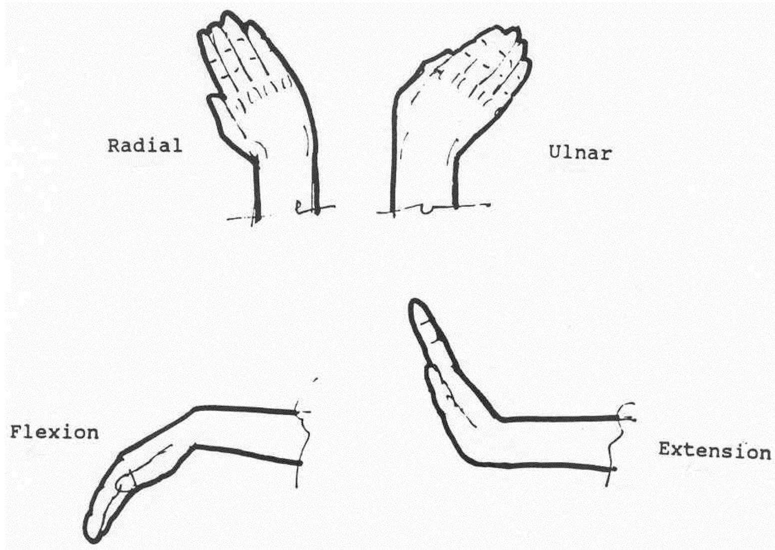


Figure 3.3 Two Planes of Wrist Movement

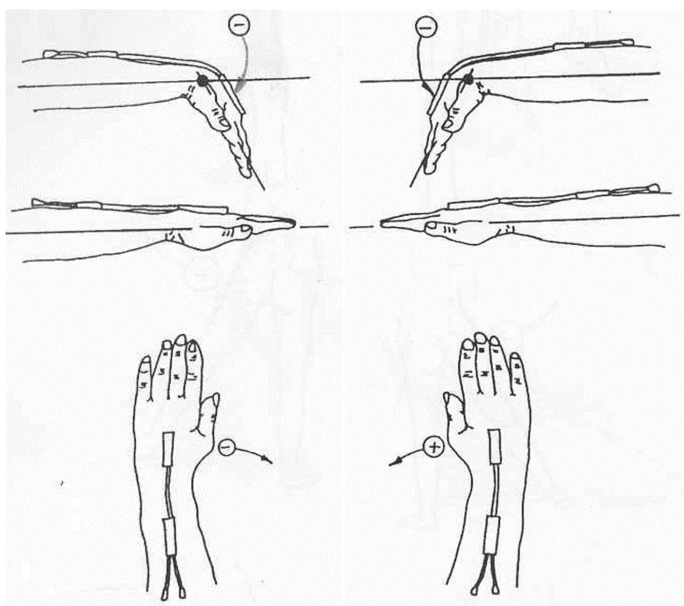


Figure 3.4 Sign Conventions for Wrist Position Data

Goniometric data were collected at 50 Hz with a DataLINK data acquisition and data management system (Biometrics Ltd, Gwent, UK). All position data collected were filtered in MATLAB using a low-pass 6th Order Butterworth filter. A 5 Hz cutoff frequency was chosen

based on previous studies and was used to filter out the higher frequency noise while leaving the wrist motion data (Hansson et al., 1996; Serina et al., 1999; Qin et al., 2008).

Once the position data were collected and filtered, wrist velocity and acceleration were determined from the position data. These were obtained through differentiation and double differentiation using 3-point central difference (Hansson et al., 1996; Qin et al., 2008). The method for obtaining these kinematic variables is included below in Formulas 3.1 and 3.2.

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

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

The descriptive statistics of minimum value, mean value, maximum value, and range were calculated for position, velocity, and acceleration. The minimum and maximum values of position represent the extreme angles in either direction (+ or -). The minimum and maximum values of velocity and acceleration represent extreme values for both directions of change. The absolute values of velocity and acceleration data were found and used to determine mean values. Range is defined as maximum value – minimum value.

3.5.2 Wrist Pause Percentage

The number of wrist pauses during movement was calculated for each trial of each task. A pause was originally counted when the wrist movement was below 1^{o}/s for a continuous period of at least 0.5 seconds (Hansson e al., 1996; Qin et al., 2008). However, pause percentages using this technique were determined to be too low for these tasks. After initially applying these criteria, both participants of each back and forth conversation task generally had a pause percentage of below 10%, which would mean both members of the conversation were

signing around 90% of the time. The different criteria of below 5^o/s for at least 0.2s captured a greater percentage of pauses which seemed more consistent with the task. This criteria was proposed by Delisle (2005) after observing the same deficiency of the Hansson et al. (1996) criteria.

3.6 Experimental Procedure

3.6.1 Overview

All data for this experiment were collected in the RIT Human Performance lab in the Kate Gleason College of Engineering. Demographic and signing history data were collected from the subjects prior to their arrival at the lab. Explanation was also given to the subjects about the nature of and background for the study. Once the subjects arrived in the lab for the study, informed consent was obtained in agreement with the Institute Review Board policy.

Experimental trials were run in 2 hour blocks. At the beginning of each block one interpreter and one student arrived at the lab. They both had the electrogoniometers attached to their wrists and performed both tasks. At the end of the first hour the first interpreter would be done with the study, and the second interpreter would arrive. The new interpreter would then go through the informed consent process and would be set up with the equipment. The student would then participate in both tasks again, this time with the second interpreter. Data were collected over the course of two months.

3.6.2 Informed Consent

Before any of the subjects agreed to participate in the study, they were provided with an overview of the study and an informed consent form via email. The experimental procedure was

then explained in detail to each subject when they arrived at the lab for the study. When necessary, the interpreter subjects interpreted this information to the subjects who were deaf. Subjects were then required to read through the informed consent form once again and sign it before participating. This consent form was approved for use by the RIT and NTID Institute Review Board (Appendix C).

3.6.3 Instrumentation

The Biometrics SG65 sensor was used to study both wrist flexion/extension and radial/ulnar deviation. This is a two-axis electrogoniometer which measures angles in two planes of movement simultaneously. The sensor range is ±150˚ (Biometrics Ltd, 2002). Goniometers were attached to both the subject's dominant and non-dominant hands. Medical grade double sided tape was used to attach the endblocks of each goniometer to the subjects' skin. The distal endblock of the goniometer was first attached to the top of the subject's hand in line with the third metacarpal. Then, with the subject's wrist fully flexed, the sensor was stretched to slightly below its maximum and attached to the subject's forearm. Medical tape was then placed over each end block to help secure the goniometer to the subject's wrists. Before each task was performed, zero angles were set by the subject holding his or her wrist in the neutral position during calibration of the sensors. Figure 3.5 shows the three steps of goniometer setup: attachment of the dorsal endblock, attachment of the proximal endblock, and calibration.

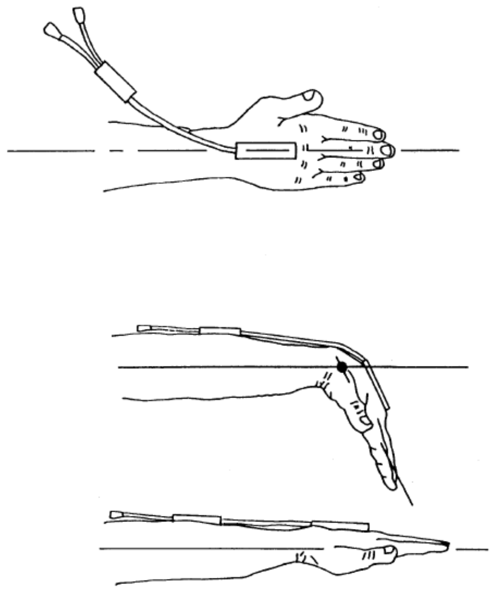


Figure 3.5 Goniometer Attachment

The DataLINK data acquisition system was positioned on a table directly between the interpreter and student. Leads connected the goniometers to this data acquisition system. Wrist position was then recorded in degrees for all tasks at 50Hz.

Two laptops were used during data collection. One laptop was connected to the data acquisition system to display and record data for the investigator as it was being collected. The second computer was placed on the table next to the interpreter and student. The video lecture was played on this laptop for all subjects to view, and the questions for the conversation task were also displayed here.

3.6.4 Interpreting Task

In order to meet the objectives of this study to analyze the kinematic differences between casual signing and formal interpreting, two different tasks were carried out by the interpreters. The formal lecture task occurred first for each interpreter. After going through the informed

consent process and having the sensors attached to their wrists, each interpreter was seated. The student was seated facing the interpreter approximately 6-8 ft away. This was done to resemble a classroom interpreting scenario. Once the subjects had a chance to interact and were ready to start the experiment, the lecture was started. The student's leads were not attached to the data acquisition system during this task. The students were only asked to watch the lecturer and interpreter as if they were in a class. The lecture was then played from the beginning during each interpreting task. After a short warm-up period, an audio cue in the lecture was used to start recording data at the same time for each session. Data collection involved the DataLink system reading in wrist position data in both the flexion/extension and radial/ulnar planes simultaneously. Data collection was stopped at 20 minutes, and the lecture was also then stopped.

3.6.5 Conversation Task

Each interpreter then participated with the student in the conversation task immediately following the lecture task. The student moved several feet closer to the interpreter and his or her leads were connected to the data acquisition system. The goniometers were recalibrated again before the conversation task. The laptop displaying the conversation questions was placed in between the interpreter and student, and it was explained to the subjects that they could go through the questions at their own pace. Once the interpreter and student began their conversation and a brief warm-up period went by, data collection was started for a period of 10 minutes. At the 10 minute mark, data acquisition was stopped, and the subjects were told that they could wrap up their conversation whenever ready. When the interpreter and student were done with the experiment, the goniometers were removed from their wrists.

3.7 Data Analysis

Raw position data were filtered to remove noise using a sixth-order Butterworth filter with a 5 Hz cutoff frequency in MATLAB (Hansson et al., 1996; Serina et al., 1999; Qin et al., 2008). The "butter" function was used to create the data filter and was assigned to the output arguments "a" and "b." This is illustrated in Formula 3.3. The order (n) was set at 6, and the cutoff frequency (ω_n) was determined to be 0.2. This is based on the cutoff frequency 5 Hz divided by the Nyquist frequency, which is half the sampling frequency of 50 Hz. A low pass filter was created to allow the lower frequency hand movement to pass through the filter while stopping the higher frequency noise. Each data file (x) was then filtered using the zero-phase filter function "filtfilt," shown in Equation 3.4. This function carries out the butter filter that was created in both the forward and reverse directions, resulting in a filtered data set with no phase shift.

$$[b, a] = butter(6, 0.2, 'low') \tag{3.3}$$

$$y = filtfilt(b, a, x) \tag{3.4}$$

Figure 3.6 below shows 250 data points (five seconds) of unfiltered and filtered data. The filtered data eliminates some of the noise and changes more gradually as the wrist naturally would.

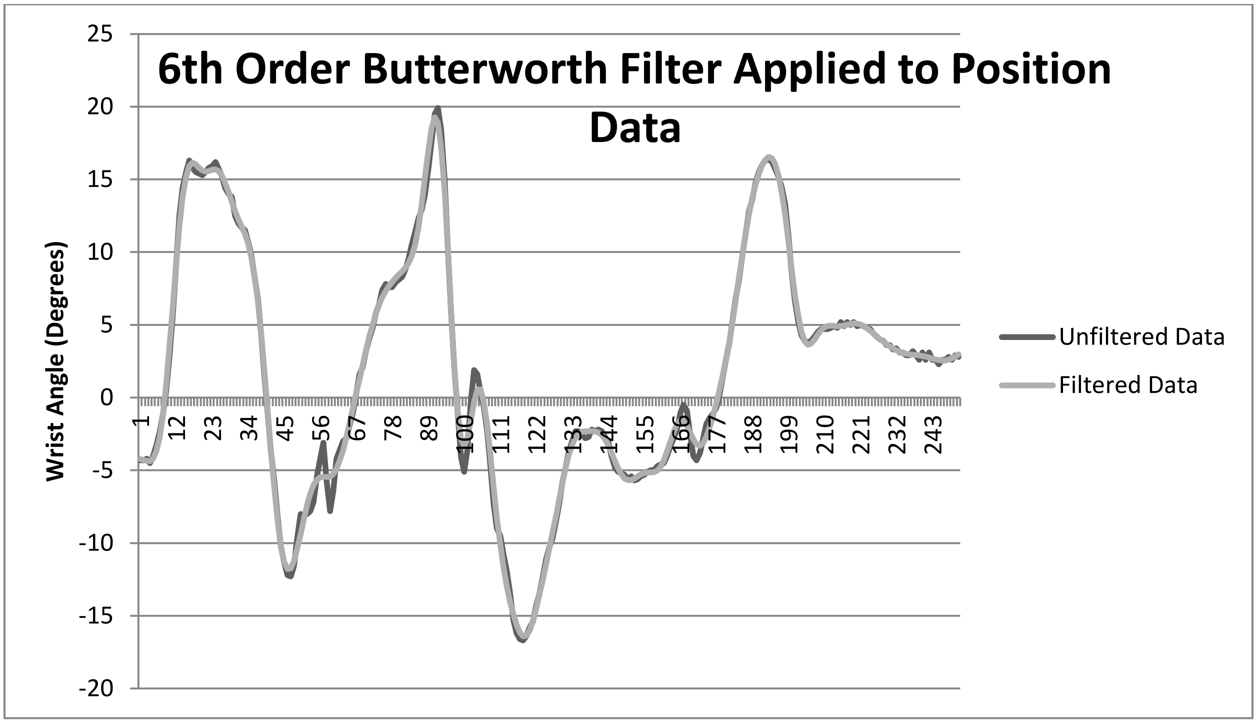


Figure 3.6 Data Before and After 6th Order Butterworth Filter

Velocity and acceleration were then derived from the filtered data. All compilation and preparation of the data for statistical analysis was performed using Microsoft Excel. Descriptive statistics were calculated and stored in Excel for each of the dependent variables.

One-way analysis of variance (ANOVA) was performed using Minitab 16 to determine the effect of signing acquisition history on the dependent variables. Separate analysis was performed to study this variable during each of the two tasks. Two-way ANOVA was then performed including the task variable and subject as a nested factor within the sign language acquisition history variable. Main effects and the interaction between the two independent variables were studied. The difference in kinematic data between tasks was calculated for each interpreter, and one-way ANOVA was performed to determine whether one interpreter group had a greater difference in kinematic data between the two tasks than the other interpreter group.

One-way ANOVA was also performed using the pause percentage dependent variable to investigate the effect of sign language acquisition history on pause percentage for each of the tasks. The same analysis was also performed on the variability within in each subject's data set to determine whether early signers display less variation in their signing. P-values < 0.05 were considered significant for all the dependent variables. Further information on data analysis can be found in Chapter 4. A key for abbreviations used in the following analysis is included below in Table 3.2.

F/E	Flexion/Extension
R/U	Radial/Ulnar
R	Right Hand
L	Left Hand
P	Wrist Position (degrees)
V	Wrist Velocity (degrees/second)
A	Wrist Acceleration (degrees/second^2)
SD	Standard Deviation
E-I	Early Singing Interpreter in the Interpreting Task
L-I	Late Signing Interpreter in the Interpreting Task
E-C	Early Signing Interpreter in the Conversation Task
L-C	Late Signing Interpreter in the Conversation Task
S	Deaf Student Subject in the Conversation Task

Table 3.2 Abbreviation Key

Chapter 4

RESULTS

4.1 Electrogoniometry Data

In order to analyze the effects of the sign language acquisition history variable and task variable on wrist kinematics, detailed analysis was performed on the electrogoniometry data collected in this study. After data filtering, the descriptive statistics of minimum, mean, maximum, and range were calculated for the previously described wrist position and motion variables. All position statistics were calculated using directional position data. Minimum, maximum, and range were calculated from raw velocity and acceleration data, but absolute values were calculated and used to find the magnitude of the mean for both velocity and acceleration. Refer to Table 3.2 for abbreviation key.

For flexion/extension, minimum represents the extreme value in the negative or flexion direction, and maximum represents the extreme value in the positive of extension direction. For radial/ulnar deviation, minimum represents the extreme value in the negative or radial deviation direction of the left wrist, and maximum represents the extreme value in the positive or ulnar deviation direction. Min and max represent the opposite extreme values in the radial/ulnar plane of the right wrist. Range always represents the full work envelope. Descriptive statistics (min, mean, max, and range) for wrist position during both the conversation and lecture tasks are summarized in Tables 4.1 through 4.3. Statistical analysis of these data are addressed in sections 4.1.1 and 4.1.2.

	Interpreting Task		Conversation Task		
	Early	Late	Early	Late	Student
FE-L					
Min	-55.05 (10.96)	-57.62 (10.82)	-45.1 (18.97)	-46.49 (12.15)	-59.01 (15.99)
Mean	-0.19 (5.63)	-2.48 (6.80)	3.49 (14.73)	-3.57 (9.01)	-2.88 (10.05)
Max	70.48 (7.24)	64.41 (9.52)	68.12 (12.87)	60.5 (15.34)	70.92 (14.88)
Range	125.53 (10.52)	122.03 (14.62)	113.21 (14.23)	106.99 (19.43)	129.94 (22.24)
RU-L					
Min	-39.32 (5.90)	-35.83 (7.78)	-34.01 (7.17)	-29.96 (11.41)	-35.99 (16.00)
Mean	-5.89 (4.54)	-0.71 (10.56)	-3.16 (8.56)	4.4 (13.16)	0.17 (8.11)
Max	26.39 (7.17)	28.01 (10.85)	27.66 (8.61)	30.58 (60.53)	32.84 (8.57)
Range	65.71 (7.16)	63.84 (11.89)	61.67 (11.08)	60.53 (12.25)	68.82 (19.10)
FE-R					
Min	-50.67 (14.95)	-59.51 (12.88)	-51.7 (23.75)	-51.4 (13.23)	-62.02 (17.98)
Mean	2.75 (10.93)	-0.9 (5.59)	0.83 (19.94)	-0.65 (8.56)	-0.08 (11.90)
Max	77.26 (7.86)	69.41 (7.56)	71.16 (15.24)	63.61 (11.83)	81.97 (12.62)
Range	127.92 (11.95)	127.92 (12.33)	122.86 (13.40)	115.01 (16.63)	143.99 (21.16)
RU-R					
Min	-30.36 (8.57)	-28.6 (11.16)	-33.21 (9.24)	-29.73 (14.00)	-37.84 (10.31)
Mean	5.38 (4.15)	4.12 (6.85)	0.17 (8.99)	-0.97 (8.17)	0.81 (7.49)
Max	38.69 (8.90)	38.52 (5.87)	35 (7.46)	29.53 (10.10)	38.56 (7.45)
Range	71.01 (7.16)	65.13 (13.59)	68.21 (7.50)	59.29 (11.50)	127.1 (190.90)

Table 4.1 – Summary Statistics of wrist position (degrees)

Refer to Table 3.2 for Abbreviation Key

	Interpreting Task		Conversation Task		
	Early	Late	Early	Late	Student
FE-L					
Min	-691.7 (130.9)	-634.5 (138.1)	-555.3 (167.8)	-500.3 (147.1)	-598.1 (200.8)
Mean	50.5 (8.2)	52.9 (15.6)	45.2 (7.6)	44.7 (11.3)	45.6 (14.0)
Max	715.9 (156.4)	652.5 (185.4)	653.3 (191.9)	566.3 (230.0)	701.6 (224.0)
Range	1407.6 (269.6)	1287.0 (306.0)	1208.6 (323.8)	1066.6 (342.9)	1299.6 (404.2)
RU-L					
Min	-316.3 (33.2)	-323.9 (88.5)	-273.7 (43.3)	-296.0 (96.6)	-325.8 (118.1)
Mean	31.2 (3.9)	31.8 (9.0)	28.6 (3.1)	30.3 (9.0)	27.0 (6.6)
Max	320.2 (32.1)	299.9 (87.8)	287.3 (44.3)	267.0 (65.4)	289.0 (97.7)
Range	636.5 (45.9)	623.8 (172.1)	561.0 (68.0)	563.0 (158.5)	614.8 (191.1)
FE-R					
Min	-792.9 (126.1)	-685.6 (118.3)	-702.7 (124.6)	-663.4 (169.6)	-783.6 (108.7)
Mean	77.0 (13.0)	75.7 (13.9)	74.6 (10.0)	71.4 (19.4)	78.8 (13.5)
Max	772.5 (117.0)	766.3 (167.1)	732.6 (151.1)	704.2 (199.8)	762.9 (285.5)
Range	1565.5 (218.3)	1451.9 (275.8)	1435.3 (262.9)	1368.0 (349.0)	1593.3 (274.6)
RU-R					
Min	-402.8 (51.1)	-359.4 (102.9)	-346.1 (46.1)	-316.6 (93.3)	-380.2 (134.9)
Mean	44.2 (4.9)	40.1 (10.2)	43.4 (4.9)	38.2 (10.3)	41.2 (6.8)
Max	400.0 (34.1)	348.8 (80.7)	361.5 (67.6)	319.8 (67.9)	399.8 (161.6)
Range	802.8 (72.7)	708.3 (177.5)	707.7 (94.6)	636.4 (155.7)	780.0 (289.2)

Table 4.2 – Summary Statistics of wrist velocity (degrees/second)

Refer to Table 3.2 for Abbreviation Key

	Interpreting Task		Conversation Task		
	Early	Late	Early	Late	Student
FE-L					
Min	-10259 (2699)	-9418 (2645)	-10265 (3744)	-10782 (6441)	-10330 (3715)
Mean	628 (105)	658 (194)	636 (114)	644 (181)	621 (211)
Max	10482 (3534)	9522 (2819)	9221 (3666)	9785 (6656)	9766 (3250)
Range	20741 (6181)	18940 (5426)	19486 (7204)	20567 (12996)	20097 (6754)
RU-L					
Min	-4856 (1521)	-4398 (1124)	-4471 (1523)	-4651 (1505)	-4856 (1521)
Mean	392 (106)	394 (49)	421 (118)	366 (101)	392 (106)
Max	4721 (1541)	4136 (566)	4231 (1454)	4980 (2268)	4721 (1541)
Range	9577 (3025)	8535 (1651)	8702 (2936)	9632 (3725)	9577 (3025)
FE-R					
Min	-10978 (2524)	-12916 (2160)	-11907 (3654)	-13264 (2804)	-10978 (2524)
Mean	995 (216)	1141 (166)	1101 (368)	1136 (239)	995 (216)
Max	11215 (2975)	10986 (1333)	11095 (3439)	12874 (3654)	11215 (2975)
Range	22193 (5452)	23902 (3272)	23002 (6949)	26138 (6339)	22193 (5452)
RU-R					
Min	-5718 (1538)	-6037 (611)	-5804 (3151)	-5933 (1473)	-5718 (1538)
Mean	520 (144)	666 (89)	583 (178)	588 (124)	520 (144)
Max	5636 (1484)	5897 (1045)	6376 (2012)	5685 (1242)	5636 (1484)
Range	11354 (2962)	11934 (1569)	12179 (4988)	11618 (2624)	11354 (2962)

Table 4.3 – Summary Statistics of wrist acceleration (degrees/second^2)

Refer to Table 3.2 for Abbreviation Key

4.1.1 Mean Electrogoniometry Values

Mean values are most useful for studying wrist velocity and acceleration, because sustained speeds and accelerations are what lead to cumulative trauma, not one or two extreme data points. Mean values are less useful for studying position. In this case, extreme hand postures captured by min, max, and range, help to best understand the impact of position on a person's wrists (Hagberg, 1995). Table 4.1 shows that in the R/U plane, mean wrist position fell within ± 6˚, and for the F/E plane, mean wrist position stayed between ±4˚. Mean position values remain relatively close to zero due to oscillations about the neutral (zero degree) position. When looking at the magnitudes of mean wrist velocity in Table 4.2 though, values were higher in the F/E-R plane at around 70-80˚/s and lower in the R/U-L plane at around 27-32˚/s. Mean velocity data for the F/E-L and R/U-R planes was somewhere in the middle at around 40-50˚/s. Mean wrist acceleration, shown in Table 4.3, data followed this same trend, with F/E-R having the highest acceleration values of around 1000˚/s^2 to 1200˚/s^2 and R/U-L having the lowest acceleration values of around 350˚/s^2 to 420˚/s^2.

