Upper Extremity Biomechanics in Native and Non-Native Signers

by

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ABSTRACT

Individuals fluent in sign language who have at least one deaf parent are considered native signers while those with non-signing, hearing parents are non-native signers. Musculoskeletal pain from repetitive motion is more common from non-natives than natives. The goal of this study was twofold: 1) to examine differences in upper extremity (UE) biomechanical measures between natives and non-natives and 2) upon creating a composite measure of injury-risk unique to signers, to compare differences in scores between natives and non-natives. Non-natives were hypothesized to have less favorable biomechanical measures and composite injury-risk scores compared to natives. Dynamometry was used for measurement of strength, electromyography for 'micro' rest breaks and muscle tension, optical motion capture for ballistic signing, non-neutral joint angle and work envelope, a numeric pain rating scale for pain, and the modified Strain Index (SI) as a composite measure of injury-risk. There were no differences in UE strength (all $p \geq 0.22$). Natives had more rest (natives 76.38%; non-natives 26.86%; $p=0.002$) and less muscle tension (natives 11.53%; non-natives 48.60%; $p=0.008$) for non-dominant upper trapezius across the first minute of the trial. For ballistic signing, no differences were found in resultant linear segment acceleration when producing the sign for 'again' (natives $27.59 m/s^2$; non-natives $21.91 m/s^2$; $p=0.20$). For non-neutral joint angle, natives had more wrist flexion-extension motion when producing the sign for 'principal' (natives 54.93°; non-natives 46.23°; $p=0.04$). Work envelope demonstrated the greatest significance when determining injury-risk. Natives had a marginally greater work envelope along the z-axis (inferior-superior) across the first minute of the trial (natives 35.80cm; non-natives 30.84cm; $p=0.051$). Natives (30%) presented with a lower pain prevalence than non-natives (40%); however, there was no significant difference in the modified SI scores (natives 4.70 points; non-natives 3.06 points; $p=0.144$) and no association between presence of pain with the modified SI score (r=0.087; p=0.680). This work offers a comprehensive analysis of all the previously identified UE biomechanics unique to signers and helped to inform a composite measure of injury-risk. Use of the modified SI demonstrates promise, although its lack of association with pain does confirm that injury-risk encompasses other variables in addition to a signer's biomechanics.

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CHAPTER 1

INTRODUCTION

1.1. Background

A total of 271 sign languages, dialects, and other sign systems are being used around the world (Gallaudet University 2016). In 1972, the National Census of the Deaf Population estimated that as many as 500,000 individuals in the United States (U.S.) use sign language to communicate in the home (Schein and Delk 1974; Mitchell 2005; Williamson 2015). Since that time, no one has determined the prevalence of sign language use in the general population. As the total U.S. population has increased at least 61% since 1970 (Forstall 1996; USCB 2017), it is presumed that those using sign language to communicate is well over the original estimate.

Communication between people who use sign language and people who use spoken language is facilitated by sign language interpreters. The American with Disabilities Act (ADA) requires that State and local governments, public businesses, and nonprofit organizations provide auxiliary aides and services for effective communication to people who have vision, hearing, or speech disabilities. For people who are deaf, this includes a qualified sign language interpreter (ADA 2014).

The number of interpreters and translators is on the rise. The Registry of Interpreters for the Deaf (RID) is a national organization that collaborates with the deaf community and advocates for delivery of interpreting services (RID n.d.). RID's total membership has increased 11% in the last eight years (RID 2009 [2016]) with a forecast to increase 18% in the next 10 years (BLS 2018). These gains, compared to an average occupational growth rate of only seven percent (BLS 2018), demonstrate that demand for sign language interpreting is growing faster than average.

1.2. Statement of the problem

Preserving the health and reducing injury-risk and pain in those who use their hands and upper extremities (UEs) to communicate is not only paramount for the well-being and livelihood of interpreters, but also for those deaf and hearing individuals fluent in sign language. Sign language requires production of physical signs for visual, rather than auditory communication (Fisher et al. 2012). Since physical exertion in sign language interpreters is significantly greater compared to other professions (Dean et al. 2010), musculoskeletal (MSK) pain is common. Over 30% of sign language interpreters are injured on the job with 57% of the primary injuries reported from repetitive motion. Of those injured, 33% express concern about return to work and 32% are unable to undergo regular treatment because of time and money constraints (Kroeger 2014). This translates to lost workdays and decreased availability of interpreting services. A survey of working interpreters described the most commonly reported body regions of UE MSK dysfunction as: right shoulder (17%), right wrist-hand (10%), left shoulder (7%), and right forearm (6%). Prevalence of MSK injury in signers increases with age and is greater when compared to the general population (Woodcock and Fisher 2008). Roman and Samar (2015) reported that 81% of signers experienced varying intensities of MSK pain, reporting the neck with the highest pain prevalence (34%), followed by the wrist-hand (11%), elbow-forearm (10%), and shoulder (10%). In a 12-month period, Durand et al. (2001) found 81% of signers reported shoulder pain, 79% reported neck pain, and 74% reported forearm-wrist-hand pain. To maintain a high-quality of life for deaf and hearing individuals fluent in sign language, it is important that the underlying factors contributing to MSK injuries among signers are better understood so that interventions can be developed to minimize injury-risk.