Histograms showing mean wrist data for position, velocity, and acceleration are displayed in Figures 4.1-4.3. The bar height represents the mean while the error bars represent one standard deviation of the data. Each combination of subject group in both tasks is displayed for all four planes of wrist position and motion. These graphs show that mean data was generally much greater in the flexion/extension plane compared to the radial/ulnar plane for both velocity and acceleration. Especially in the flexion/extension plane, data were greater for the right hand compared to the left hand. When looking at Figure 4.2 showing mean wrist velocity, a trend can be seen as well between the two signing tasks. In studying each interpreter group's data between the tasks, a decrease in wrist velocity is always seen in the conversation task. Higher values

were recorded for wrist velocity in the interpreting task. Figure 4.3 shows the opposite trend, where mean wrist velocity increases in the conversation task. Refer to table 3.2 for abbreviations key.

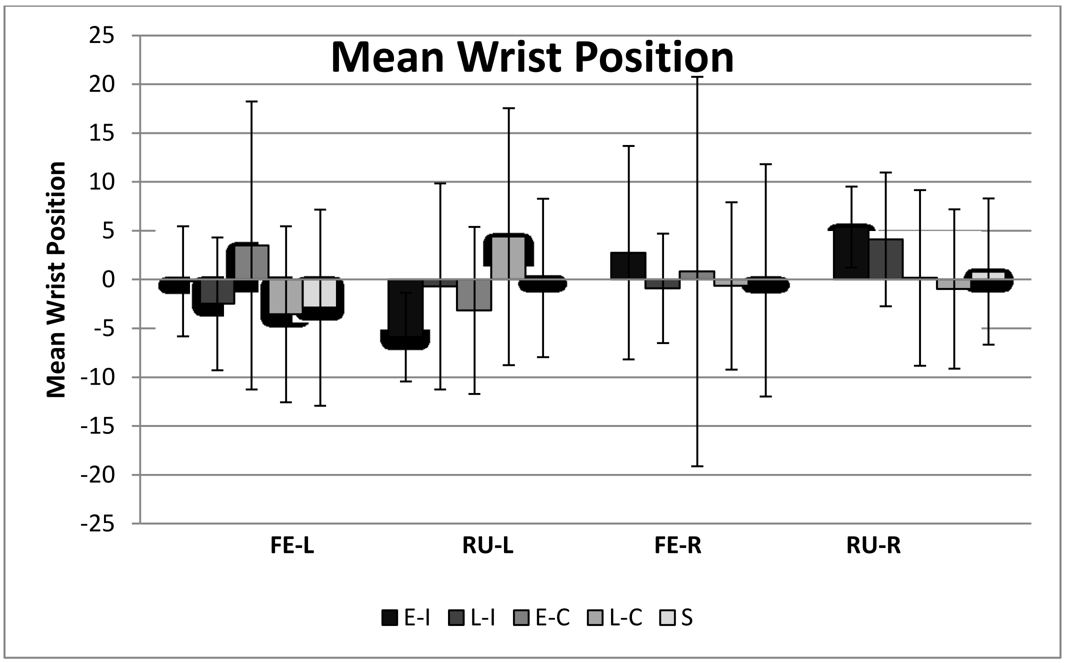


Figure 4.1- Mean wrist position (degrees) under different factor combinations

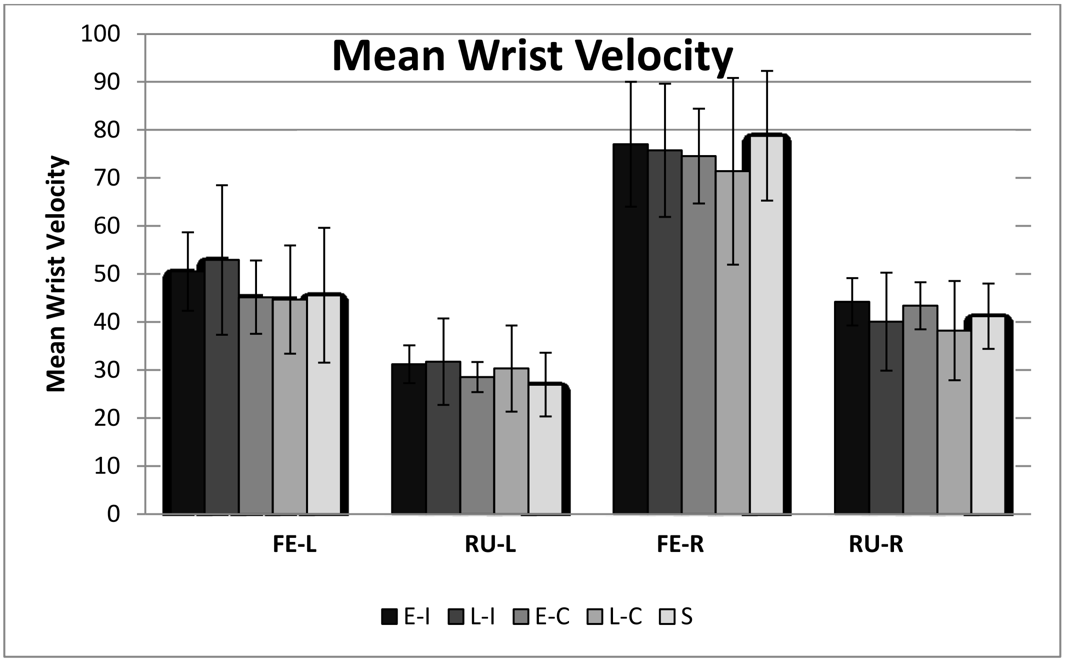


Figure 4.2 – Mean wrist velocity (degrees/second) under different factor combinations

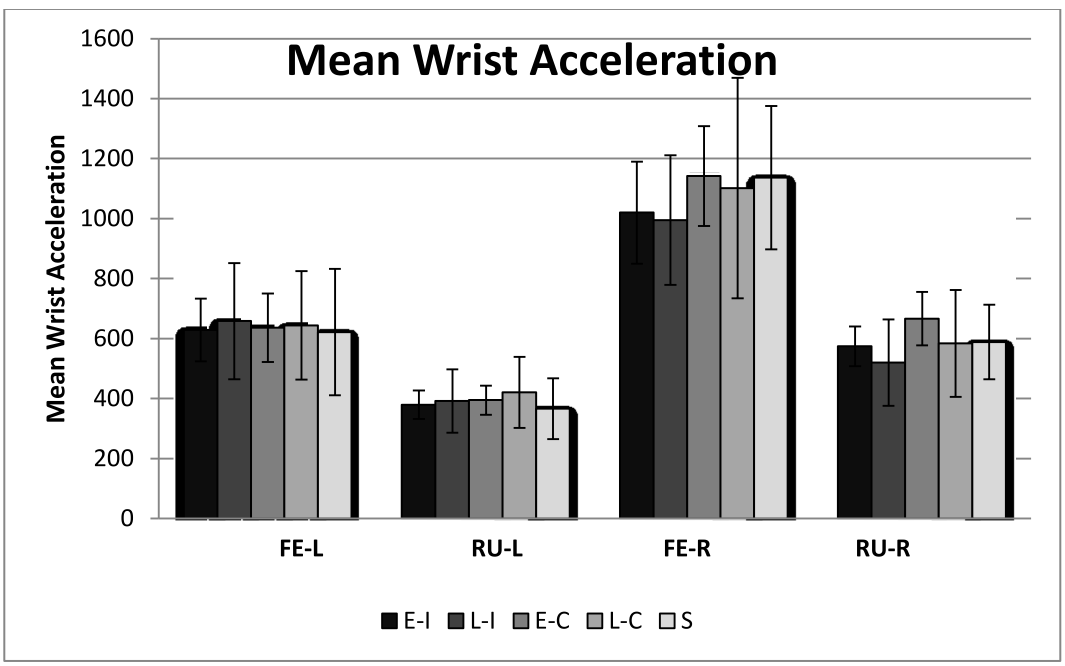


Figure 4.3 – Mean wrist acceleration (degrees/second^2) under different factor combinations

For wrist position, velocity, and acceleration, two-way ANOVA were performed on the mean position, velocity, and acceleration data. Both factors of task and sign language acquisition history were tested as well as the interaction effect between the two main factors. The subject variable was nested within the Sign Language Acquisition History independent variable to account for the natural variability between subjects. Table 4.4 below shows the p-values resulting from this analysis. An asterisk designates any statistically significant effects. Full results for all ANOVA performed in this study are presented in Appendix D. Task had a significant effect on the mean data, while sign language acquisition history and the interaction effect had no significant impact.

Significant differences were found in mean wrist position, velocity, and acceleration between the two signing tasks. Mean wrist position was significantly different in the RU-R plane. Mean wrist velocity was significantly different in the FE-L and RU-L planes, and acceleration was significantly different in all but the FE-L plane. This supports the observation that interpreting generally had higher wrist position and velocity data but lower acceleration data. No difference was found for the sign language acquisition factor for position, velocity, or acceleration in any plane, nor for the interaction between task and sign language acquisition history.

	Variable	Task	E/L	Interaction
Mean				
	FE-L-P	0.581	0.292	0.316
	RU-L-P	0.060	0.176	0.543
	FE-R-P	0.779	0.653	0.715
	RU-R-P	0.011*	0.712	0.973
	FE-L-V	0.002*	0.859	0.427
	RU-L-V	0.001*	0.741	0.204
	FE-R-V	0.128	0.765	0.659
	RU-R-V	0.161	0.256	0.580
	FE-L-A	0.889	0.802	0.653
	RU-L-A	0.032*	0.655	0.462
	FE-R-A	0.021*	0.793	0.864
	RU-R-A	0.001*	0.279	0.461

*Significant at an alpha level of 0.05

Table 4.4 – Significant findings for mean wrist motion (P-Values)

4.1.2 Minimum, Maximum, and Range of Electrogoniometry Data

For wrist position, a greater difference existed between all the min, max, and range statistics than was seen with the mean values. This is shown in Figure 4.4. Max and min values represent the extreme position values that were observed, which is important when studying wrist posture. The magnitude of minimum and maximum wrist position for the R/U plane stayed between 25 and 40 for both hands. The magnitude of minimum and maximum wrist position for the F/E plane fell between 45 and 70 for the left hand and 50 and 80 for the right hand. Although not as important to the study of wrist velocity and acceleration, minimum, maximum, and range values were calculated and analyzed. These values for velocity were highest for F/E-R and lowest for R/U-L. Minimum, maximum, and range values of acceleration for F/E-R and R/U-L were also the highest and lowest respectively.

Histograms showing wrist range for position, velocity, and acceleration are displayed in Figures 4.4-4.6. The bar height represents the range while the error bars represent one standard deviation of the data. As was seen with the mean data, range is higher in the F/E plane than in the R/U plane for position, velocity, and acceleration. The difference in data between tasks is also present for the range statistic. Depicted in Figures 4.4 and 4.5, both position and velocity range data follow the trend of decreased range for the conversation task. This is seen in both interpreter groups. Student range data is relatively high here compared to most interpreter data. A trend in range of acceleration data is less apparent. Range is higher in the interpreting task in most instances, but it is lower in the interpreting task for late signing interpreters in the FE-L, FE-R, and RU-R planes. For the most part early and late signing interpreters show an opposite trend in acceleration range difference between the tasks, but as was stated before, range is not a very meaningful statistic to the study of wrist acceleration.

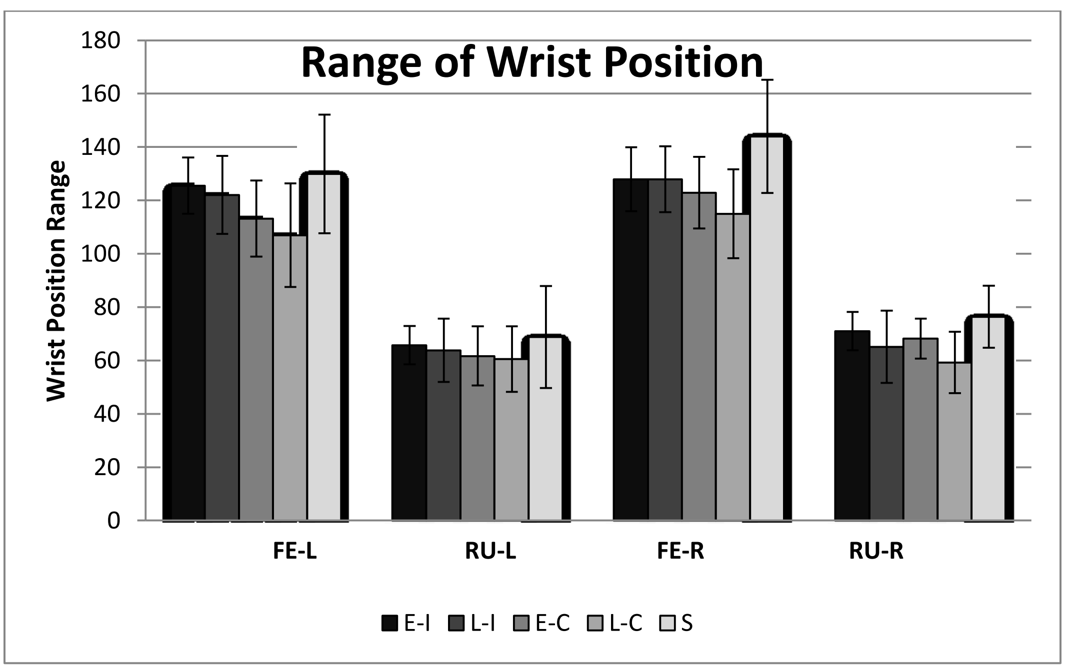


Figure 4.4 – Range of wrist position (degrees) under different factor combinations

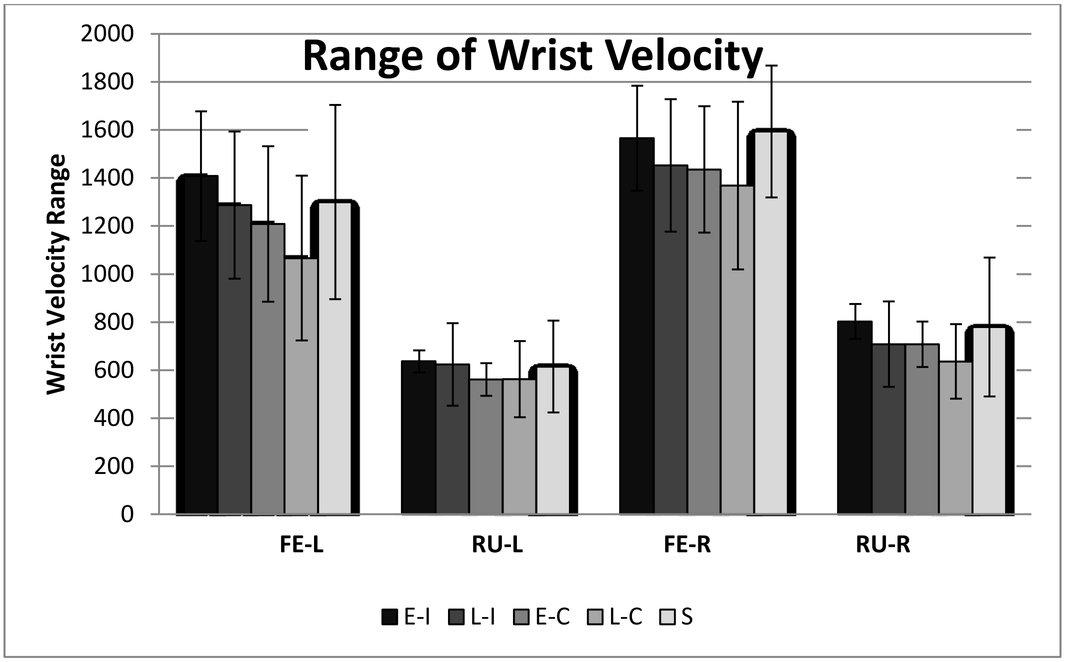


Figure 4.5 – Range of wrist velocity (degrees/second) under different factor combinations

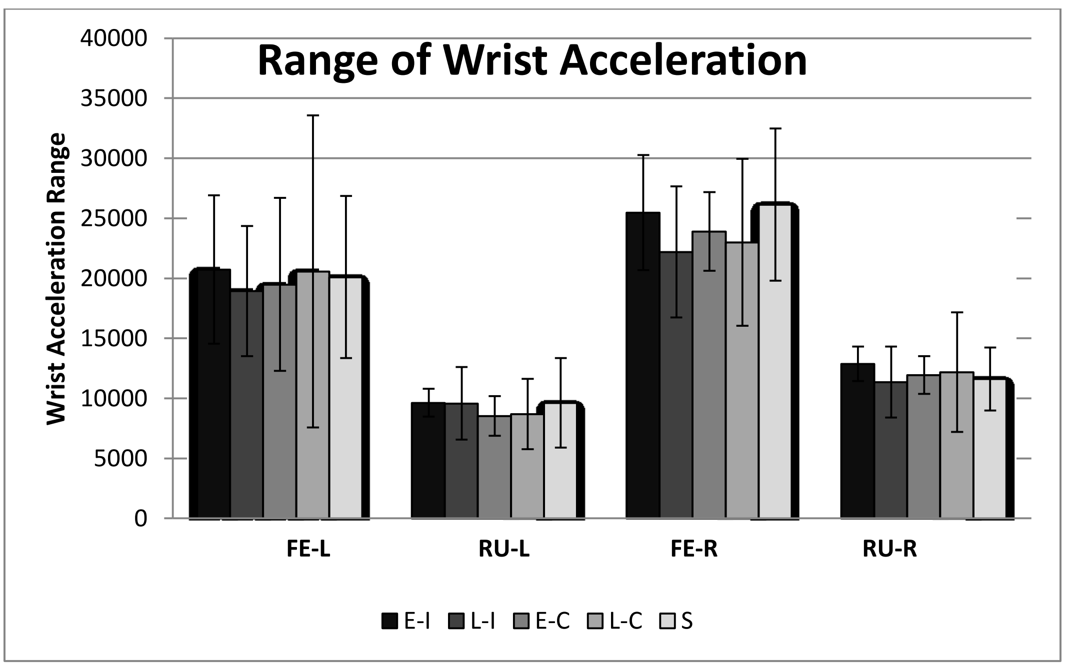


Figure 4.6 – Range of wrist acceleration (degrees/second^2) under different factor combinations

Two-way ANOVA were performed on the min, max, and range of data. As with the mean data analysis, both factors of task and sign language acquisition history were tested as well as the interaction effect between the two main factors. The subject variable was also nested within the Sign Language Acquisition History independent variable to account for the natural variability between subjects. Table 4.5 shows the results from this analysis, and an asterisk designates any statistically significant effects. Task had a significant effect in some planes for all the statistics tested: min, max, and range. Sign language acquisition history and the interaction effect had no significant impact on min, max, or range.

Significant differences were found for minimum wrist position and velocity in the FE-L and RU-L planes as well as for velocity in the RU-R plane. A significant difference was found for maximum wrist position in the FE-R plane, as well wrist velocity in the RU-L and RU-R planes and wrist acceleration in the RU-L plane. Significance was also found for the range of wrist position and for range of wrist velocity between the two signing tasks. A significant difference in range of position was found in all planes, and a significant difference in the range of wrist velocity was found in all but the FE-R plane. No significant difference was found in min or range of wrist acceleration. Also, no difference in min, max, or range was found for the sign language acquisition factor for position, velocity, or acceleration in any plane, nor for the interaction between task and sign language acquisition history.

	Variable	Task	E/L	Interaction
Min				
	FE-L-P	0.004*	0.750	0.849
	RU-L-P	0.003*	0.347	0.857
	FE-R-P	0.299	0.598	0.186
	RU-R-P	0.376	0.610	0.697
	FE-L-V	0.001*	0.405	0.974
	RU-L-V	0.031*	0.650	0.624
	FE-R-V	0.052	0.286	0.218
	RU-R-V	0.034*	0.280	0.749
	FE-L-A	0.569	0.927	0.573
	RU-L-A	0.201	0.863	0.912
	FE-R-A	0.455	0.290	0.697
	RU-R-A	0.716	0.405	0.621
Max				
	FE-L-P	0.177	0.226	0.731
	RU-L-P	0.346	0.628	0.747
	FE-R-P	0.047*	0.148	0.957
	RU-R-P	0.058	0.322	0.403
	FE-L-V	0.104	0.398	0.786
	RU-L-V	0.019*	0.480	0.997
	FE-R-V	0.263	0.815	0.803
	RU-R-V	0.025*	0.138	0.731
	FE-L-A	0.696	0.915	0.552
	RU-L-A	0.016*	0.929	0.546
	FE-R-A	0.152	0.545	0.204
	RU-R-A	0.645	0.896	0.178
Range				
	FE-L-P	0.000*	0.499	0.627
	RU-L-P	0.043*	0.774	0.829
	FE-R-P	0.006*	0.561	0.178
	RU-R-P	0.009*	0.157	0.302
	FE-L-V	0.007*	0.368	0.873
	RU-L-V	0.010*	0.928	0.753
	FE-R-V	0.111	0.506	0.720
	RU-R-V	0.009*	0.190	0.677
	FE-L-A	0.939	0.920	0.555
	RU-L-A	0.054	0.960	0.814
	FE-R-A	0.787	0.400	0.407
	RU-R-A	0.957	0.598	0.393

*Significant at an alpha level of 0.05

Table 4.5 – Significant findings for minimum, maximum and range of wrist position and motion (P-Values)

4.2 Wrist Range of Motion

Analysis was performed on the wrist position range displayed in this study and compared to the standard range of motion (ROM) using the same methodology as Qin et al. (2008). The range between the 5^{th} and 95^{th} percentiles was calculated for each plane of wrist displacement for both interpreter groups during the conversation and lecture tasks. Each experimental range was then compared to the standard 50^{th} percentile male and female range of motion for flexion/extension and radial/ulnar deviation (Kroemer et al., 1997). Experimental values were compared as a percentage of the standard values. The averages and standard deviations for each independent variable combination and each plane were calculated and are presented in Table 4.6. The results are also displayed as a histogram in Figure 4.7.

Within the interpreting task, late signer ROM% was higher than that of the early signing group in all planes. In the conversation task, however, ROM% was higher for the late signer group in the RU plane but higher for the early signer in the FE plane. ROM% was much higher for both groups in all planes during the interpreting task as opposed to the conversation task. Radial/ulnar deviation generally reached higher percentages of the 50^{th} percentile ROM (~50%-75%) then flexion/extension did (~30%-50%). Analysis of variance on the ROM% showed no significant difference due to the subject group, but it did show a significant difference based on the task for F/E of both hands in the early signer group and for all planes in the late signer group. In all these situations, the percentage of ROM used was much higher during the interpreting task.

Plane	N-I	NN-I	N-C	NN-C
FE-L	42.1 (8.9)	43.6 (5.4)	33.3 (6.8)	29.6 (8.8)
RU-L	55.3 (26.1)	65.6 (8.8)	47.4 (13.0)	50.7 (12.7)
FE-R	47.5 (4.0)	53.4 (16.4)	38.9 (8.7)	35.8 (16.2)
RU-R	65.0 (14.4)	74.8 (6.5)	57.2 (14.8)	63.5 (9.3)

Table 4.6 – Wrist motion range as a percentage of ROM (%)

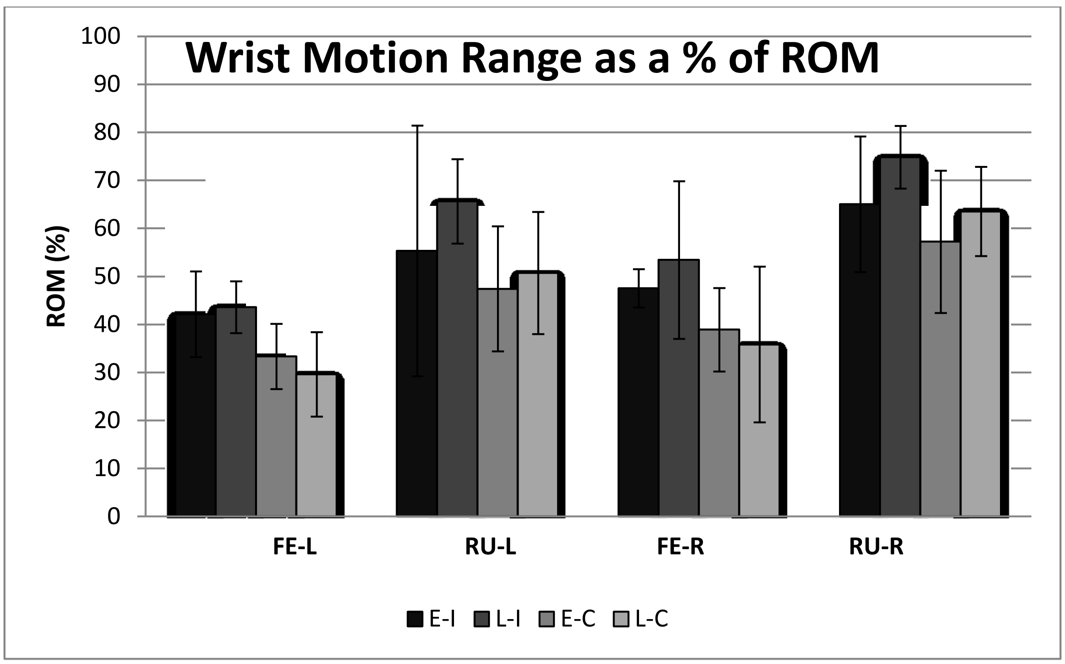


Figure 4.7 - Wrist motion range as a percentage of ROM (%)

Variable	Lecture	Conversation
ROM %		
FE-L	0.681	0.358
RU-L	0.306	0.623
FE-R	0.334	0.644
RU-R	0.099	0.331

**No significance was found

Table 4.7 – Significant Findings for ROM% between Subject Groups (P-Values)

Variable	Early	Late
ROM %		
FE-L	0.044*	0.002*
RU-L	0.461	0.016*
FE-R	0.023*	0.049*
RU-R	0.308	0.013*

*Significant at an alpha level of 0.05

Table 4.8 – Significant Findings for ROM% between Tasks (P-Values)

4.3 Wrist Pause Data

In this study, a "pause" was defined as velocity below 5^{o}/s for at least .2s (Delisle, 2005). Originally a pause was defined as wrist velocity below 1°/s for at least .5s (Hansson et al, 1996). However, Delisle's criteria were preferred over Hansson's when checking percentage values against what should be reasonably expected for the task. Hansson's criteria resulted in pause percentage values that appeared too low, and it was thought that not all pauses were being

captured. Pause percentage is defined as the amount of time in pause divided by the total time. Pause percentage was found for all the wrist variables for each subject and each task, and summary statistics are presented in Table 4.9.

For the interpreting task, pause percentage was highest in the RU-L plane (~19%) and lowest in the FE-R plane (~5%-7%) for both early and late signing interpreters. Pause percentage data for this task was very similar for both interpreter groups and not significantly different. For the conversation task, pause percentage data were more consistent among each of the different planes of wrist movement, but a greater difference was seen between subject groups. Late signing interpreters exhibited the greatest pause percentage (~53%-60%), with early signing interpreters following (~37%-48%). The student subjects displayed the lowest percentages of pause during the conversation task (~24%-42%). Pause percentage was still slightly higher for each group in the RU-L plane and slightly lower in the FE-R plane.

	Interpreting Task		**Conversation Task**		
	Early	Late	Early	Late	Student
Pause %					
FE-L	14.28 (5.84)	14.44 (3.99)	48.16 (16.30)	54.73 (16.06)	36.05 (16.45)
RU-L	19.36 (6.83)	19.00 (4.42)	51.07 (16.06)	60.28 (16.51)	42.52 (16.84)
FE-R	5.31 (1.67)	7.38 (4.49)	37.29 (14.18)	50.64 (20.22)	24.80 (16.19)
RU-R	9.28 (4.18)	11.22 (5.65)	40.40 (12.89)	53.40 (19.59)	28.45 (15.53)

Table 4.9 – Summary statistics of wrist pause percentage (%)

Histograms of the pause percentage data during the interpreting and lecture tasks are presented in Figures 4.8-4.9. Bar height represents mean pause percentage. The error bars represent one standard deviation of mean pause percentage.

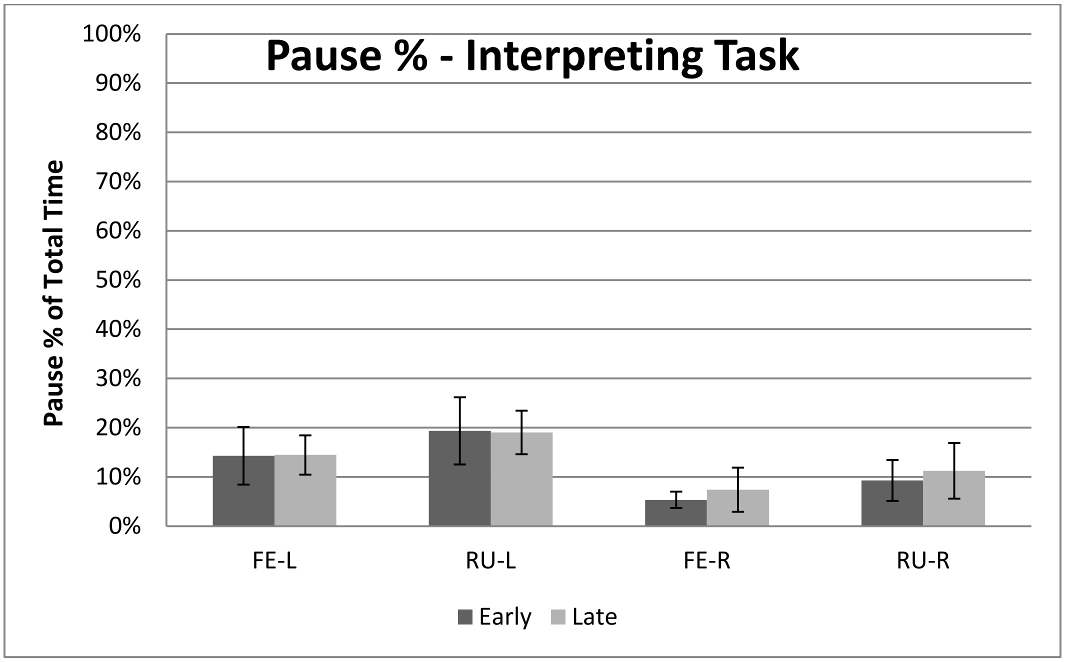


Figure 4.8 – Pause of wrist motion during the interpreting task

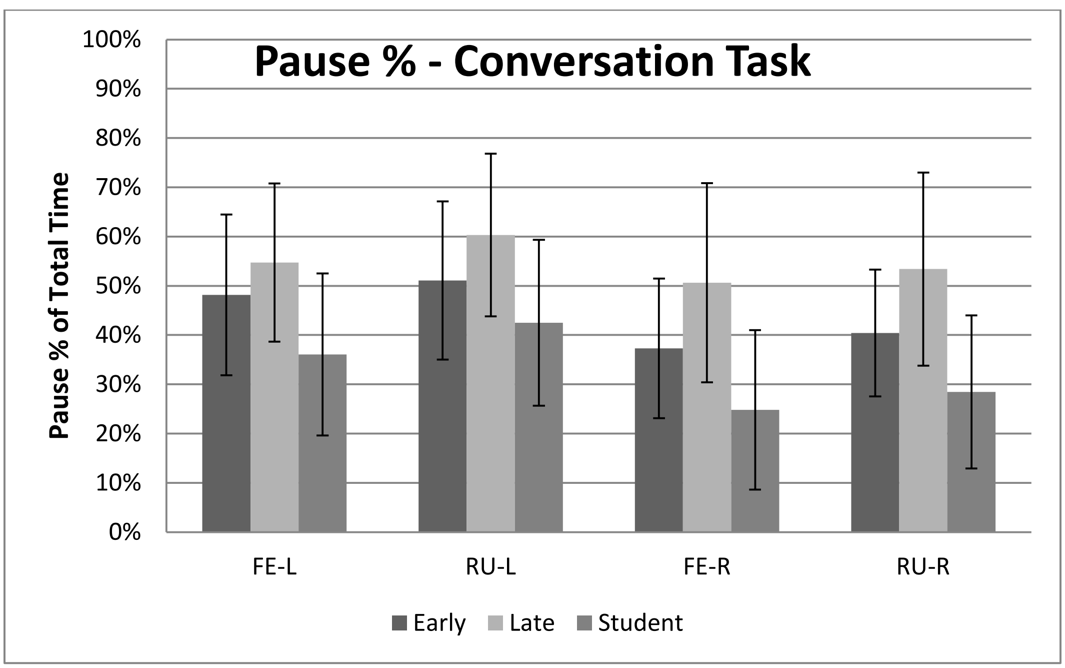


Figure 4.9– Pause of wrist motion during the conversation task

One-way ANOVA was performed for each signing task to test for a significant difference in pause percentage values between subject groups. One-way ANOVA was also performed on the pause percentage difference between the tasks. ANOVA results are presented in Tables 4.10 and 4.11. No significant difference was found between subject groups during the interpreting task. For the conversation task, a significant difference was found in pause percentage data between subject groups in the FE-L, FE-R, and RU-R planes. The RU-L plane was also very close to being significant with a p-value of 0.07. Tukey's HSD test was used to perform pairwise comparisons on the subject groups. For the three subject groups that participated in the conversation task (early signing interpreters, late signing interpreters, and deaf student subjects), the significant difference found in each of the three cases existed between the late signer group and deaf student groups. In each plane, the student group exhibited a significantly lower pause percentage compared to the interpreters (10%-20% difference). This means that the students were generally signing for a greater amount of time during the conversation task than the interpreters.

For the analysis performed on the difference between tasks, significance was found in all cases. This was to be expected since the tasks involve very different amounts of signing, and interpreting is inherently one-sided while conversation is shared. Both interpreter groups were paused for a significantly larger amount of time during the conversation task, since they were only signing some of the time and watching the student sign the rest of the time.

Variable	Lecture	Conversation
Pause %		
FE-L	0.95	0.04*
RU-L	0.90	0.07
FE-R	0.27	0.01*
RU-R	0.45	0.01*

*Significant at an alpha level of 0.05

Table 4.10 – Significant findings for pause percentage of wrist motion between subject groups (P-Values)

Variable	Early	Late
Pause %		
FE-L	0.00*	0.00*
RU-L	0.00*	0.00*
FE-R	0.00*	0.00*
RU-R	0.00*	0.00*

*Significant at an alpha level of 0.05

Table 4.11 – Significant findings for pause percentage of wrist motion between tasks (P-Values)

4.4 Wrist Motion Variation

To address the second hypothesis, which theorized that early signers will exhibit greater variation in wrist kinematic data, standard deviations for each of the velocity and acceleration wrist variables were calculated for each interpreter and each task. For the purposes of comparing variability across conditions, standard deviation was treated as a dependent variable. The mean

and standard deviation of the mean were calculated for each plane and for both interpreter groups and tasks, and ANOVA was used to evaluate the significance of these values. The results are displayed in Table 4.12, and separate histograms for velocity and acceleration illustrating these results are presented in Figures 4.10 and 4.11. Standard deviation of velocity data between subject groups was very consistent for both tasks. Standard deviation was also consistent between tasks. The histograms help illustrate how uniform the data was within each plane of motion. Where variation differed the most was between these planes of movement. The variation among data was greatest in flexion/extension, especially for the right hand. Variation in the flexion/extension plane was roughly twice that of the radial/ulnar deviation plane for the same hand, but this is to be expected given the larger ROM in the F/E plane. The same trends were seen with the variation of acceleration data.

	Interpreting Task		Conversation Task	
	Early	Late	Early	Late
Variation				
FE-L-V	65.9 (6.4)	65.3 (3.7)	59.2 (6.1)	61.0 (4.0)
RU-L-V	36.0 (4.0)	36.2 (1.4)	36.4 (4.2)	33.9 (1.5)
FE-R-V	86.7 (6.0)	93.6 (5.8)	84.2 (8.0)	90.3 (5.1)
RU-R-V	43.5 (4.4)	48.7 (1.6)	42.3 (4.5)	47.6 (1.8)
FE-L-A	830 (78)	819 (52)	865 (100)	864 (68)
RU-L-A	460 (49)	448 (19)	491 (55)	470 (26)
FE-R-A	1162 (93)	1295 (103)	1314 (143)	1361 (91)
RU-R-A	583 (61)	650 (25)	640 (67)	726 (39)

Table 4.12 – Standard Deviation of Wrist Velocity and Acceleration under Different Conditions

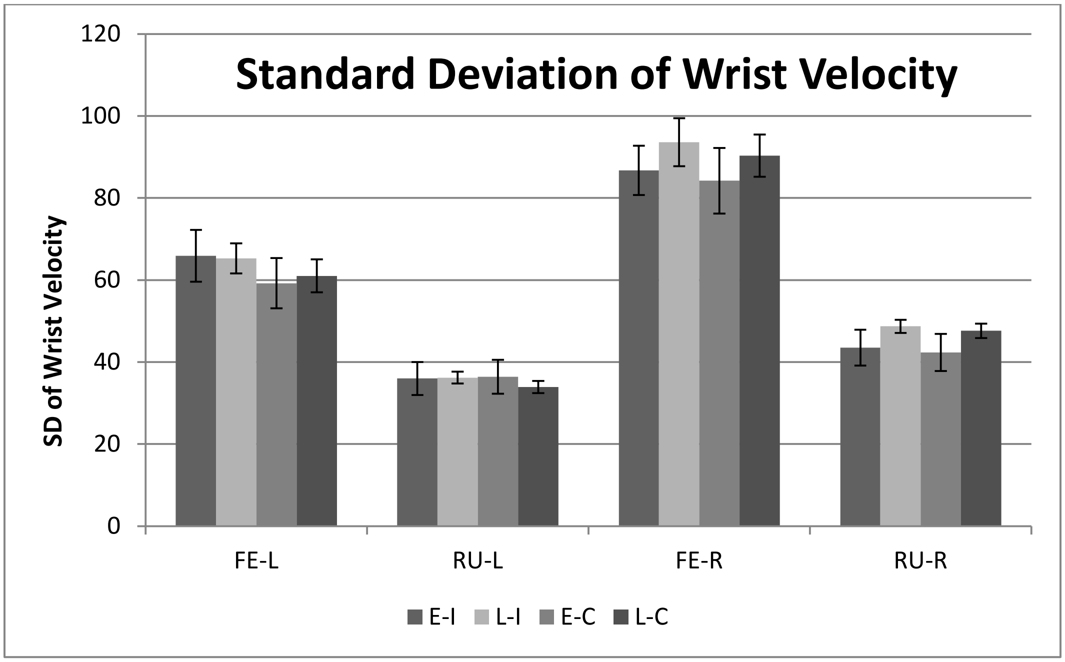


Figure 4.10 – Standard Deviation of Wrist Velocity

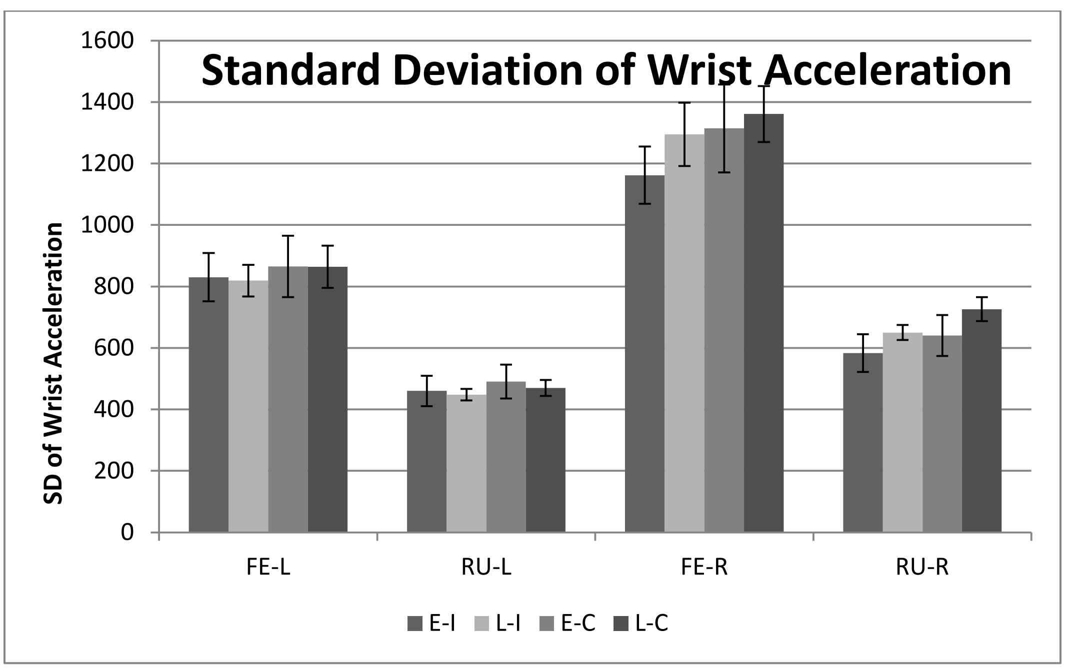


Figure 4.11 – Standard Deviation of Wrist Acceleration

Analysis of variance was performed on the standard deviation of wrist velocity and acceleration. This was performed to look for a statistically significant difference in variation between the early signing interpreters and the late signing interpreters. Based on the very consistent looking data presented in Figures 4.10 and 4.11, a significant difference was not expected. No significance was found in performing the ANOVA, and no p-values were close to 0.05. The results are shown in Table 4.13.

Variable	Lecture	Conversation
Variation		
FE-L-V	0.94	0.81
RU-L-V	0.97	0.75
FE-R-V	0.42	0.55
RU-R-V	0.29	0.30
FE-L-A	0.91	0.99
RU-L-A	0.83	0.74
FE-R-A	0.35	0.79
RU-R-A	0.32	0.28

**No significance was found

Table 4.13 – Significant findings for variation difference between subject groups (P-Values)

4.5 Wrist Position and Motion Difference between Tasks

It was hypothesized that for all interpreters there would be a difference in data between tasks but that this difference would be greater for the late signer group. To evaluate this, the difference in wrist position and motion data between the two tasks was calculated for each interpreter subject. It was thought that the early signer group would be less impacted by the differing tasks than the late signer group. The summary statistics for this difference in data are presented in Tables 4.14-4.16.

Displacement

	Early	Late
FE-L		
Min	10.45 (10.41)	14.51 (8.76)
Mean	8.1 (6.82)	5.61 (5.31)
Max	6.85 (4.82)	8.32 (4.83)
Range	12.31 (9.85)	16.88 (8.81)
RU-L		
Min	6.32 (3.31)	8.02 (3.98)
Mean	5.59 (4.66)	8.48 (3.95)
Max	5.65 (5.31)	6.7 (4.26)
Range	5.95 (6.17)	4.18 (4.47)
FE-R		
Min	13.72 (8.06)	8.56 (6.77)
Mean	12.92 (6.98)	3.78 (3.78)
Max	10.49 (8.10)	8.5 (5.54)
Range	5.96 (6.73)	15.62 (8.51)
RU-R		
Min	4.05 (3.54)	7.84 (7.80)
Mean	6.19 (5.28)	6.67 (6.16)
Max	7.56 (10.42)	12.49 (7.57)
Range	3.96 (2.62)	7.81 (4.27)

Table 4.14 –Summary statistics of the difference in wrist displacement between tasks (degrees)

Velocity

	Early	Late
FE-L		
Min	158.1 (98.1)	160.4 (100.2)
Mean	5.4 (2.8)	8.5 (9.3)
Max	101.5 (103.7)	159.9 (140.3)
Range	241.7 (187.1)	267.5 (237.9)
RU-L		
Min	48.7 (30.1)	59.1 (47.7)
Mean	2.6 (1.2)	2.4 (1.1)
Max	36.8 (23.6)	54.3 (43.6)
Range	75.4 (43.6)	95.0 (93.1)
FE-R		
Min	91.4 (84.0)	91.3 (63.0)
Mean	4.4 (4.2)	8.3 (6.0)
Max	89.3 (66.9)	154.0 (140.4)
Range	179.7 (69.3)	220.9 (205.0)
RU-R		
Min	56.7 (70.0)	42.9 (96.8)
Mean	2.6 (2.3)	3.5 (1.8)
Max	62.0 (33.1)	44.4 (26.0)
Range	103.2 (74.8)	96.0 (108.9)

Table 4.15 –Summary statistics of the difference in wrist velocity between tasks (degrees/second)

Acceleration

	Early	Late
FE-L		
Min	2425 (2277)	3501 (4523)
Mean	19.16 (18)	88.6 (90)
Max	2392 (1320)	4193 (4859)
Range	4501 (3459)	7694 (9142)
RU-L		
Min	787 (679)	833 (753)
Mean	19.25 (14)	35.1 (44)
Max	821 (583)	800 (898)
Range	1608 (1063)	1524 (1606)
FE-R		
Min	2075 (1738)	2539 (2091)
Mean	129.2 (92)	159.3 (164)
Max	1871 (1558)	2414 (1772)
Range	2947 (3228)	4841 (3519)
RU-R		
Min	782 (497)	2219 (2647)
Mean	91.8 (68)	67.2 (77)
Max	769 (560)	1457 (1508)
Range	1388 (1134)	3630 (3897)

Table 4.16 –Summary statistics of the difference in wrist acceleration between tasks (degrees/second^2)

4.5.1 Mean of Wrist Position and Motion Difference between Tasks

As with the analysis of the original electrogoniometric data, mean values provide important information about velocity and acceleration data but provide less meaningful information about the position data. The difference in mean values was very close between the subject groups, and the group that had a greater difference between tasks differed based on the plane. Mean difference in position between tasks was greater for the early signer group in the FE-L and FE-R planes and greater for the late signer group in the RU-L and RU-R planes. Mean

velocity difference between tasks was greater for the late signer group in all planes except RU-L where it was almost even. Mean acceleration difference between tasks was greater for the late signer group in all planes except RU-R. Overwhelming differences or trends are not present in the data.

One-way ANOVA was performed on the mean values to test for a significant task difference between subject groups. The results are presented in Table 4.17. No significant differences were found in velocity or acceleration, but one significant difference between subject groups was found for displacement. Mean position was found to be significantly different in the FE-R plane where the early signer group had a greater mean difference in position.

	Variable	**Task Difference**
Mean		
	FE-L-P	0.428
	RU-L-P	0.203
	FE-R-P	0.007*
	RU-R-P	0.872
	FE-L-V	0.370
	RU-L-V	0.620
	FE-R-V	0.182
	RU-R-V	0.417
	FE-L-A	0.050
	RU-L-A	0.348
	FE-R-A	0.675
	RU-R-A	0.509

*Significant at an alpha level of 0.05

Table 4.17 – Significant Findings for difference in mean data between subject groups (P-values)

4.5.2 Minimum, Maximum, and Range of Wrist Position and Motion Difference between Tasks

No trend was seen in min, max, or range statistics for the difference in position values between tasks. Range was greater for the late signer group in all but the RU-L plane, but min and max value difference varied by plane. Min, max, and range provide little value to the discussion on task difference for velocity and acceleration data, and no trends were present here either. The group that displayed a greater difference in data between tasks was highly variable among planes.

One-way ANOVA was performed to test for a significant task difference between subject groups. This test was performed for min, max and range statistics of displacement, velocity, and acceleration. The results are presented in Table 4.18. As with the mean data, no significant differences were found in velocity or acceleration. Position range was found to be significant in the FE-R and RU-R planes, so both planes of the right hand. In the FE-R plane, range was greater for the early signer group. However, in the RU-R plane, there was a greater range of difference in displacement seen in the late signer group. Little evidence was found in this analysis to support the idea that late signers displayed a greater difference in wrist position and motion data between the formal and informal task.

	Variable	Task Difference
Min		
	FE-L-P	0.413
	RU-L-P	0.369
	FE-R-P	0.200
	RU-R-P	0.231
	FE-L-V	0.965
	RU-L-V	0.610
	FE-R-V	0.999
	RU-R-V	0.749
	FE-L-A	0.558
	RU-L-A	0.899
	FE-R-A	0.651
	RU-R-A	0.153
Max		
	FE-L-P	0.552
	RU-L-P	0.670
	FE-R-P	0.587
	RU-R-P	0.297
	FE-L-V	0.360
	RU-L-V	0.334
	FE-R-V	0.287
	RU-R-V	0.255
	FE-L-A	0.329
	RU-L-A	0.956
	FE-R-A	0.542
	RU-R-A	0.247
Range		
	FE-L-P	0.345
	RU-L-P	0.522
	FE-R-P	0.031*
	RU-R-P	0.048*
	FE-L-V	0.813
	RU-L-V	0.599
	FE-R-V	0.621
	RU-R-V	0.880
	FE-L-A	0.371
	RU-L-A	0.904
	FE-R-A	0.299
	RU-R-A	0.141

*Significant at an alpha level of 0.05

Table 4.18 – Significant Findings for difference in min, max, and range of data between subject groups (P-values)

4.6 Adjusted Interpreter Subject Groups

The two interpreter groups were adjusted to determine if a greater separation between early and late signers would result in a significant difference in wrist kinematics between these adjusted subject groups. In order to further separate the mean age of sign language acquisition between the two interpreter groups, only the four earliest signers and the four latest signers from the original data collection were included in this analysis. The mean age of sign language acquisition for the adjusted early signer and adjusted late signer groups was 3 years and 30 years respectively. Analysis of variance was performed on mean position, velocity, and acceleration and the results are displayed below in Table 4.19. A significant difference was seen between the adjusted early and late signer groups for mean wrist velocity and acceleration in the RU-R plane. This was not observed in the original analysis. These means were not found to be significantly different in the original analysis.

	Variable	Task	E/L	Interaction
Mean				
	FE-L-P	0.838	0.982	0.443
	RU-L-P	0.014*	0.560	0.121
	FE-R-P	0.459	0.942	0.583
	RU-R-P	0.047*	0.485	0.701
	FE-L-V	0.036	0.872	0.581
	RU-L-V	0.014*	0.984	0.502
	FE-R-V	0.121	0.072	0.492
	RU-R-V	0.474	0.004*	0.572
	FE-L-A	0.662	0.909	0.581
	RU-L-A	0.120	0.905	0.946
	FE-R-A	0.134	0.108	0.252
	RU-R-A	0.015*	0.006*	0.245

*Significant at an alpha level of 0.05

Table 4.19 – Significant findings for mean wrist data of adjusted groups (p-values)

Analysis of variance was also performed on min, max, and range of wrist position, velocity, and acceleration, and the results are presented below in Table 4.20. Minimum wrist velocity in the RU-R plane was found to be significantly different for early and late signers, as was the range of wrist position and acceleration in the RU-R plane. A significant difference for these statistics was not found in the original analysis.

	Variable	Task	E/L	Interaction
Min				
	FE-L-P	0.252	0.666	0.884
	RU-L-P	0.005*	0.969	0.228
	FE-R-P	0.800	0.822	0.422
	RU-R-P	0.476	0.088	0.993
	FE-L-V	0.012	0.310	0.467
	RU-L-V	0.095	0.641	0.896
	FE-R-V	0.046*	0.063	0.783
	RU-R-V	0.417	0.007*	0.888
	FE-L-A	0.604	0.986	0.879
	RU-L-A	0.711	0.678	0.906
	FE-R-A	0.632	0.107	0.685
	RU-R-A	0.769	0.198	0.923
Max				
	FE-L-P	0.064	0.579	0.501
	RU-L-P	0.146	0.327	0.525
	FE-R-P	0.093	0.509	0.992
	RU-R-P	0.143	0.987	0.891
	FE-L-V	0.642	0.607	0.642
	RU-L-V	0.165	0.232	0.528
	FE-R-V	0.388	0.310	0.345
	RU-R-V	0.487	0.026	0.479
	FE-L-A	0.977	0.827	0.948
	RU-L-A	0.282	0.698	0.739
	FE-R-A	0.122	0.173	0.868
	RU-R-A	0.557	0.418	0.535
Range				
	FE-L-P	0.025*	0.388	0.738
	RU-L-P	0.118	0.575	0.725
	FE-R-P	0.028*	0.250	0.175
	RU-R-P	0.138	0.007*	0.744
	FE-L-V	0.114	0.454	0.529
	RU-L-V	0.101	0.384	0.822
	FE-R-V	0.185	0.135	0.523
	RU-R-V	0.342	0.008*	0.671
	FE-L-A	0.814	0.904	0.914
	RU-L-A	0.448	0.682	0.815
	FE-R-A	0.284	0.134	0.887
	RU-R-A	0.974	0.244	0.864

*Significant at an alpha level of 0.05

Table 4.20 – Significant findings for min, max, and range of wrist data of adjusted groups (p-values)

Table 2.1 below shows the mean and standard deviation for each of the wrist variables that were found to be significant in the adjusted subject group data. These averages represent both signing tasks. In each situation where significance was found, the early signing group displayed greater wrist data. As with the original early and late signing interpreter groups, the adjusted subject groups from this study do not support the original hypothesis that early signers have lower wrist position and kinematic data during a signing task.

Adjusted Subject Groups

	Early	Late
RU-R-P		
Range	71.02 (4.80)	60.36 (2.26)
RU-R-V		
Min	-387.5 (37.5)	-301.9 (80.7)
Mean	44.9 (4.5)	33.0 (3.39)
Max	393.0 (58.9)	301.7 (41.2)
Range	780.5 (69.7)	603.6 (111.3)
RU-R-A		
Mean	624.7 (93.0)	450.2 (55.4)

Table 4.21 – Summary statistics for significant results of adjusted subject groups (degrees, degrees/s, degrees/s^2)

Chapter 5

DISCUSSION

The hypotheses developed for this research all relate to two main factors in question: the experience or sign language acquisition factor (early vs. late signers) and the setting factor (formal interpreting vs. casual signing). It was hypothesized that late signers would display increased wrist kinematic data during each of the tasks. Additionally, it was hypothesized that the group of students who are deaf, who were included in this research, would closely resemble the early signer group in terms of wrist kinematic data. It was also hypothesized that the early signer group would have a lower percentage of pauses in their signing and an increase in wrist kinematic variability compared to the early signers. In terms of the task factor analyzed in this research, it was theorized that all subjects would display increased wrist kinematic data during the lecture task compared to the conversation component of the experiment. It was also hypothesized that the late signer group would show a greater difference in any wrist kinematics between the tasks than the early signers would.

5.1 Early vs. Late Signers

5.1.1 Wrist Motion

The experimental results did not support the first hypothesis, which theorized that early signers would exhibit lower wrist kinematics compared to late signers. When analysis of variance was performed on the data, none of the wrist position and kinematic data were affected by the sign language acquisition factor (Tables 4.4 and 4.5). It is possible that the two subject

groups used in this study (early and late signers) were not different enough in their acquisition history to show a significant difference in their wrist data. However, the age when a subject started signing was found to be significantly different between the early signer and late signer subject groups (Table 3.1). Average age when the subjects started signing was 5.7 for the early signer group and 24.3 for the late signer group. This seems relatively far apart, but the ranges (0-15) and (17-42) almost overlap. Sensitivity analysis was performed on the allocation of individual subjects assigned to the two groups, including eliminating subjects who were close to the middle range of acquisition age, but this had no impact on finding any significant difference in wrist data. It may also be the case that hypothesis one is incorrect, and that learning to sign at a young age has no effect on a person's signing style and wrist kinematics while signing.

While Feuerstein and Fitzgerald (1992) show that individual factors and signing style can cause some people to sign with greater wrist deviation and kinematics than others, this experiment strongly suggests that the age when a person learns and starts using sign language is not an individual factor that impacts signing style in a way that causes greater wrist kinematics. The finding that in this study sign language acquisition history had little to no impact on wrist position and kinematics is consistent with Podhorodecki and Spielholz's (1993) study of native and non-native signers. Of their 16 subjects who reported pain, none were native signers. However, supramaximal motor and sensory nerve conduction studies showed findings suggestive of cumulative trauma disorders in five subjects, three of which were native signers. This is evidence that native signers can get these disorders. It has been suggested anecdotally that due to their culture, people who are deaf do not like to discuss their pain related to their main form of communication, and that this is leading to a general belief that early signers (people who are deaf, CODA, SODA, etc.) do not develop cumulative trauma disorders (Woodcock, 2011). A positive result of this finding is that it does help imply that someone wanting to learn ASL and

become a sign language interpreter later in life is not automatically at a higher risk for developing pain and musculoskeletal disorders just because they did not learn sign language when they were younger.

It was also stated in hypothesis five that the data from the students who are deaf would closely resemble data produced by the early signing interpreter group, as it was assumed that the students would provide a control group of early signers. The late signer group was then expected to have higher wrist kinematic data compared to the early signing interpreters and students. The early signing interpreter group and student group did end up having similar data values, illustrated in Figures 4.1-4.6., and they were not found to be significantly different from one another as was expected. Where the results differed from the hypothesized outcome was in the fact that the late signer group was also not significantly different from the early signer groups. This statistical analysis is found in Tables 4.4 and 4.5. All three groups had very similar wrist kinematic data, which opposes the expected outcome stated in hypothesis five.

It is important to note that due to the profiles of students available and willing to participate in the study, the group of students who are deaf did not turn out to be a purely early signer control group as was planned. Based on the age at which they started signing, several students, in fact, would have been classified as late signers if they were interpreters. The average age of the students when they learned ASL was 11.8 with a standard deviation of 7.2. This means that the average age of sign language acquisition falls into the criteria for the early signer group, but three of the students clearly fall into the late signer group and several more are in the borderline area. It was a misconception to assume that all students who are deaf and sign generally have learned ASL at a young age. A number of students learned ASL once they came to RIT for college. Therefore, the student group is not a very good comparison to the early

signing interpreter group. Regardless of this fact though, none of the three groups were found to produce significantly different results from any of the other groups.

In this study, wrist kinematics were studied to identify any possible differences between early and late signers. This analysis did not result in any significant difference being found, but there are variables that could be studied related to early and late signers. It is possible that another variable would uncover a significant difference between the populations. Several other variables have been used in previous research to quantify the effects of signing on a person's risk for upper extremity musculoskeletal disorders. A systematic review of existing research performed by Fischer, Marshall, and Woodcock (2012) found several other dependent variables used to measure sign language and its effect on musculoskeletal disorder development. Some examples that could be applied to the study of early vs. late signing interpreters include electromyography to study muscle activity, finger motion (related to finger spelling), nerve conduction which would provide a comparison to Podhorodecki and Speilholz (1993), and psychological stress.

5.1.2 Wrist Pause Percentage

Similar to the wrist motion findings, the experimental results did not support the theory that pause percentage values would be significantly higher for the early signing group compared to the late signing group. The results of this statistical analysis can be found in Table 4.10. Pauses, defined as velocity below 5^{o}/s for at least 0.2s, were found much more significantly in the conversation task compared to the interpreting task, as was expected. This is shown in Table 4.11. Statistical significance was found for the difference in pause percentage between the two tasks for every plane and both subject groups. This result was predicted since an interpreter pauses more during a conversation to allow the student to respond.

Within the lecture task, wrist pause percentage was higher for both planes of the left hand, with RU-L having the highest pause percentage (~19%). Pause percentage was lowest in the FE-R plane (~5%-7%). All but one of the subjects were right hand dominant. This suggests that the non-dominant hand is generally able to rest more than the dominant hand. It can also be seen in Figure 4.3 and 4.5 that mean wrist velocity and mean wrist acceleration are greater for the right hand than the left hand. A more pronounced difference is seen in the FE plane for both velocity and acceleration. This difference between hands makes sense when looking at how signs are performed in ASL. As Wilbur (1979) explains, for a right handed person, the right hand is usually dominant when signing, while the left hand is passive. Signs are either one-handed or two-handed, and both place more emphasis on the dominant hand. One-handed signs are performed only with the dominant hand. Many two-handed signs involve use of the dominant hand while the non-dominant hand remains relatively static. This does not mean that the non-dominant hand is truly resting, however. Many times it is holding a hand shape to help convey a sign. So, it is important to note that for the method that was used to calculate pauses in this study, there is an undetermined portion of the pause time that does not represent a rest but represents a sign being held, and this should be more prevalent in the non-dominant hand.

More consistency was seen in mean pause percentage among both hands and planes during the conversation task. However for the conversation task, standard deviation was higher in all hand and plane combinations compared to the interpreting task, which can be explained by the non-constant stimulus used during the conversation task. Like the interpreting task, pause percentage for the left hand was greater than that of the right, but in this case only a slight difference was seen. The difference between hands is more apparent in the interpreting task. This may be due to the higher variation in pause percentage between the subjects and its influence on mean pause percentage.

The analysis of variance showed no statistically significant difference in pause percentage between subject groups in the interpreting task. It was theorized that the early signing interpreter group may have developed a more efficient signing technique, allowing them to convey the same message while allowing time for more short pauses. However, these results do not support this hypothesis. After analyzing the initial wrist kinematic data which showed no statistically significant difference between the wrist motion of the early and late signing interpreters, the fact that the groups do not differ in terms of pause percentage is not surprising. All three subject groups (early signing interpreters, late signing interpreters, and subjects who are deaf) were included in the analysis of pause percentage during the conversation task, and a statistically significant difference was found for all planes except RU-L. The results can be found in Table 4.10. Tukey's HSD test showed that in each case of significance, the difference fell between the students who are deaf and the interpreter groups. In terms of the relationship between the early and late signing interpreter groups, however, no statistically significant difference was found for pause percentage in the conversation task.

The student group demonstrated a much lower percentage of pauses in all plane and hand combinations than the interpreter groups. One explanation for this occurrence is that it was very obvious to the investigator that the students were signing during a greater percentage of each conversation in almost every interpreter-student pairing. This could possibly be due to an acquired feeling of many of the interpreters that they are there to serve the students and receive their feedback and concerns rather than express all their feelings to the students. Though it was emphasized that the conversation task should be balanced between the student and the interpreter, it does not appear that this was the case. The important takeaway is that there was no difference in pause percentage found between interpreter groups for either task.

5.1.3 Wrist Motion Variance

The results of this experiment did not support hypothesis two, which stated that variation within the late signing interpreter group would be greater than the variation within the early signer group. The summary statistics of the variation data, shown in Table 4.12, demonstrated very consistent variation between the two subject groups, contradicting what was theorized in the second hypothesis. Although it was not stated as part of the hypothesis pertaining to variation, it is important to point out that both interpreter groups' variation was also quite consistent between the tasks. Velocity variation was only slightly higher for both groups in the lecture task, and acceleration variation was slightly higher for both groups in the conversation task. Analysis of variation was performed on these differences, and none were found to be statistically significant. No statistical significance was found either for a difference between the interpreter groups' variation.

Both groups did show a difference in variation between the four planes of wrist movement studied in this research. These differences can be seen in Figures 4.10 and 4.11. Greater variation was seen in the F/E plane. This makes sense when considering the range of motion that the average individual has in each plane. The 50^{th} percentile male and female have a range of motion in the flexion/extension plane of 130^{o} and 144^{o} respectively, compared to 53^{o} and 55^{o} for males and females in the radial/ulnar deviation plane (Kroemer,1997). Greater variation would be expected when the range of possible data points is almost three times larger for the F/E plane. These results suggest that there is a relatively consistent level of variation in wrist biomechanical data that one could expect. At least for this experiment, variation was not significantly affected by sign language acquisition history or the formality of the signing task.

5.1.4 Adjusted Interpreter Subject Groups

The early and late interpreter groups were adjusted in order to test whether a greater separation between early and late signers would result in finding a significant difference between wrist kinematics for the two groups. It was hypothesized that this greater separation would show significantly greater wrist data for the early signers which was not observed in the original interpreter groups used in this study. Several wrist variables in the RU-R plane were found to be significantly different between the two groups. However, analysis of the data showed that greater wrist position, velocity, and acceleration statistics were observed for the late signers as opposed to the early signers in each case where the variables were significant. As with the original early and late signing interpreter groups, statistical analysis of the adjusted groups did not support hypothesis one, which stated that early signers would display lower wrist kinematics during signing. For this smaller subset of the data, the results showed a contrasting outcome to was expected in hypothesis one.

5.2 Formal vs. Informal Signing Task

5.2.1 Wrist Motion

The results of this experiment did support hypothesis three, which theorized that all sign language interpreter subjects would display greater wrist kinematic data during the formal signing task than the informal task. When two-way ANOVA was performed on each of the wrist variables, the task factor was found to have a statistically significant impact on several position, velocity, and acceleration statistics (Tables 4.4 and 4.5). Minimum wrist position was significantly different in the FE-L and RU-L planes, and maximum wrist position was significant

in the FE-R plane. Also, range of wrist position was significant for all variables, which is not surprising given the min and max results. These factors are most important in describing the extreme position differences between tasks. The maximum and minimum statistics refer to the extreme wrist excursions from neutral. As can be seen in Figure 4.4, wrist position range was greater for interpreting compared to conversation in each plane, which supports hypothesis three. This means that due to the additional demands and stress involved in the interpreting task, the subjects must reach more extreme wrist positions, possibly due to the momentum involved in signing faster to maintain pace with the lecture. This result could also arise from the acquired practice of trying to sign bigger and more deliberately to be seen by students in a classroom setting. It would not be necessary to do this in a one on one conversation in a close area, so the extreme position values should be lower as was seen in this study.

When looking at the difference between tasks for velocity and acceleration of the wrist, mean values are important for studying the cumulative effect of the task on a person's body. These are illustrated in Figures 4.2 and 4.3. Marras and Schoenmarklin (1993) have shown the importance of dynamic variables like velocity and acceleration in assessing cumulative trauma disorder risk. They describe that wrist acceleration dramatically increases the resultant reaction force on the tendons passing through the carpal tunnel. This can contribute to the development of a number of different cumulative trauma disorders (Marras & Schoenmarklin, 1990). Mean velocity was found to be significantly different for both FE and RU planes of the left hand (Table 4.4). This supports hypothesis three, since in both planes, the mean of left hand motion was greater during the lecture task. The data also followed this trend for the right hand but was not statistically significant. During the lecture task, just as was discussed relative to wrist position, interpreters had to maintain pace with the speaker, and one would reasonably assume this would produce signs with greater velocity than a casual conversation that can be paced by the

participants. There are also other stressors that are more prevalent in an interpreting task, such as the interpreter's unfamiliarity with the subject matter and all the focus of the student and the investigator on the interpreter at that point of the study. The interpreters were given no reference material for the lecture prior to the experiment, so it is possible that an increased level of pressure would exist to keep up with new vocabulary and ideas and to convey that well.

In a 2008 study by Qin, Marshall, Mozrall, and Marschark, when sign language interpreters were studied under stressed and non-stressed conditions, the stressed group displayed an increase in non-dominant wrist velocity between 14.8% and 19.5%. This is somewhat similar to this study since in the Qin et al. study the more stressful situation produced greater wrist velocity, and in this research the formal task produced an increase in wrist velocity. Both studies showed a greater increase in wrist velocity in the non-dominant hand for the stressed or formal task. This is not a direct comparison since stress was not measured in this study, but it is reasonable to assume that the formal task may be more stressful than the conversation task. Understanding the role of the dominant and dominant hand in American Sign Language may help explain these results. As was described before from Wilbur (1979), during many signs, the dominant hand is moving while the non-dominant hand remains static. Another important fact to note about ASL is that when a person wants to place special emphasis on a word or idea, one way to do this is to perform the sign with the non-dominant hand instead of the usual dominant hand. It may be that in the more formal or more stressful lecture task, the interpreters placed more emphasis with their non-dominant hand than in the conversation task. In the future, stress could be measured in a study like this and further research could be performed related to the idea of increased non-dominant wrist velocity in more stressful situations.

Mean wrist acceleration was also found to be statistically different between the tasks (Table 4.4). A difference was found in all variables except FE-L. When a significant difference was found for mean acceleration between tasks, acceleration was actually higher in the conversation task compared to the lecture task. Although this is the opposite of what was predicted in hypothesis three, the results make sense after further consideration. It is likely that all the starts and stops when taking turns in conversation produce more instances of rapidly changing velocity. Each time that one person is paused to watch the other person sign, they would then go through a rapid acceleration from zero velocity to start signing a response. This leads to a mixed result for hypothesis three. Position and velocity followed what was predicted in terms of the lecture task creating higher wrist data, but acceleration brought the opposite effect. The mitigating factor here is pause percentage. While the conversation tasks produced greater wrist acceleration, the increased pause percentage in this task allowed for more wrist recovery.

5.2.2 Wrist Motion Difference between Tasks

Hypothesis four, relating to the interaction effect between the task and sign language acquisition variables, was not supported by the results of this study. It was hypothesized that the late signing interpreter group would show a significantly greater difference in wrist data between the two tasks than the early signer group would. Once no statistically significant difference was found between early and late signing interpreters (Hypothesis #1), it became apparent that this hypothesis would also be false.

When analysis of variance was performed on the calculated difference between tasks, no statistically significance difference was found for velocity or acceleration. Furthermore, the interaction effect of both independent variables, presented in Tables 4.4 and 4.5 is another test of

this same idea that the sign language acquisition variable further exacerbates any effects of the task variable. No significant results were found in the interaction of the two variables, further refuting hypothesis four. It makes sense that since no difference was seen for the sign language acquisition variable, that it could not increase the effect of the task variable.

5.3 Limitations

Several factors affected the results of this study. They are mostly related to the selection of subjects for the study, methods used for data analysis, and representation of real life signing situations. The most relevant possible limitations are listed below.

- Based on the interpreters who were available and willing to participate in this study, the two interpreter groups were not populated exactly as would have been desired. A stronger distinction between interpreters who learned ASL at a very young age and then who learned ASL much later would have been preferred. This could have provided stronger evidence for or against the hypotheses, but sensitivity analysis on the allocation of subjects to the groups suggests that it may not have that significant of an affect.
- As a result of the students who were available and willing to participate in the study, the student group was not an early signer group as was expected. Being able to select only early signers for the student group would have provided a much better control group to compare the early signing interpreters to. This would have allowed for comparisons to be made between different types of early signers (hearing and deaf) to determine if one has a signing style more prone to developing upper extremity musculoskeletal disorders.

- Pause percentage data did not represent only true pauses in signing. The pause percentage statistics include an undetermined amount of time when signs were being held, which makes the pause percentage data presented in this research less accurate. To really measure pause percentages, only the time when an interpreter's hands are down and resting should be measured. This would have allowed for a more accurate analysis of pauses between interpreter groups to determine if one group creates more recovery time during signing, decreasing musculoskeletal disorder risk. This could be performed with a more detailed analysis of the pause data, but video analysis would be a good solution as well.
- Differing techniques exist for defining pauses in sign language (Hansson et al., 1996; Delisle, 2005). This study used the criteria set forth by Delisle, so when comparing pause data with other studies, the pause criteria used in the studies should be considered. Any different pause criteria would have affected pause percentage results. This may or may not have shown a statistically significant difference between early and late signers for pause percentage.
- A completely casual conversation task was not analyzed in this research. In order to make conversation sessions more comparable, facilitating questions were used, which made the conversation task not a completely natural conversation. Conversations without built in constraints should be analyzed and compared to interpreting. This may have produced an even greater difference in wrist kinematics due to the task variable.
- Two-tailed statistical tests were used throughout this research. In many instances, a more powerful one-tailed test could have been used since one data set was hypothesized to be greater or less than another data set. This may have helped significance to become visible by providing more power in one direction and increasing the probability of

finding significant results that are indeed significant. However, in most instances the data were so close that a one-tailed test probably would not have shown any different results.

5.4 Future Research

- A limiting factor of this study could be the size of the subject groups. A sample size of eight subjects was used for each interpreter group, but a larger sample size would reduce variability in the data. Since data were generally very close between the groups and p-values were not close to being significant, this may not have had an effect on significant differences found between groups.
- Quantitative measures could be used to evaluate stress and arousal during casual and formal signing tasks so that this can be studied along with biomechanics. The data could then be compared to other studies measuring stress such as Qin et al. (2008). This type of analyses was not included in this research and would have provided other dependent variables to consider when studying the difference between early and late signers.
- Future sign language data collection should be videotaped to be able to observe actual pauses in signing, or a different method should be considered for defining pauses. These observations could then be compared to calculated pause statistics from the same signing trial using pause percentage criteria from previous studies (Hansson et al., 1996; Delisle, 2005). In this study, it was determined that calculated pause values encompassed both real pauses and instances where a still hand was holding a sign but not necessarily in a neutral wrist position. A more accurate method of determining pause percentage would give a better view of pause differences between groups like early and late signers.

- There are still many factors that have not been studied that may impact an individual's wrist biomechanics during singing. Future research is necessary to analyze any significant impact those other factors may have on signing biomechanics. Also, other dependent variables could be considered to study possible differences between early and late signing interpreters further.
- In future research, analysis on the effectiveness and accuracy of an interpreter's signing should be incorporated in order to map interpreting effectiveness to wrist biomechanical data. Analysis on whether early signers produce more accurate or easier to understand signs was not performed as part of this study but would be useful knowledge.

Chapter 6

Conclusion

This study analyzed the effect that learning sign language early in life has on wrist biomechanics produced while signing. The differences in wrist kinematic data exhibited in a formal interpreting task and a casual conversation task were also studied as part of this research. Angular wrist position, velocity, and acceleration were measured in both the flexion/extension plane and the radial/ulnar deviation plane to quantify differences in signing biomechanics. Wrist motion variability and pause percentage while signing were also studied as possible differentiating factors between the two tasks and between the two interpreter groups. Eight early signing interpreters who started signing at a young age and eight late signing interpreters who started signing after high school were studied while participating in both the formal and informal tasks. Nine students who are deaf participated actively with the interpreters in the conversation task, and their wrist biomechanics were also analyzed.

It was originally hypothesized that early signers would sign with a technique that, biomechanically, is easier on the body than the technique utilized by late signers. Specifically, it was theorized that early signers would exhibit lower velocity and acceleration while signing, compared to late signers. The findings of this research do not support the original hypothesis, as the interpreter groups displayed mean velocity with an average of 5% difference between early and late signer groups and mean acceleration within 6% of each other, on average. Greater wrist kinematics differed based on the plane, and no statistical significance was found for the difference between early and late signers.

Evidence was not found in this study to show that learning to sign at a young age helps a person to develop a less risky signing style, which would be categorized by lower wrist velocity and lower wrist acceleration while signing. However, this research does help show that a person is not at an increased risk for developing a musculoskeletal disorder simply because he or she did not learn to sign until adulthood.

In addition to evaluating differences in biomechanics between early and late signers, this research hypothesized that all sign language interpreter subjects, regardless of ASL acquisition history, will display increased wrist kinematic data during the formal signing task as opposed to during the informal signing task. The findings of this research do support this hypothesis, as an increase in mean wrist velocity of 8%, on average, was seen for both interpreter groups in the formal task. This finding was statistically significant for both flexion/extension and radial/ulnar deviation of the left hand. A 10% increase, on average, was seen for mean wrist acceleration in the conversation task, which, after further consideration, makes sense due to the increased starts and stops present in a conversation. This increased acceleration is mitigated by a greater time spent pausing during the conversation task. This increased acceleration was statistically significant for both hands in the radial/ulnar plane and for the right hand in the flexion/extension plane.

These results make it apparent that sign language interpreting is more demanding on the wrists than casual signing and provides evidence for the high prevalence of musculoskeletal disorders seen in sign language interpreters. Future research could help to further identify and understand the factors within sign language interpreting that cause increased biomechanical demands on interpreters.

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Appendix A: Demographic Questionnaires

QUESTIONNAIRE – for Interpreters

Name:

Sex:

Age:

Dominant hand:

How did you learn ASL and who did you primarily learn it from?

What age were you when you started learning ASL?

At what age did you feel that you gained ASL fluency?

At what age did you start interpreting professionally?

How many years you have been interpreting professionally?

Do you currently use ASL regularly at home or in your social life outside of work? If so, please estimate the number of hours in a week that you use ASL outside of your work.

QUESTIONNAIRE – for Students

Name:

Sex:

Age:

Dominant hand:

What is your major at RIT?

What is your year level at RIT?

At what age did you start using ASL?

How did you learn ASL?

How fluent do you feel that you are with ASL?

Appendix B: Conversation Task Facilitating Questions

How did you come to your major or career path?

What do you like to do outside of work and school for fun?

What do you like or dislike about Rochester?

Compared to Rochester, what do you like more or less about your hometown?

Describe your favorite place that you have visited or the place that you would most like to visit?

What were your favorite activities as a child?

Appendix C: Consent Forms

CONSENT FORM – for Internal Interpreter Subjects

A Biomechanical Assessment of Early and Late Sign Language Learners: Impact on Work Style and Musculoskeletal Disorder Risk

Investigators: Abbey Donner, Matthew M. Marshall, Ph.D

Rochester Institute of Technology; Phone: 585-475-7260

You understand that you are 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 evaluate whether biomechanical differences exist between interpreters who are early signers and individuals who are late signers.

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 high levels of upper extremity exertion.

This study involves having electrogoniometers placed over both your 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 your arms. Once the sensors are attached, you will perform an interpreting task for 20 minutes, during which time the instrumentation will remain on your arms. The sign language interpreting task will consist of pre-recorded material that will be projected onto a screen adjacent to the experimental set-up. After the interpreting session you will use ASL to converse with a student for approximately 10 minutes. The sensors will continue to be used to monitor your wrist motions during this conversation.

The risks of the study are minimal. The cables extending from the instrumentation to the portable computer might interfere with your work activities, although every attempt will be made to minimize this potential problem. You understand that your participation in this study is

voluntary and you may stop at any time, without penalty. You are under no pressure to participate.

You will not receive payment beyond your normal work compensation for participating in this study, which will take approximately one hour to complete. You realize that you are voluntarily participating in this project and can withdraw from participation at any time. You have read (or had explained) the information given above. You understand the meaning of this information. Project personnel have offered to answer any questions you may have concerning the study and have provided complete answers to all your questions. You hereby consent to participate in the study. One copy of this document will be kept together with our research records on this study at RIT. As a participant you will receive a copy to keep if you request it

Name____

Date___________

Witness____

Date____________

CONSENT FORM – for External Interpreter Subjects

A Biomechanical Assessment of Early and Late Sign Language Learners: Impact on Work Style and Musculoskeletal Disorder Risk

Investigators: Abbey Donner, Matthew M. Marshall, Ph.D

Rochester Institute of Technology; Phone: 585-475-7260

You understand that you are 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 evaluate whether biomechanical differences exist between interpreters who are early signers and individuals who are late signers.

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 high levels of upper extremity exertion.

This study involves having electrogoniometers placed over both your 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 your arms. Once the sensors are attached, you will perform an interpreting task for 20 minutes, during which time the instrumentation will remain on your arms. The sign language interpreting task will consist of pre-recorded material that will be projected onto a screen adjacent to the experimental set-up. After the interpreting session you will use ASL to converse with a student for approximately 10 minutes. The sensors will continue to be used to monitor your wrist motions during this conversation.

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

You will receive payment of $50 for participating in this study, which will take approximately one hour to complete. You realize that you are voluntarily participating in this project and can withdraw from participation at any time. You have read (or had explained) the information given above. You understand the meaning of this information. Project personnel have offered to answer any questions you may have concerning the study and have provided complete answers to all your questions. You hereby consent to participate in the study. One copy of this document will be kept together with our research records on this study at RIT. As a participant you will receive a copy to keep if you request it.

Name____

Date___________

Witness____

Date____________

CONSENT FORM – for Student Subjects

A Biomechanical Assessment of Early and Late Sign Language Learners: Impact on Work Style and Musculoskeletal Disorder Risk

Investigators: Abbey Donner, Matthew M. Marshall, Ph.D

Rochester Institute of Technology; Phone: 585-475-7260

You understand that you are 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 evaluate whether biomechanical differences exist between interpreters who are early signers and individuals who are late signers.

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 high levels of upper extremity exertion.

This study involves having electrogoniometers placed over both your 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 your arms. Once the sensors are attached, you will watch the interpreter as he/she interprets a prerecorded lecture. After the interpreting session, you will use ASL to converse with an interpreter for approximately 10-15 minutes. The sensors will be used to monitor your wrist motions during this conversation. This procedure will be repeated for a second interpreter.

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

You will receive payment of $30 for participating in this study, which will take approximately two hours to complete. You realize that you are voluntarily participating in this project and can withdraw from participation at any time. You have read (or had explained) the information given above. You understand the meaning of this information. Project personnel

have offered to answer any questions you may have concerning the study and have provided complete answers to all your questions. You hereby consent to participate in the study. One copy of this document will be kept together with our research records on this study at RIT. As a participant you will receive a copy to keep if you request it.

Name____

Date____________

Witness____

Date_____________

Appendix D: Results from Statistical Analysis

Main Effects of Wrist Position and Motion Variables

General Linear Model: DFEL Min versus Task, E/L, Subject

Analysis of Variance for DFEL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	4176.80	4176.80	298.34	4.04	0.007
Task	1	889.27	889.27	889.27	12.03	0.004
E/L	1	31.43	31.43	31.43	0.11	0.750
Task*E/L	1	2.78	2.78	2.78	0.04	0.849
Error	14	1035.06	1035.06	73.93		
Total	31	6135.35				

S = 8.59842   R-Sq = 83.13%   R-Sq(adj) = 62.64%

General Linear Model: DFEL Mean versus Task, E/L, Subject

Analysis of Variance for DFEL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	2040.37	2040.37	145.74	3.45	0.014
Task	1	13.45	13.45	13.45	0.32	0.581
E/L	1	174.89	174.89	174.89	1.20	0.292
Task*E/L	1	45.62	45.62	45.62	1.08	0.316
Error	14	591.00	591.00	42.21		
Total	31	2865.33				

S = 6.49724   R-Sq = 79.37%   R-Sq(adj) = 54.33%

General Linear Model: DFEL Max versus Task, E/L, Subject

Analysis of Variance for DFEL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	3263.93	3263.93	233.14	5.99	0.001
Task	1	78.52	78.52	78.52	2.02	0.177
E/L	1	374.01	374.01	374.01	1.60	0.226
Task*E/L	1	4.79	4.79	4.79	0.12	0.731
Error	14	544.75	544.75	38.91		
Total	31	4266.00				

S = 6.23783   R-Sq = 87.23%   R-Sq(adj) = 71.72%

General Linear Model: DFEL Range versus Task, E/L, Subject

Analysis of Variance for DFEL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	5484.74	5484.74	391.77	6.48	0.001
Task	1	1496.29	1496.29	1496.29	24.76	0.000
E/L	1	188.60	188.60	188.60	0.48	0.499
Task*E/L	1	14.88	14.88	14.88	0.25	0.627
Error	14	846.04	846.04	60.43		
Total	31	8030.54				

S = 7.77375   R-Sq = 89.46%   R-Sq(adj) = 76.67%

General Linear Model: DRUL Min versus Task, E/L, Subject

Analysis of Variance for DRUL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P

Subject(E/L)	14	1677.56	1677.56	119.83	6.44	0.001
Task	1	250.05	250.05	250.05	13.45	0.003
E/L	1	113.61	113.61	113.61	0.95	0.347
Task*E/L	1	0.63	0.63	0.63	0.03	0.857
Error	14	260.37	260.37	18.60		
Total	31	2302.22				

S = 4.31252   R-Sq = 88.69%   R-Sq(adj) = 74.96%

General Linear Model: DRUL Mean versus Task, E/L, Subject
Analysis of Variance for DRUL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	2239.24	2239.24	159.95	5.47	0.002
Task	1	122.68	122.68	122.68	4.19	0.060
E/L	1	324.94	324.94	324.94	2.03	0.176
Task*E/L	1	11.37	11.37	11.37	0.39	0.543
Error	14	409.62	409.62	29.26		
Total	31	3107.85				

S = 5.40913   R-Sq = 86.82%   R-Sq(adj) = 70.82%

General Linear Model: DRUL Max versus Task, E/L, Subject
Analysis of Variance for DRUL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	2358.43	2358.43	168.46	5.40	0.002
Task	1	29.66	29.66	29.66	0.95	0.346
E/L	1	41.24	41.24	41.24	0.24	0.628
Task*E/L	1	3.39	3.39	3.39	0.11	0.747
Error	14	436.52	436.52	31.18		
Total	31	2869.24				

S = 5.58390   R-Sq = 84.79%   R-Sq(adj) = 66.31%

General Linear Model: DRUL Range versus Task, E/L, Subject
Analysis of Variance for DRUL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	2952.71	2952.71	210.91	9.65	0.000
Task	1	107.84	107.84	107.84	4.94	0.043
E/L	1	18.10	18.10	18.10	0.09	0.774
Task*E/L	1	1.06	1.06	1.06	0.05	0.829
Error	14	305.88	305.88	21.85		
Total	31	3385.59				

S = 4.67424   R-Sq = 90.97%   R-Sq(adj) = 79.99%

General Linear Model: DFER Min versus Task, E/L, Subject
Analysis of Variance for DFER Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	6070.87	6070.87	466.99	5.83	0.002
Task	1	110.91	93.61	93.61	1.17	0.299
E/L	1	136.31	136.31	136.31	0.29	0.598
Task*E/L	1	155.92	155.92	155.92	1.95	0.186
Error	13	1040.76	1040.76	80.06		
Total	29	7514.77				

S = 8.94754   R-Sq = 86.15%   R-Sq(adj) = 69.10%

General Linear Model: DFER Mean versus Task, E/L, Subject
Analysis of Variance for DFER Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	3008.69	3008.69	231.44	3.65	0.013
Task	1	4.35	5.19	5.19	0.08	0.779
E/L	1	49.01	49.01	49.01	0.21	0.653
Task*E/L	1	8.82	8.82	8.82	0.14	0.715
Error	13	824.89	824.89	63.45		
Total	29	3895.76				

S = 7.96574   R-Sq = 78.83%   R-Sq(adj) = 52.77%

General Linear Model: DFER Max versus Task, E/L, Subject

Analysis of Variance for DFER Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	2428.40	2428.40	186.80	3.40	0.018
Task	1	264.47	264.17	264.17	4.81	0.047
E/L	1	442.19	442.19	442.19	2.37	0.148
Task*E/L	1	0.16	0.16	0.16	0.00	0.957
Error	13	714.70	714.70	54.98		
Total	29	3849.92				

S = 7.41466   R-Sq = 81.44%   R-Sq(adj) = 58.59%

General Linear Model: DFER Range versus Task, E/L, Subject

Analysis of Variance for DFER Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	4199.98	4199.98	323.08	5.72	0.002
Task	1	641.55	603.11	603.11	10.68	0.006
E/L	1	114.99	114.99	114.99	0.36	0.561
Task*E/L	1	114.72	114.72	114.72	2.03	0.178
Error	13	734.20	734.20	56.48		
Total	29	5805.44				

S = 7.51512   R-Sq = 87.35%   R-Sq(adj) = 71.79%

General Linear Model: DRUR Min versus Task, E/L, Subject

Analysis of Variance for DRUR Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	2823.78	2823.78	201.70	5.32	0.002
Task	1	31.64	31.64	31.64	0.83	0.376
E/L	1	54.90	54.90	54.90	0.27	0.610
Task*E/L	1	6.01	6.01	6.01	0.16	0.697
Error	14	530.63	530.63	37.90		
Total	31	3446.95				

S = 6.15645   R-Sq = 84.61%   R-Sq(adj) = 65.91%

General Linear Model: DRUR Mean versus Task, E/L, Subject

Analysis of Variance for DRUR Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	1133.29	1133.29	80.95	3.25	0.018
Task	1	212.40	212.40	212.40	8.52	0.011
E/L	1	11.47	11.47	11.47	0.14	0.712
Task*E/L	1	0.03	0.03	0.03	0.00	0.973
Error	14	349.11	349.11	24.94		
Total	31	1706.31				

S = 4.99367   R-Sq = 79.54%   R-Sq(adj) = 54.70%

General Linear Model: DRUR Max versus Task, E/L, Subject

Analysis of Variance for DRUR Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	843.48	843.48	60.25	0.80	0.660
Task	1	321.76	321.76	321.76	4.27	0.058
E/L	1	63.46	63.46	63.46	1.05	0.322
Task*E/L	1	55.98	55.98	55.98	0.74	0.403
Error	14	1056.01	1056.01	75.43		
Total	31	2340.68				

S = 8.68499   R-Sq = 54.88%   R-Sq(adj) = 0.10%

General Linear Model: DRUR Range versus Task, E/L, Subject

Analysis of Variance for DRUR Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	2743.98	2743.98	196.00	12.13	0.000
Task	1	149.74	149.74	149.74	9.27	0.009
E/L	1	438.22	438.22	438.22	2.24	0.157
Task*E/L	1	18.52	18.52	18.52	1.15	0.302
Error	14	226.25	226.25	16.16		
Total	31	3576.72				

S = 4.02006   R-Sq = 93.67%   R-Sq(adj) = 85.99%

General Linear Model: VFEL Min versus Task, E/L, Subject

Analysis of Variance for VFEL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	477003	477003	34072	3.81	0.009
Task	1	146577	146577	146577	16.39	0.001
E/L	1	25157	25157	25157	0.74	0.405
Task*E/L	1	10	10	10	0.00	0.974
Error	14	125172	125172	8941		
Total	31	773918				

S = 94.5561   R-Sq = 83.83%   R-Sq(adj) = 64.19%

General Linear Model: VFEL Mean versus Task, E/L, Subject

Analysis of Variance for VFEL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	3114.16	3114.16	222.44	8.93	0.000
Task	1	370.06	370.06	370.06	14.85	0.002
E/L	1	7.26	7.26	7.26	0.03	0.859
Task*E/L	1	16.66	16.66	16.66	0.67	0.427
Error	14	348.82	348.82	24.92		
Total	31	3856.95				

S = 4.99158   R-Sq = 90.96%   R-Sq(adj) = 79.97%

General Linear Model: VFEL Max versus Task, E/L, Subject

Analysis of Variance for VFEL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	835069	835069	59648	4.08	0.006
Task	1	44219	44219	44219	3.02	0.104
E/L	1	45248	45248	45248	0.76	0.398
Task*E/L	1	1118	1118	1118	0.08	0.786
Error	14	204667	204667	14619		
Total	31	1130320				

S = 120.909   R-Sq = 81.89%   R-Sq(adj) = 59.91%

General Linear Model: VFEL Range versus Task, E/L, Subject

Analysis of Variance for VFEL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	2234927	2234927	159638	4.58	0.004
Task	1	351831	351831	351831	10.10	0.007
E/L	1	137871	137871	137871	0.86	0.368
Task*E/L	1	919	919	919	0.03	0.873
Error	14	487783	487783	34842		
Total	31	3213330				

S = 186.659   R-Sq = 84.82%   R-Sq(adj) = 66.39%

General Linear Model: VRUL Min versus Task, E/L, Subject

Analysis of Variance for VRUL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	116722	116722	8337	4.83	0.003
Task	1	9937	9937	9937	5.75	0.031
E/L	1	1795	1795	1795	0.22	0.650
Task*E/L	1	434	434	434	0.25	0.624
Error	14	24181	24181	1727		
Total	31	153070				

S = 41.5598   R-Sq = 84.20%   R-Sq(adj) = 65.02%

General Linear Model: VRUL Mean versus Task, E/L, Subject

Analysis of Variance for VRUL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	1288.052	1288.052	92.004	56.10	0.000
Task	1	33.117	33.117	33.117	20.19	0.001
E/L	1	10.476	10.476	10.476	0.11	0.741
Task*E/L	1	2.912	2.912	2.912	1.78	0.204
Error	14	22.959	22.959	1.640		
Total	31	1357.516				

S = 1.28059   R-Sq = 98.31%   R-Sq(adj) = 96.26%

General Linear Model: VRUL Max versus Task, E/L, Subject

Analysis of Variance for VRUL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	87624	87624	6259	5.10	0.002
Task	1	8644	8644	8644	7.05	0.019
E/L	1	3296	3296	3296	0.53	0.480
Task*E/L	1	0	0	0	0.00	0.997
Error	14	17175	17175	1227		
Total	31	116739				

S = 35.0254   R-Sq = 85.29%   R-Sq(adj) = 67.42%

General Linear Model: VRUL Range versus Task, E/L, Subject

Analysis of Variance for VRUL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	371903	371903	26564	6.38	0.001
Task	1	37118	37118	37118	8.92	0.010
E/L	1	226	226	226	0.01	0.928
Task*E/L	1	429	429	429	0.10	0.753
Error	14	58271	58271	4162		
Total	31	467946				

S = 64.5152   R-Sq = 87.55%   R-Sq(adj) = 72.43%

General Linear Model: VFER Min versus Task, E/L, Subject

Analysis of Variance for VFER Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	420522	420522	32348	6.26	0.001
Task	1	21795	23563	23563	4.56	0.052
E/L	1	40127	40127	40127	1.24	0.286
Task*E/L	1	8644	8644	8644	1.67	0.218
Error	13	67188	67188	5168		
Total	29	558276				

S = 71.8908   R-Sq = 87.97%   R-Sq(adj) = 73.15%

General Linear Model: VFER Mean versus Task, E/L, Subject

Analysis of Variance for VFER Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	5168.83	5168.83	397.60	12.18	0.000
Task	1	89.97	86.35	86.35	2.65	0.128
E/L	1	37.18	37.18	37.18	0.09	0.765
Task*E/L	1	6.64	6.64	6.64	0.20	0.659
Error	13	424.38	424.38	32.64		
Total	29	5727.01				

S = 5.71355   R-Sq = 92.59%   R-Sq(adj) = 83.47%

General Linear Model: VFER Max versus Task, E/L, Subject

Analysis of Variance for VFER Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	509849	509849	39219	2.77	0.039
Task	1	20072	19416	19416	1.37	0.263
E/L	1	2246	2246	2246	0.06	0.815
Task*E/L	1	915	915	915	0.06	0.803
Error	13	184245	184245	14173		
Total	29	717326				

S = 119.049   R-Sq = 74.32%   R-Sq(adj) = 42.70%

General Linear Model: VFER Range versus Task, E/L, Subject

Analysis of Variance for VFER Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	1703982	1703982	131076	4.46	0.006
Task	1	83698	85758	85758	2.92	0.111
E/L	1	61358	61358	61358	0.47	0.506
Task*E/L	1	3934	3934	3934	0.13	0.720
Error	13	382111	382111	29393		
Total	29	2235083				

S = 171.444   R-Sq = 82.90%   R-Sq(adj) = 61.86%

General Linear Model: VRUR Min versus Task, E/L, Subject

Analysis of Variance for VRUR Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	118195	118195	8443	2.37	0.059
Task	1	19823	19823	19823	5.55	0.034
E/L	1	10642	10642	10642	1.26	0.280
Task*E/L	1	381	381	381	0.11	0.749
Error	14	49961	49961	3569		

Total	31	199002

S = 59.7381   R-Sq = 74.89%   R-Sq(adj) = 44.41%

General Linear Model: VRUR Mean versus Task, E/L, Subject

Analysis of Variance for VRUR Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	1728.16	1728.16	123.44	18.85	0.000
Task	1	14.32	14.32	14.32	2.19	0.161
E/L	1	173.07	173.07	173.07	1.40	0.256
Task*E/L	1	2.10	2.10	2.10	0.32	0.580
Error	14	91.69	91.69	6.55		
Total	31	2009.35				

S = 2.55915   R-Sq = 95.44%   R-Sq(adj) = 89.90%

General Linear Model: VRUR Max versus Task, E/L, Subject

Analysis of Variance for VRUR Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	97804	97804	6986	4.84	0.003
Task	1	9104	9104	9104	6.31	0.025
E/L	1	17258	17258	17258	2.47	0.138
Task*E/L	1	177	177	177	0.12	0.731
Error	14	20200	20200	1443		
Total	31	144544				

S = 37.9853   R-Sq = 86.02%   R-Sq(adj) = 69.05%

General Linear Model: VRUR Range versus Task, E/L, Subject

Analysis of Variance for VRUR Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	406212	406212	29015	4.86	0.003
Task	1	55796	55796	55796	9.34	0.009
E/L	1	55004	55004	55004	1.90	0.190
Task*E/L	1	1079	1079	1079	0.18	0.677
Error	14	83643	83643	5975		
Total	31	601733				

S = 77.2949   R-Sq = 86.10%   R-Sq(adj) = 69.22%

General Linear Model: AFEL Min versus Task, E/L, Subject

Analysis of Variance for AFEL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	333660911	333660911	23832922	2.15	0.082
Task	1	3753363	3753363	3753363	0.34	0.569
E/L	1	209475	209475	209475	0.01	0.927
Task*E/L	1	3688891	3688891	3688891	0.33	0.573
Error	14	154847493	154847493	11060535		
Total	31	496160134				

S = 3325.74   R-Sq = 68.79%   R-Sq(adj) = 30.89%

General Linear Model: AFEL Mean versus Task, E/L, Subject

Analysis of Variance for AFEL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	598253	598253	42732	9.75	0.000
Task	1	89	89	89	0.02	0.889
E/L	1	2795	2795	2795	0.07	0.802

Task*E/L	1	922	922	922	0.21	0.653
Error	14	61345	61345	4382		
Total	31	663404				

S = 66.1951   R-Sq = 90.75%   R-Sq(adj) = 79.52%

General Linear Model: AFEL Max versus Task, E/L, Subject

Analysis of Variance for AFEL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	371865290	371865290	26561806	2.12	0.086
Task	1	1990208	1990208	1990208	0.16	0.696
E/L	1	314926	314926	314926	0.01	0.915
Task*E/L	1	4646025	4646025	4646025	0.37	0.552
Error	14	175330705	175330705	12523622		
Total	31	554147153				

S = 3538.87   R-Sq = 68.36%   R-Sq(adj) = 29.94%

General Linear Model: AFEL Range versus Task, E/L, Subject

Analysis of Variance for AFEL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	1383666115	1383666115	98833294	2.18	0.079
Task	1	277321	277321	277321	0.01	0.939
E/L	1	1038089	1038089	1038089	0.01	0.920
Task*E/L	1	16614694	16614694	16614694	0.37	0.555
Error	14	635358199	635358199	45382728		
Total	31	2036954417				

S = 6736.67   R-Sq = 68.81%   R-Sq(adj) = 30.93%

General Linear Model: ARUL Min versus Task, E/L, Subject

Analysis of Variance for ARUL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	37346841	37346841	2667632	4.76	0.003
Task	1	1010331	1010331	1010331	1.80	0.201
E/L	1	82554	82554	82554	0.03	0.863
Task*E/L	1	7012	7012	7012	0.01	0.912
Error	14	7840593	7840593	560042		
Total	31	46287331				

S = 748.360   R-Sq = 83.06%   R-Sq(adj) = 62.49%

General Linear Model: ARUL Mean versus Task, E/L, Subject

Analysis of Variance for ARUL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	198591	198591	14185	20.69	0.000
Task	1	3876	3876	3876	5.65	0.032
E/L	1	2962	2962	2962	0.21	0.655
Task*E/L	1	393	393	393	0.57	0.462
Error	14	9598	9598	686		
Total	31	215419				

S = 26.1839   R-Sq = 95.54%   R-Sq(adj) = 90.13%

General Linear Model: ARUL Max versus Task, E/L, Subject

Analysis of Variance for ARUL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P

Subject(E/L)	14	29881115	29881115	2134365	5.06	0.002
Task	1	3196750	3196750	3196750	7.58	0.016
E/L	1	17598	17598	17598	0.01	0.929
Task*E/L	1	161409	161409	161409	0.38	0.546
Error	14	5905945	5905945	421853		
Total	31	39162816				

S = 649.502   R-Sq = 84.92%   R-Sq(adj) = 66.61%

General Linear Model: ARUL Range versus Task, E/L, Subject

Analysis of Variance for ARUL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	128204147	128204147	9157439	5.19	0.002
Task	1	7801440	7801440	7801440	4.42	0.054
E/L	1	23924	23924	23924	0.00	0.960
Task*E/L	1	101133	101133	101133	0.06	0.814
Error	14	24716470	24716470	1765462		
Total	31	160847114				

S = 1328.71   R-Sq = 84.63%   R-Sq(adj) = 65.97%

General Linear Model: AFER Min versus Task, E/L, Subject

Analysis of Variance for AFER Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	140201919	140201919	10784763	2.28	0.075
Task	1	3009481	2799559	2799559	0.59	0.455
E/L	1	13121691	13121691	13121691	1.22	0.290
Task*E/L	1	750077	750077	750077	0.16	0.697
Error	13	61449214	61449214	4726863		
Total	29	218532381				

S = 2174.13   R-Sq = 71.88%   R-Sq(adj) = 37.27%

General Linear Model: AFER Mean versus Task, E/L, Subject

Analysis of Variance for AFER Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	1430313	1430313	110024	7.84	0.000
Task	1	96416	96844	96844	6.90	0.021
E/L	1	7863	7863	7863	0.07	0.793
Task*E/L	1	428	428	428	0.03	0.864
Error	13	182521	182521	14040		
Total	29	1717541				

S = 118.491   R-Sq = 89.37%   R-Sq(adj) = 76.29%

General Linear Model: AFER Max versus Task, E/L, Subject

Analysis of Variance for AFER Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	147851698	147851698	11373208	3.56	0.015
Task	1	6588793	7401437	7401437	2.32	0.152
E/L	1	4384906	4384906	4384906	0.39	0.545
Task*E/L	1	5717187	5717187	5717187	1.79	0.204
Error	13	41514982	41514982	3193460		
Total	29	206057565				

S = 1787.03   R-Sq = 79.85%   R-Sq(adj) = 55.06%

General Linear Model: AFER Range versus Task, E/L, Subject

Analysis of Variance for AFER Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	13	560775040	560775040	43136542	2.99	0.029
Task	1	692355	1096984	1096984	0.08	0.787
E/L	1	32677277	32677277	32677277	0.76	0.400
Task*E/L	1	10608920	10608920	10608920	0.74	0.407
Error	13	187444840	187444840	14418834		
Total	29	792198432				

S = 3797.21   R-Sq = 76.34%   R-Sq(adj) = 47.22%

General Linear Model: ARUR Min versus Task, E/L, Subject

Analysis of Variance for ARUR Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	47382259	47382259	3384447	1.03	0.482
Task	1	456514	456514	456514	0.14	0.716
E/L	1	2491015	2491015	2491015	0.74	0.405
Task*E/L	1	843509	843509	843509	0.26	0.621
Error	14	46221297	46221297	3301521		
Total	31	97394594				

S = 1817.01   R-Sq = 52.54%   R-Sq(adj) = 0.00%

General Linear Model: ARUR Mean versus Task, E/L, Subject

Analysis of Variance for ARUR Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	414499	414499	29607	10.69	0.000
Task	1	48281	48281	48281	17.43	0.001
E/L	1	37594	37594	37594	1.27	0.279
Task*E/L	1	1594	1594	1594	0.58	0.461
Error	14	38782	38782	2770		
Total	31	540751				

S = 52.6321   R-Sq = 92.83%   R-Sq(adj) = 84.12%

General Linear Model: ARUR Max versus Task, E/L, Subject

Analysis of Variance for ARUR Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	36959332	36959332	2639952	2.15	0.082
Task	1	272284	272284	272284	0.22	0.645
E/L	1	47216	47216	47216	0.02	0.896
Task*E/L	1	2469003	2469003	2469003	2.01	0.178
Error	14	17169726	17169726	1226409		
Total	31	56917561				

S = 1107.43   R-Sq = 69.83%   R-Sq(adj) = 33.20%

General Linear Model: ARUR Range versus Task, E/L, Subject

Analysis of Variance for ARUR Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	14	155326179	155326179	11094727	1.39	0.274
Task	1	23670	23670	23670	0.00	0.957
E/L	1	3224135	3224135	3224135	0.29	0.598
Task*E/L	1	6198774	6198774	6198774	0.78	0.393
Error	14	111849169	111849169	7989226		
Total	31	276621926				

S = 2826.52   R-Sq = 59.57%   R-Sq(adj) = 10.47%

ROM %

One-way ANOVA: L-DFEL versus E/L
```
Source     DF     SS    MS     F      P
E/L         1    9.5   9.5  0.18  0.681
Error      14  752.4  53.7
Total      15  761.9

S = 7.331   R-Sq = 1.25%   R-Sq(adj) = 0.00%
```

One-way ANOVA: L-DRUL versus E/L
```
Source     DF    SS   MS     F      P
E/L         1   430  430  1.13  0.306
Error      14  5329  381
Total      15  5759

S = 19.51   R-Sq = 7.46%   R-Sq(adj) = 0.85%
```

One-way ANOVA: L-DFER versus E/L
```
Source     DF    SS   MS     F      P
E/L         1   142  142  1.00  0.334
Error      14  1991  142
Total      15  2134

S = 11.93   R-Sq = 6.67%   R-Sq(adj) = 0.00%
```

One-way ANOVA: L-DRUR versus E/L
```
Source     DF    SS   MS     F      P
E/L         1   390  390  3.12  0.099
Error      14  1748  125
Total      15  2138

S = 11.17   R-Sq = 18.23%   R-Sq(adj) = 12.39%
```

One-way ANOVA: C-DFEL versus E/L
```
Source     DF     SS    MS     F      P
E/L         1   55.1  55.1  0.90  0.358
Error      14  856.4  61.2
Total      15  911.5

S = 7.821   R-Sq = 6.05%   R-Sq(adj) = 0.00%
```

One-way ANOVA: C-DRUL versus E/L
```
Source     DF    SS   MS     F      P
E/L         1    42   42  0.25  0.623
Error      14  2315  165
Total      15  2357

S = 12.86   R-Sq = 1.78%   R-Sq(adj) = 0.00%
```

One-way ANOVA: C-DFER versus E/L
```
Source     DF    SS   MS     F      P
E/L         1    38   38  0.22  0.644
Error      14  2367  169
Total      15  2404

S = 13.00   R-Sq = 1.57%   R-Sq(adj) = 0.00%
```

One-way ANOVA: C-DRUR versus E/L
```
Source     DF    SS   MS     F      P
E/L         1   155  155  1.01  0.331
Error      14  2142  153
Total      15  2298
```

```
S = 12.37   R-Sq = 6.76%   R-Sq(adj) = 0.10%
```

One-way ANOVA: E-DFEL versus Task

```
Source  DF      SS     MS     F      P
Task     1   303.1  303.1  4.89  0.044
Error   14   868.0   62.0
Total   15  1171.2

S = 7.874   R-Sq = 25.88%   R-Sq(adj) = 20.59%
```

One-way ANOVA: E-DRUL versus Task

```
Source  DF    SS   MS     F      P
Task     1   245  245  0.57  0.461
Error   14  5977  427
Total   15  6222

S = 20.66   R-Sq = 3.94%   R-Sq(adj) = 0.00%
```

One-way ANOVA: E-DRUR versus Task

```
Source  DF    SS   MS     F      P
Task     1   239  239  1.12  0.308
Error   14  2993  214
Total   15  3232

S = 14.62   R-Sq = 7.39%   R-Sq(adj) = 0.77%
```

One-way ANOVA: L-DFEL versus Task

```
Source  DF      SS     MS      F      P
Task     1   779.0  779.0  14.72  0.002
Error   14   741.1   52.9
Total   15  1520.1

S = 7.276   R-Sq = 51.25%   R-Sq(adj) = 47.76%
```

One-way ANOVA: L-DRUL versus Task

```
Source  DF    SS   MS     F      P
Task     1   894  894  7.51  0.016
Error   14  1667  119
Total   15  2561

S = 10.91   R-Sq = 34.92%   R-Sq(adj) = 30.27%
```

One-way ANOVA: L-DFER versus Task

```
Source  DF    SS    MS     F      P
Task     1  1241  1241  4.66  0.049
Error   14  3725   266
Total   15  4966

S = 16.31   R-Sq = 24.99%   R-Sq(adj) = 19.63%
```

One-way ANOVA: L-DRUR versus Task

```
Source  DF      SS     MS     F      P
Task     1   516.6  516.6  8.06  0.013
Error   14   897.3   64.1
Total   15  1413.9

S = 8.006   R-Sq = 36.54%   R-Sq(adj) = 32.01%
```

Pause %

One-way ANOVA: VFEL Pause % E versus C/L

Source	DF	SS	MS	F	P
C/L	1	0.4592	0.4592	30.65	0.000
Error	14	0.2097	0.0150		
Total	15	0.6689			

S = 0.1224   R-Sq = 68.65%   R-Sq(adj) = 66.41%

One-way ANOVA: VRUL Pause % E versus C/L

Source	DF	SS	MS	F	P
C/L	1	0.4021	0.4021	26.41	0.000
Error	14	0.2132	0.0152		
Total	15	0.6153			

S = 0.1234   R-Sq = 65.36%   R-Sq(adj) = 62.88%

One-way ANOVA: VFER Pause % E versus C/L

Source	DF	SS	MS	F	P
C/L	1	0.3579	0.3579	35.10	0.000
Error	12	0.1224	0.0102		
Total	13	0.4802			

S = 0.1010   R-Sq = 74.52%   R-Sq(adj) = 72.40%

One-way ANOVA: VRUR Pause % E versus C/L

Source	DF	SS	MS	F	P
C/L	1	0.38753	0.38753	42.23	0.000
Error	14	0.12849	0.00918		
Total	15	0.51602			

S = 0.09580   R-Sq = 75.10%   R-Sq(adj) = 73.32%

One-way ANOVA: VFEL Pause % L versus C/L

Source	DF	SS	MS	F	P
C/L	1	0.6493	0.6493	47.43	0.000
Error	14	0.1917	0.0137		
Total	15	0.8410			

S = 0.1170   R-Sq = 77.21%   R-Sq(adj) = 75.58%

One-way ANOVA: VRUL Pause % L versus C/L

Source	DF	SS	MS	F	P
C/L	1	0.6817	0.6817	46.65	0.000
Error	14	0.2046	0.0146		
Total	15	0.8863			

S = 0.1209   R-Sq = 76.92%   R-Sq(adj) = 75.27%

One-way ANOVA: VFER Pause % L versus C/L

Source	DF	SS	MS	F	P
C/L	1	0.7485	0.7485	34.91	0.000
Error	14	0.3002	0.0214		
Total	15	1.0487			

S = 0.1464   R-Sq = 71.38%   R-Sq(adj) = 69.33%

One-way ANOVA: VRUR Pause % L versus C/L

Source	DF	SS	MS	F	P
C/L	1	0.7118	0.7118	34.24	0.000
Error	14	0.2910	0.0208		
Total	15	1.0028			

S = 0.1442   R-Sq = 70.98%   R-Sq(adj) = 68.91%

Variation

One-way ANOVA: C-VFEL versus E/L

```
Source     DF    SS   MS     F      P
E/L   1    13    13  0.06  0.808
Error      14  3011  215
Total      15  3024

S = 14.66   R-Sq = 0.43%   R-Sq(adj) = 0.00%
```

One-way ANOVA: C-VRUL versus E/L

```
Source     DF      SS    MS     F      P
E/L   1     8.3    8.3  0.11  0.750
Error      14  1097.7  78.4
Total      15  1106.0

S = 8.855   R-Sq = 0.75%   R-Sq(adj) = 0.00%
```

One-way ANOVA: C-VFER versus E/L

```
Source     DF      SS    MS     F      P
E/L   1    9001  9001  1.25  0.282
Error      14  100737  7195
Total      15  109738

S = 84.83   R-Sq = 8.20%   R-Sq(adj) = 1.65%
```

One-way ANOVA: C-VRUR versus E/L

```
Source     DF      SS     MS     F      P
E/L   1   109.7  109.7  1.16  0.299
Error      14  1319.4   94.2
Total      15  1429.1

S = 9.708   R-Sq = 7.68%   R-Sq(adj) = 1.08%
```

One-way ANOVA: C-AFEL versus E/L

```
Source     DF      SS     MS     F      P
E/L   1       8      8  0.00  0.991
Error      14  817384  58385
Total      15  817392

S = 241.6   R-Sq = 0.00%   R-Sq(adj) = 0.00%
```

One-way ANOVA: C-ARUL versus E/L

```
Source     DF      SS     MS     F      P
E/L   1    1681   1681  0.11  0.742
Error      14  208563  14897
Total      15  210244

S = 122.1   R-Sq = 0.80%   R-Sq(adj) = 0.00%
```

One-way ANOVA: C-AFER versus E/L

```
Source     DF       SS      MS     F      P
E/L   1     8430    8430  0.07  0.790
Error      13  1485681  114283
Total      14  1494110

S = 338.1   R-Sq = 0.56%   R-Sq(adj) = 0.00%
```

One-way ANOVA: C-ARUR versus E/L

```
Source     DF      SS     MS     F      P
E/L   1   29670  29670  1.25  0.282
Error      14  332049  23718
Total      15  361719
```

```
S = 154.0   R-Sq = 8.20%   R-Sq(adj) = 1.65%
```

One-way ANOVA: L-VFEL versus E/L

```
Source      DF    SS   MS     F      P
E/L   1      1     1  0.01  0.937
Error       14  3014  215
Total       15  3016

S = 14.67   R-Sq = 0.05%   R-Sq(adj) = 0.00%
```

One-way ANOVA: L-VRUL versus E/L

```
Source      DF      SS    MS     F      P
E/L   1      0.1    0.1  0.00  0.966
Error       14  1017.2  72.7
Total       15  1017.4

S = 8.524   R-Sq = 0.01%   R-Sq(adj) = 0.00%
```

One-way ANOVA: L-FVER versus E/L

```
Source      DF    SS   MS     F      P
E/L   1    193  193  0.69  0.421
Error       14  3923  280
Total       15  4116

S = 16.74   R-Sq = 4.68%   R-Sq(adj) = 0.00%
```

One-way ANOVA: L-VRUR versus E/L

```
Source      DF      SS     MS     F      P
E/L   1   106.6  106.6  1.21  0.290
Error       14  1232.6   88.0
Total       15  1339.2

S = 9.383   R-Sq = 7.96%   R-Sq(adj) = 1.39%
```

One-way ANOVA: L-AFEL versus E/L

```
Source      DF      SS     MS     F      P
E/L   1      484    484  0.01  0.908
Error       14  492766  35198
Total       15  493250

S = 187.6   R-Sq = 0.10%   R-Sq(adj) = 0.00%
```

One-way ANOVA: L-ARUL versus E/L

```
Source      DF      SS     MS     F      P
E/L   1      518    518  0.05  0.832
Error       14  155769  11126
Total       15  156287

S = 105.5   R-Sq = 0.33%   R-Sq(adj) = 0.00%
```

One-way ANOVA: L-AFER versus E/L

```
Source      DF       SS     MS     F      P
E/L   1     70623  70623  0.92  0.353
Error       14  1071216  76515
Total       15  1141839

S = 276.6   R-Sq = 6.19%   R-Sq(adj) = 0.00%
```

One-way ANOVA: L-ARUR versus E/L

```
Source      DF      SS     MS     F      P
E/L   1   18293  18293  1.06  0.321
Error       14  241755  17268
Total       15  260048
```

S = 131.4   R-Sq = 7.03%   R-Sq(adj) = 0.39%

Kinematic Data Difference between Tasks

General Linear Model: Difference DFEL Min versus E/L

Analysis of Variance for Difference DFEL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	65.80	65.80	65.80	0.71	0.413
Error	14	1296.15	1296.15	92.58		
Total	15	1361.95				

S = 9.62198   R-Sq = 4.83%   R-Sq(adj) = 0.00%

General Linear Model: Difference DFEL Mean versus E/L

Analysis of Variance for Difference DFEL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	24.89	24.89	24.89	0.67	0.428
Error	14	523.29	523.29	37.38		
Total	15	548.18				

S = 6.11374   R-Sq = 4.54%   R-Sq(adj) = 0.00%

General Linear Model: Difference DFEL Max versus E/L

Analysis of Variance for Difference DFEL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	8.64	8.64	8.64	0.37	0.552
Error	14	325.89	325.89	23.28		
Total	15	334.53				

S = 4.82474   R-Sq = 2.58%   R-Sq(adj) = 0.00%

General Linear Model: Difference DFEL Range versus E/L

Analysis of Variance for Difference DFEL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	83.40	83.40	83.40	0.95	0.345
Error	14	1222.64	1222.64	87.33		
Total	15	1306.04				

S = 9.34512   R-Sq = 6.39%   R-Sq(adj) = 0.00%

General Linear Model: Difference DRUL Min versus E/L

Analysis of Variance for Difference DRUL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	11.54	11.54	11.54	0.86	0.369
Error	14	187.40	187.40	13.39		
Total	15	198.94				

S = 3.65866   R-Sq = 5.80%   R-Sq(adj) = 0.00%

General Linear Model: Difference DRUL Mean versus E/L

Analysis of Variance for Difference DRUL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	33.39	33.39	33.39	1.79	0.203

Error	14	261.50	261.50	18.68	
Total	15	294.89			

S = 4.32188   R-Sq = 11.32%   R-Sq(adj) = 4.99%

General Linear Model: Difference DRUL Max versus E/L

Analysis of Variance for Difference DRUL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	4.40	4.40	4.40	0.19	0.670
Error	14	324.06	324.06	23.15		
Total	15	328.46				

S = 4.81115   R-Sq = 1.34%   R-Sq(adj) = 0.00%

General Linear Model: Difference DRUL Range versus E/L

Analysis of Variance for Difference DRUL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	12.53	12.53	12.53	0.43	0.522
Error	14	406.62	406.62	29.04		
Total	15	419.15				

S = 5.38926   R-Sq = 2.99%   R-Sq(adj) = 0.00%

General Linear Model: Difference DFER Min versus E/L

Analysis of Variance for Difference DFER Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	99.54	99.54	99.54	1.82	0.200
Error	13	710.99	710.99	54.69		
Total	14	810.53				

S = 7.39539   R-Sq = 12.28%   R-Sq(adj) = 5.53%

General Linear Model: Difference DFER Mean versus E/L

Analysis of Variance for Difference DFER Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	312.00	312.00	312.00	10.34	0.007
Error	13	392.22	392.22	30.17		
Total	14	704.22				

S = 5.49281   R-Sq = 44.30%   R-Sq(adj) = 40.02%

General Linear Model: Difference DFER Max versus E/L

Analysis of Variance for Difference DFER Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	14.55	14.55	14.55	0.31	0.587
Error	13	608.30	608.30	46.79		
Total	14	622.86				

S = 6.84052   R-Sq = 2.34%   R-Sq(adj) = 0.00%

General Linear Model: Difference DFER Range versus E/L

Analysis of Variance for Difference DFER Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	348.49	348.49	348.49	5.82	0.031
Error	13	778.95	778.95	59.92		

Total 14 1127.44

S = 7.74074 R-Sq = 30.91% R-Sq(adj) = 25.60%

General Linear Model: Difference DRUR Min versus E/L

Analysis of Variance for Difference DRUR Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	57.54	57.54	57.54	1.57	0.231
Error	14	513.43	513.43	36.67		
Total	15	570.97				

S = 6.05584 R-Sq = 10.08% R-Sq(adj) = 3.65%

General Linear Model: Difference DRUR Mean versus E/L

Analysis of Variance for Difference DRUR Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	0.89	0.89	0.89	0.03	0.872
Error	14	460.75	460.75	32.91		
Total	15	461.64				

S = 5.73681 R-Sq = 0.19% R-Sq(adj) = 0.00%

General Linear Model: Difference DRUR Max versus E/L

Analysis of Variance for Difference DRUR Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	97.40	97.40	97.40	1.17	0.297
Error	14	1161.96	1161.96	83.00		
Total	15	1259.35				

S = 9.11027 R-Sq = 7.73% R-Sq(adj) = 1.14%

General Linear Model: Difference DRUR Range versus E/L

Analysis of Variance for Difference DRUR Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	59.20	59.20	59.20	4.71	0.048
Error	14	175.81	175.81	12.56		
Total	15	235.01				

S = 3.54366 R-Sq = 25.19% R-Sq(adj) = 19.85%

General Linear Model: Difference VFEL Min versus E/L

Analysis of Variance for Difference VFEL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	20	20	20	0.00	0.965
Error	14	137725	137725	9838		
Total	15	137745				

S = 99.1843 R-Sq = 0.01% R-Sq(adj) = 0.00%

General Linear Model: Difference VFEL Mean versus E/L

Analysis of Variance for Difference VFEL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	40.33	40.33	40.33	0.86	0.370
Error	14	658.77	658.77	47.06		
Total	15	699.11				

S = 6.85968   R-Sq = 5.77%   R-Sq(adj) = 0.00%

General Linear Model: Difference VFEL Max versus E/L

Analysis of Variance for Difference VFEL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	13651	13651	13651	0.90	0.360
Error	14	213158	213158	15226		
Total	15	226809				

S = 123.392   R-Sq = 6.02%   R-Sq(adj) = 0.00%

General Linear Model: Difference VFEL Range versus E/L

Analysis of Variance for Difference VFEL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	2656	2656	2656	0.06	0.813
Error	14	641325	641325	45809		
Total	15	643981				

S = 214.030   R-Sq = 0.41%   R-Sq(adj) = 0.00%

General Linear Model: Difference VRUL Min versus E/L

Analysis of Variance for Difference VRUL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	432	432	432	0.27	0.610
Error	14	22213	22213	1587		
Total	15	22645				

S = 39.8324   R-Sq = 1.91%   R-Sq(adj) = 0.00%

General Linear Model: Difference VRUL Mean versus E/L

Analysis of Variance for Difference VRUL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	0.333	0.333	0.333	0.26	0.620
Error	14	18.155	18.155	1.297		
Total	15	18.489				

S = 1.13878   R-Sq = 1.80%   R-Sq(adj) = 0.00%

General Linear Model: Difference VRUL Max versus E/L

Analysis of Variance for Difference VRUL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	1231	1231	1231	1.00	0.334
Error	14	17205	17205	1229		
Total	15	18436				

S = 35.0559   R-Sq = 6.68%   R-Sq(adj) = 0.01%

General Linear Model: Difference VRUL Range versus E/L

Analysis of Variance for Difference VRUL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	1528	1528	1528	0.29	0.599
Error	14	73940	73940	5281		
Total	15	75468				

S = 72.6736 R-Sq = 2.02% R-Sq(adj) = 0.00%

General Linear Model: Difference VFER Min versus E/L

Analysis of Variance for Difference VFER Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	0	0	0	0.00	0.999
Error	13	70058	70058	5389		
Total	14	70058				

S = 73.4103 R-Sq = 0.00% R-Sq(adj) = 0.00%

General Linear Model: Difference VFER Mean versus E/L

Analysis of Variance for Difference VFER Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	54.72	54.72	54.72	1.99	0.182
Error	13	357.85	357.85	27.53		
Total	14	412.57				

S = 5.24658 R-Sq = 13.26% R-Sq(adj) = 6.59%

General Linear Model: Difference VFER Max versus E/L

Analysis of Variance for Difference VFER Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	15654	15654	15654	1.23	0.287
Error	13	164827	164827	12679		
Total	14	180481				

S = 112.601 R-Sq = 8.67% R-Sq(adj) = 1.65%

General Linear Model: Difference VFER Range versus E/L

Analysis of Variance for Difference VFER Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	6365	6365	6365	0.26	0.621
Error	13	322998	322998	24846		
Total	14	329363				

S = 157.626 R-Sq = 1.93% R-Sq(adj) = 0.00%

General Linear Model: Difference VRUR Min versus E/L

Analysis of Variance for Difference VRUR Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	763	763	763	0.11	0.749
Error	14	99922	99922	7137		
Total	15	100685				

S = 84.4824 R-Sq = 0.76% R-Sq(adj) = 0.00%

General Linear Model: Difference VRUR Mean versus E/L

Analysis of Variance for Difference VRUR Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	2.933	2.933	2.933	0.70	0.417
Error	14	58.639	58.639	4.189		
Total	15	61.572				

S = 2.04659   R-Sq = 4.76%   R-Sq(adj) = 0.00%

General Linear Model: Difference VRUR Max versus E/L

Analysis of Variance for Difference VRUR Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	1246.1	1246.1	1246.1	1.41	0.255
Error	14	12406.3	12406.3	886.2		
Total	15	13652.5				

S = 29.7686   R-Sq = 9.13%   R-Sq(adj) = 2.64%

General Linear Model: Difference VRUR Range versus E/L

Analysis of Variance for Difference VRUR Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	207	207	207	0.02	0.880
Error	14	122139	122139	8724		
Total	15	122346				

S = 93.4033   R-Sq = 0.17%   R-Sq(adj) = 0.00%

General Linear Model: Difference AFEL Min versus E/L

Analysis of Variance for Difference AFEL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	4628476	4628476	4628476	0.36	0.558
Error	14	179500212	179500212	12821444		
Total	15	184128688				

S = 3580.70   R-Sq = 2.51%   R-Sq(adj) = 0.00%

General Linear Model: Difference AFEL Mean versus E/L

Analysis of Variance for Difference AFEL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	19301	19301	19301	4.59	0.050
Error	14	58934	58934	4210		
Total	15	78235				

S = 64.8809   R-Sq = 24.67%   R-Sq(adj) = 19.29%

General Linear Model: Difference AFEL Max versus E/L

Analysis of Variance for Difference AFEL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	12985353	12985353	12985353	1.02	0.329
Error	14	177497470	177497470	12678391		
Total	15	190482822				

S = 3560.67   R-Sq = 6.82%   R-Sq(adj) = 0.16%

General Linear Model: Difference AFEL Range versus E/L

Analysis of Variance for Difference AFEL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	40776983	40776983	40776983	0.85	0.371
Error	14	668827002	668827002	47773357		
Total	15	709603984				

S = 6911.83   R-Sq = 5.75%   R-Sq(adj) = 0.00%

General Linear Model: Difference ARUL Min versus E/L

Analysis of Variance for Difference ARUL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	8521	8521	8521	0.02	0.899
Error	14	7203001	7203001	514500		
Total	15	7211522				

S = 717.287   R-Sq = 0.12%   R-Sq(adj) = 0.00%

General Linear Model: Difference ARUL Mean versus E/L

Analysis of Variance for Difference ARUL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	1005	1005	1005	0.94	0.348
Error	14	14914	14914	1065		
Total	15	15919				

S = 32.6384   R-Sq = 6.32%   R-Sq(adj) = 0.00%

General Linear Model: Difference ARUL Max versus E/L

Analysis of Variance for Difference ARUL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	1787	1787	1787	0.00	0.956
Error	14	8023608	8023608	573115		
Total	15	8025395				

S = 757.044   R-Sq = 0.02%   R-Sq(adj) = 0.00%

General Linear Model: Difference ARUL Range versus E/L

Analysis of Variance for Difference ARUL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	27959	27959	27959	0.02	0.904
Error	14	25964935	25964935	1854638		
Total	15	25992894				

S = 1361.85   R-Sq = 0.11%   R-Sq(adj) = 0.00%

General Linear Model: Difference AFER Min versus E/L

Analysis of Variance for Difference AFER Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	804466	804466	804466	0.21	0.651
Error	13	48723794	48723794	3747984		
Total	14	49528260				

S = 1935.97   R-Sq = 1.62%   R-Sq(adj) = 0.00%

General Linear Model: Difference AFER Mean versus E/L

Analysis of Variance for Difference AFER Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	3385	3385	3385	0.18	0.675
Error	13	238838	238838	18372		
Total	14	242223				

S = 135.544   R-Sq = 1.40%   R-Sq(adj) = 0.00%

General Linear Model: Difference AFER Max versus E/L

Analysis of Variance for Difference AFER Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	1101344	1101344	1101344	0.39	0.542
Error	13	36534691	36534691	2810361		
Total	14	37636035				

S = 1676.41   R-Sq = 2.93%   R-Sq(adj) = 0.00%

General Linear Model: Difference AFER Range versus E/L

Analysis of Variance for Difference AFER Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	13405111	13405111	13405111	1.17	0.299
Error	13	149202780	149202780	11477137		
Total	14	162607891				

S = 3387.79   R-Sq = 8.24%   R-Sq(adj) = 1.19%

General Linear Model: Difference ARUR Min versus E/L

Analysis of Variance for Difference ARUR Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	8260052	8260052	8260052	2.28	0.153
Error	14	50773753	50773753	3626697		
Total	15	59033805				

S = 1904.39   R-Sq = 13.99%   R-Sq(adj) = 7.85%

General Linear Model: Difference ARUR Mean versus E/L

Analysis of Variance for Difference ARUR Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	2419	2419	2419	0.46	0.509
Error	14	73756	73756	5268		
Total	15	76175				

S = 72.5829   R-Sq = 3.18%   R-Sq(adj) = 0.00%

General Linear Model: Difference ARUR Max versus E/L

Analysis of Variance for Difference ARUR Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	1891494	1891494	1891494	1.46	0.247
Error	14	18119216	18119216	1294230		
Total	15	20010710				

S = 1137.64   R-Sq = 9.45%   R-Sq(adj) = 2.98%

General Linear Model: Difference ARUR Range versus E/L

Analysis of Variance for Difference ARUR Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
E/L	1	20095737	20095737	20095737	2.44	0.141
Error	14	115324335	115324335	8237453		
Total	15	135420073				

S = 2870.10   R-Sq = 14.84%   R-Sq(adj) = 8.76%

Adjusted Subject Group Analysis

General Linear Model: DFEL Min

Analysis of Variance for DFEL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	2477.68	2477.68	412.95	4.96	0.036
Task	1	133.64	133.64	133.64	1.61	0.252
E/L	1	84.80	84.80	84.80	0.21	0.666
Task*E/L	1	1.93	1.93	1.93	0.02	0.884
Error	6	499.45	499.45	83.24		
Total	15	3197.50				

S = 9.12366   R-Sq = 84.38%   R-Sq(adj) = 60.95%

General Linear Model: DFEL Mean

Analysis of Variance for DFEL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	1171.98	1171.98	195.33	2.80	0.118
Task	1	3.18	3.18	3.18	0.05	0.838
E/L	1	0.11	0.11	0.11	0.00	0.982
Task*E/L	1	46.91	46.91	46.91	0.67	0.443
Error	6	418.06	418.06	69.68		
Total	15	1640.24				

S = 8.34725   R-Sq = 74.51%   R-Sq(adj) = 36.28%

General Linear Model: DFEL Max

Analysis of Variance for DFEL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	1549.79	1549.79	258.30	6.84	0.017
Task	1	193.45	193.45	193.45	5.13	0.064
E/L	1	88.70	88.70	88.70	0.34	0.579
Task*E/L	1	19.36	19.36	19.36	0.51	0.501
Error	6	226.42	226.42	37.74		
Total	15	2077.72				

S = 6.14303   R-Sq = 89.10%   R-Sq(adj) = 72.76%

General Linear Model: DFEL Range

Analysis of Variance for DFEL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	2403.24	2403.24	400.54	5.42	0.029
Task	1	648.65	648.65	648.65	8.78	0.025
E/L	1	346.95	346.95	346.95	0.87	0.388
Task*E/L	1	9.06	9.06	9.06	0.12	0.738
Error	6	443.12	443.12	73.85		
Total	15	3851.02				

S = 8.59378   R-Sq = 88.49%   R-Sq(adj) = 71.23%

General Linear Model: DRUL Min

Analysis of Variance for DRUL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	707.831	707.831	117.972	12.41	0.004
Task	1	172.907	172.907	172.907	18.18	0.005
E/L	1	0.192	0.192	0.192	0.00	0.969
Task*E/L	1	17.147	17.147	17.147	1.80	0.228
Error	6	57.058	57.058	9.510		
Total	15	955.134				

S = 3.08377   R-Sq = 94.03%   R-Sq(adj) = 85.07%

General Linear Model: DRUL Mean

Analysis of Variance for DRUL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	219.08	219.08	36.51	2.64	0.131
Task	1	162.43	162.43	162.43	11.76	0.014
E/L	1	13.86	13.86	13.86	0.38	0.560
Task*E/L	1	45.03	45.03	45.03	3.26	0.121
Error	6	82.87	82.87	13.81		
Total	15	523.28				

S = 3.71647   R-Sq = 84.16%   R-Sq(adj) = 60.41%

General Linear Model: DRUL Max

Analysis of Variance for DRUL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	289.31	289.31	48.22	2.49	0.146
Task	1	53.99	53.99	53.99	2.78	0.146
E/L	1	54.96	54.96	54.96	1.14	0.327
Task*E/L	1	8.81	8.81	8.81	0.45	0.525
Error	6	116.39	116.39	19.40		
Total	15	523.46				

S = 4.40431   R-Sq = 77.77%   R-Sq(adj) = 44.41%

General Linear Model: DRUL Range

Analysis of Variance for DRUL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	833.10	833.10	138.85	13.74	0.003
Task	1	33.66	33.66	33.66	3.33	0.118
E/L	1	48.66	48.66	48.66	0.35	0.575
Task*E/L	1	1.38	1.38	1.38	0.14	0.725
Error	6	60.63	60.63	10.11		
Total	15	977.43				

S = 3.17888   R-Sq = 93.80%   R-Sq(adj) = 84.49%

General Linear Model: DFER Min

Analysis of Variance for DFER Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	3000.4	3000.4	600.1	3.82	0.084
Task	1	24.7	11.2	11.2	0.07	0.800
E/L	1	33.9	33.9	33.9	0.06	0.822
Task*E/L	1	119.8	119.8	119.8	0.76	0.422
Error	5	784.7	784.7	156.9		
Total	13	3963.5				

S = 12.5274   R-Sq = 80.20%   R-Sq(adj) = 48.53%

General Linear Model: DFER Mean

Analysis of Variance for DFER Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	2085.94	2085.94	417.19	4.49	0.062
Task	1	48.81	59.63	59.63	0.64	0.459
E/L	1	2.48	2.48	2.48	0.01	0.942
Task*E/L	1	31.91	31.91	31.91	0.34	0.583
Error	5	464.27	464.27	92.85		
Total	13	2633.42				

S = 9.63609   R-Sq = 82.37%   R-Sq(adj) = 54.16%

General Linear Model: DFER Max

Analysis of Variance for DFER Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	1547.34	1547.34	309.47	4.23	0.070
Task	1	319.52	313.46	313.46	4.29	0.093
E/L	1	156.57	156.57	156.57	0.51	0.509
Task*E/L	1	0.01	0.01	0.01	0.00	0.992
Error	5	365.39	365.39	73.08		
Total	13	2388.83				

S = 8.54856   R-Sq = 84.70%   R-Sq(adj) = 60.23%

General Linear Model: DFER Range

Analysis of Variance for DFER Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	991.94	991.94	198.39	4.21	0.070
Task	1	521.71	443.35	443.35	9.41	0.028
E/L	1	336.25	336.25	336.25	1.69	0.250
Task*E/L	1	117.85	117.85	117.85	2.50	0.175
Error	5	235.62	235.62	47.12		
Total	13	2203.37				

S = 6.86470   R-Sq = 89.31%   R-Sq(adj) = 72.20%

General Linear Model: DRUR Min

Analysis of Variance for DRUR Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	667.77	667.77	111.30	2.78	0.120
Task	1	23.14	23.14	23.14	0.58	0.476
E/L	1	460.17	460.17	460.17	4.13	0.088
Task*E/L	1	0.00	0.00	0.00	0.00	0.993
Error	6	240.41	240.41	40.07		
Total	15	1391.49				

S = 6.32989   R-Sq = 82.72%   R-Sq(adj) = 56.81%

General Linear Model: DRUR Mean

Analysis of Variance for DRUR Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	460.03	460.03	76.67	3.34	0.084
Task	1	141.59	141.59	141.59	6.18	0.047
E/L	1	42.34	42.34	42.34	0.55	0.485
Task*E/L	1	3.73	3.73	3.73	0.16	0.701
Error	6	137.56	137.56	22.93		
Total	15	785.24				

S = 4.78811   R-Sq = 82.48%   R-Sq(adj) = 56.21%

General Linear Model: DRUR Max

Analysis of Variance for DRUR Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	188.0	188.0	31.3	0.25	0.941
Task	1	351.7	351.7	351.7	2.84	0.143
E/L	1	0.0	0.0	0.0	0.00	0.987
Task*E/L	1	2.5	2.5	2.5	0.02	0.891
Error	6	742.5	742.5	123.8		
Total	15	1284.8				

S = 11.1244   R-Sq = 42.21%   R-Sq(adj) = 0.00%

General Linear Model: DRUR Range

Analysis of Variance for DRUR Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	172.00	172.00	28.67	0.94	0.527
Task	1	88.89	88.89	88.89	2.93	0.138
E/L	1	454.47	454.47	454.47	15.85	0.007
Task*E/L	1	3.55	3.55	3.55	0.12	0.744
Error	6	182.27	182.27	30.38		
Total	15	901.18				

S = 5.51160   R-Sq = 79.77%   R-Sq(adj) = 49.44%

General Linear Model: VFEL Min

Analysis of Variance for VFEL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	146874	146874	24479	2.62	0.133
Task	1	116164	116164	116164	12.43	0.012
E/L	1	30124	30124	30124	1.23	0.310
Task*E/L	1	5633	5633	5633	0.60	0.467
Error	6	56080	56080	9347		
Total	15	354875				

S = 96.6780   R-Sq = 84.20%   R-Sq(adj) = 60.49%

General Linear Model: VFEL Mean

Analysis of Variance for VFEL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	1627.17	1627.17	271.19	6.53	0.019
Task	1	300.89	300.89	300.89	7.25	0.036
E/L	1	7.69	7.69	7.69	0.03	0.872
Task*E/L	1	14.09	14.09	14.09	0.34	0.581
Error	6	249.14	249.14	41.52		
Total	15	2198.99				

S = 6.44387   R-Sq = 88.67%   R-Sq(adj) = 71.68%

General Linear Model: VFEL Max

Analysis of Variance for VFEL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	418858	418858	69810	2.96	0.106
Task	1	5650	5650	5650	0.24	0.642
E/L	1	20602	20602	20602	0.30	0.607
Task*E/L	1	5633	5633	5633	0.24	0.642
Error	6	141373	141373	23562		
Total	15	592116				

S = 153.500   R-Sq = 76.12%   R-Sq(adj) = 40.31%

General Linear Model: VFEL Range

Analysis of Variance for VFEL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	943266	943266	157211	3.11	0.097
Task	1	173052	173052	173052	3.42	0.114
E/L	1	100551	100551	100551	0.64	0.454
Task*E/L	1	22531	22531	22531	0.45	0.529
Error	6	303632	303632	50605		
Total	15	1543031				

S = 224.956   R-Sq = 80.32%   R-Sq(adj) = 50.81%

General Linear Model: VRUL Min

Analysis of Variance for VRUL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	32775	32775	5463	2.23	0.176
Task	1	9612	9612	9612	3.93	0.095
E/L	1	1319	1319	1319	0.24	0.641
Task*E/L	1	45	45	45	0.02	0.896
Error	6	14685	14685	2448		
Total	15	58437				

S = 49.4723   R-Sq = 74.87%   R-Sq(adj) = 37.18%

General Linear Model: VRUL Mean

Analysis of Variance for VRUL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	577.509	577.509	96.252	45.40	0.000
Task	1	24.964	24.964	24.964	11.77	0.014
E/L	1	0.041	0.041	0.041	0.00	0.984
Task*E/L	1	1.081	1.081	1.081	0.51	0.502
Error	6	12.721	12.721	2.120		
Total	15	616.317				

S = 1.45609   R-Sq = 97.94%   R-Sq(adj) = 94.84%

General Linear Model: VRUL Max

Analysis of Variance for VRUL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	19356	19356	3226	2.12	0.192
Task	1	3809	3809	3809	2.50	0.165
E/L	1	5691	5691	5691	1.76	0.232
Task*E/L	1	682	682	682	0.45	0.528
Error	6	9146	9146	1524		
Total	15	38684				

S = 39.0419   R-Sq = 76.36%   R-Sq(adj) = 40.89%

General Linear Model: VRUL Range

Analysis of Variance for VRUL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	85151	85151	14192	2.09	0.196
Task	1	25522	25522	25522	3.76	0.101
E/L	1	12489	12489	12489	0.88	0.384
Task*E/L	1	376	376	376	0.06	0.822
Error	6	40723	40723	6787		
Total	15	164262				

S = 82.3847   R-Sq = 75.21%   R-Sq(adj) = 38.02%

General Linear Model: VRUR Min

Analysis of Variance for VRUR Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	11198	11198	1866	0.29	0.924
Task	1	4955	4955	4955	0.76	0.417
E/L	1	29281	29281	29281	15.69	0.007
Task*E/L	1	140	140	140	0.02	0.888
Error	6	39188	39188	6531		
Total	15	84762				

S = 80.8166   R-Sq = 53.77%   R-Sq(adj) = 0.00%

General Linear Model: VRUR Mean

Analysis of Variance for VRUR Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	169.656	169.656	28.276	3.60	0.072
Task	1	4.577	4.577	4.577	0.58	0.474
E/L	1	569.229	569.229	569.229	20.13	0.004
Task*E/L	1	2.800	2.800	2.800	0.36	0.572
Error	6	47.132	47.132	7.855		
Total	15	793.394				

S = 2.80273   R-Sq = 94.06%   R-Sq(adj) = 85.15%

General Linear Model: VRUR Max

Analysis of Variance for VRUR Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	22985	22985	3831	2.08	0.198
Task	1	1013	1013	1013	0.55	0.487
E/L	1	33348	33348	33348	8.71	0.026
Task*E/L	1	1048	1048	1048	0.57	0.479
Error	6	11068	11068	1845		
Total	15	69462				

S = 42.9498   R-Sq = 84.07%   R-Sq(adj) = 60.16%

General Linear Model: VRUR Range

Analysis of Variance for VRUR Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	49480	49480	8247	0.84	0.580
Task	1	10448	10448	10448	1.07	0.342
E/L	1	125128	125128	125128	15.17	0.008
Task*E/L	1	1954	1954	1954	0.20	0.671
Error	6	58807	58807	9801		
Total	15	245817				

S = 99.0011   R-Sq = 76.08%   R-Sq(adj) = 40.19%

General Linear Model: VFER Min

Analysis of Variance for VFER Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	117092	117092	23418	6.46	0.031
Task	1	25136	25415	25415	7.01	0.046
E/L	1	132389	132389	132389	5.65	0.063
Task*E/L	1	307	307	307	0.08	0.783
Error	5	18129	18129	3626		

Total 13 293054

S = 60.2150   R-Sq = 93.81%   R-Sq(adj) = 83.92%

General Linear Model: VFER Mean

Analysis of Variance for VFER Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	934.58	934.58	186.92	7.40	0.023
Task	1	100.28	87.96	87.96	3.48	0.121
E/L	1	970.12	970.12	970.12	5.19	0.072
Task*E/L	1	13.89	13.89	13.89	0.55	0.492
Error	5	126.25	126.25	25.25		
Total	13	2145.11				

S = 5.02486   R-Sq = 94.11%   R-Sq(adj) = 84.70%

General Linear Model: VFER Max

Analysis of Variance for VFER Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	186464	186464	37293	1.81	0.265
Task	1	25157	18398	18398	0.89	0.388
E/L	1	47616	47616	47616	1.28	0.310
Task*E/L	1	22320	22320	22320	1.09	0.345
Error	5	102816	102816	20563		
Total	13	384374				

S = 143.399   R-Sq = 73.25%   R-Sq(adj) = 30.45%

General Linear Model: VFER Range

Analysis of Variance for VFER Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	534876	534876	106975	2.90	0.134
Task	1	100587	87062	87062	2.36	0.185
E/L	1	338800	338800	338800	3.17	0.135
Task*E/L	1	17389	17389	17389	0.47	0.523
Error	5	184263	184263	36853		
Total	13	1175914				

S = 191.970   R-Sq = 84.33%   R-Sq(adj) = 59.26%

General Linear Model: AFEL Min

Analysis of Variance for AFEL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	202486853	202486853	33747809	1.61	0.290
Task	1	6290688	6290688	6290688	0.30	0.604
E/L	1	11629	11629	11629	0.00	0.986
Task*E/L	1	532107	532107	532107	0.03	0.879
Error	6	126096861	126096861	21016144		
Total	15	335418137				

S = 4584.34   R-Sq = 62.41%   R-Sq(adj) = 6.02%

General Linear Model: AFEL Mean

Analysis of Variance for AFEL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	292407	292407	48735	8.89	0.009
Task	1	1155	1155	1155	0.21	0.662
E/L	1	685	685	685	0.01	0.909

Task*E/L	1	1862	1862	1862	0.34	0.581
Error	6	32890	32890	5482		
Total	15	328999				

S = 74.0381   R-Sq = 90.00%   R-Sq(adj) = 75.01%

General Linear Model: AFEL Max

Analysis of Variance for AFEL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	209779381	209779381	34963230	1.33	0.370
Task	1	22970	22970	22970	0.00	0.977
E/L	1	1816877	1816877	1816877	0.05	0.827
Task*E/L	1	122109	122109	122109	0.00	0.948
Error	6	158265877	158265877	26377646		
Total	15	370007213				

S = 5135.92   R-Sq = 57.23%   R-Sq(adj) = 0.00%

General Linear Model: AFEL Range

Analysis of Variance for AFEL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	808210303	808210303	134701717	1.46	0.329
Task	1	5553407	5553407	5553407	0.06	0.814
E/L	1	2119217	2119217	2119217	0.02	0.904
Task*E/L	1	1164020	1164020	1164020	0.01	0.914
Error	6	553982461	553982461	92330410		
Total	15	1371029408				

S = 9608.87   R-Sq = 59.59%   R-Sq(adj) = 0.00%

General Linear Model: ARUL Min

Analysis of Variance for ARUL Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	13210589	13210589	2201765	3.21	0.091
Task	1	103519	103519	103519	0.15	0.711
E/L	1	417404	417404	417404	0.19	0.678
Task*E/L	1	10334	10334	10334	0.02	0.906
Error	6	4115242	4115242	685874		
Total	15	17857089				

S = 828.175   R-Sq = 76.95%   R-Sq(adj) = 42.39%

General Linear Model: ARUL Mean

Analysis of Variance for ARUL Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	85532.5	85532.5	14255.4	26.19	0.000
Task	1	1780.8	1780.8	1780.8	3.27	0.120
E/L	1	223.2	223.2	223.2	0.02	0.905
Task*E/L	1	2.7	2.7	2.7	0.00	0.946
Error	6	3265.9	3265.9	544.3		
Total	15	90805.0				

S = 23.3304   R-Sq = 96.40%   R-Sq(adj) = 91.01%

General Linear Model: ARUL Max

Analysis of Variance for ARUL Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	14403212	14403212	2400535	3.26	0.088

Task	1	1029176	1029176	1029176	1.40	0.282
E/L	1	398567	398567	398567	0.17	0.698
Task*E/L	1	89689	89689	89689	0.12	0.739
Error	6	4419805	4419805	736634		
Total	15	20340449				

S = 858.274   R-Sq = 78.27%   R-Sq(adj) = 45.68%

General Linear Model: ARUL Range

Analysis of Variance for ARUL Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	52741067	52741067	8790178	3.25	0.089
Task	1	1785497	1785497	1785497	0.66	0.448
E/L	1	1631729	1631729	1631729	0.19	0.682
Task*E/L	1	160914	160914	160914	0.06	0.815
Error	6	16241636	16241636	2706939		
Total	15	72560844				

S = 1645.28   R-Sq = 77.62%   R-Sq(adj) = 44.04%

General Linear Model: AFER Min

Analysis of Variance for AFER Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	51051231	51051231	10210246	1.88	0.252
Task	1	1806828	1409636	1409636	0.26	0.632
E/L	1	39370218	39370218	39370218	3.86	0.107
Task*E/L	1	1003619	1003619	1003619	0.19	0.685
Error	5	27092942	27092942	5418588		
Total	13	120324838				

S = 2327.79   R-Sq = 77.48%   R-Sq(adj) = 41.46%

General Linear Model: AFER Mean

Analysis of Variance for AFER Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	324687	324687	64937	7.98	0.020
Task	1	21342	26004	26004	3.20	0.134
E/L	1	248670	248670	248670	3.83	0.108
Task*E/L	1	13616	13616	13616	1.67	0.252
Error	5	40677	40677	8135		
Total	13	648991				

S = 90.1967   R-Sq = 93.73%   R-Sq(adj) = 83.70%

General Linear Model: AFER Max

Analysis of Variance for AFER Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	49336505	49336505	9867301	2.24	0.198
Task	1	15145808	15243788	15243788	3.46	0.122
E/L	1	24859304	24859304	24859304	2.52	0.173
Task*E/L	1	134976	134976	134976	0.03	0.868
Error	5	21998820	21998820	4399764		
Total	13	111475412				

S = 2097.56   R-Sq = 80.27%   R-Sq(adj) = 48.69%

General Linear Model: AFER Range

Analysis of Variance for AFER Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	5	198819352	198819352	39763870	2.21	0.203
Task	1	27415115	25924493	25924493	1.44	0.284
E/L	1	126798402	126798402	126798402	3.19	0.134
Task*E/L	1	402485	402485	402485	0.02	0.887
Error	5	90086549	90086549	18017310		
Total	13	443521903				

S = 4244.68   R-Sq = 79.69%   R-Sq(adj) = 47.19%

General Linear Model: ARUR Min

Analysis of Variance for ARUR Min, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	14995740	14995740	2499290	0.36	0.883
Task	1	664009	664009	664009	0.09	0.769
E/L	1	5234127	5234127	5234127	2.09	0.198
Task*E/L	1	71596	71596	71596	0.01	0.923
Error	6	42115888	42115888	7019315		
Total	15	63081359				

S = 2649.40   R-Sq = 33.24%   R-Sq(adj) = 0.00%

General Linear Model: ARUR Mean

Analysis of Variance for ARUR Mean, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	42152	42152	7025	3.37	0.082
Task	1	23929	23929	23929	11.48	0.015
E/L	1	121714	121714	121714	17.32	0.006
Task*E/L	1	3459	3459	3459	1.66	0.245
Error	6	12502	12502	2084		
Total	15	203757				

S = 45.6475   R-Sq = 93.86%   R-Sq(adj) = 84.66%

General Linear Model: ARUR Max

Analysis of Variance for ARUR Max, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	7942874	7942874	1323812	0.56	0.748
Task	1	909187	909187	909187	0.39	0.557
E/L	1	999726	999726	999726	0.76	0.418
Task*E/L	1	1016243	1016243	1016243	0.43	0.535
Error	6	14086170	14086170	2347695		
Total	15	24954201				

S = 1532.22   R-Sq = 43.55%   R-Sq(adj) = 0.00%

General Linear Model: ARUR Range

Analysis of Variance for ARUR Range, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject(E/L)	6	38808850	38808850	6468142	0.38	0.868
Task	1	19223	19223	19223	0.00	0.974
E/L	1	10808869	10808869	10808869	1.67	0.244
Task*E/L	1	548361	548361	548361	0.03	0.864
Error	6	102346762	102346762	17057794		
Total	15	152532065				