In a systematic review by Fisher et al. (2012), various factors impacting MSK dysfunction experienced by signers were identified. Of the evidence reviewed, increased mechanical exposure, increased speaker pace, and increased psychological, psychosocial, and environmental stress were the strongest factors associated with the presence of MSK dysfunction. However, of the 23 studies that met the inclusion criteria, none were considered of high quality, five were of medium quality, and 18 were of low quality. Thus, the availability of high level evidence to inform the development of protocols for reduction and prevention of MSK dysfunction in signers is lacking. The purpose of this study was to provide much needed quality evidence exploring the differences in UE biomechanics and thus, promote a greater understanding of the contributors to increased pain in signers.

1.3. Native and non-native signers

It is estimated that deaf children are born to hearing parents more than 95% of the time (Mitchell and Karchmer 2004) and hearing children are born to deaf parents 80% of the time (Bishop and Hicks 2008; Mitchell et al. 2006). Deaf or hearing individuals who have at least one deaf parent can be considered native signers. Native signers, or heritage language users are an overlooked demographic within the sign language research (Williamson 2015). Demographic data on language acquisition status is not systematically collected by RID, however in a British Sign Language/English interpreting survey, 13% of the respondents identified as natives (Mapson 2014). Therefore, most interpreters are individuals born to non-signing, hearing parents and can be considered non-native signers. Williamson (2015) identified the handshapes and movement of heritage language users as native-like and unique from non-native signers. Podhorodecki and Spielholz (1993) found that MSK pain is more common from non-native than native signers. Clearly, exploring the differences in UE biomechanics of native versus non-native signers is necessary to understand what may underlie the increased MSK injury-risk in non-natives. The idea that language acquisition status (native versus non-native) relates to level of injury-risk and pain prevalence warrants further investigation.

1.4. Biomechanical considerations unique to signers

Little work has examined the specific contribution of UE biomechanics to the high percent of MSK pain and injury in signers. The seminal work of Feuerstein and Fitzgerald (1992) on UE biomechanical factors affecting signers informed a text published by the Rochester Institute of Technology, National Technical Institute for the Deaf (NTID) in Rochester, NY on cumulative trauma disorders (RIT 2005). During the 1989-90 academic year, 74% of the interpreting staff at NTID reported work-related MSK symptoms. This prompted a cross-sectional examination of the work style and demands of the staff (Feuerstein and Fitzgerald 1992) and results identified several factors unique to signers that may contribute to the MSK symptoms reported. They include: 1) insufficient 'micro' rest breaks, 2) muscle tension, 3) ballistic signing, 4) excessive hand and wrist deviations from a neutral position, and 5) movement outside the normal interpreting work envelope. 'Micro' rest breaks are brief periods during the interpreting task when one or both hands are lowered. Muscle tension is prolonged muscle contraction because of an awkward position or a physiological reaction to stress. Ballistic signing is defined as a consistently hard, forceful, or abrupt production of signs. Neutral joint positions are considered the midpoint of opposing motions within the same cardinal plane (e.g. midpoint between wrist flexion-extension in the sagittal plane), therefore non-neutral joint positions are deviations from neutral. Work envelope is defined as the area in which signs can be produced with a minimal amount of exertion. NTID described the normal work envelope height as the distance from the head to the waist, width as one inch beyond the shoulder distance, and depth as half the distance of a fully extended arm (RIT 2005). Whereas, the Occupational Health and Safety for Sign

Language Interpreters described ideal work envelope as hand movement in front of the chest within a boundary of 25cm^2 (Feuerstein and Fitzgerald 1992; Woodcock and Fischer 2008). After institutional changes to interpreting processes were made (e.g. use of teaming, increased prep time, etc.), a follow-up report during the 1991-92 academic year revealed only five NTID interpreters out of a staff of 86, a 68% reduction from just two years prior, reported symptoms (RIT 2005). Further quantification of the biomechanical factors involved using more current instrumentation is needed to be able to generalize these findings beyond the group studied at NTID.

1.5. High- and low-cumulative trauma disorder risk

Marras and Schoenmarklin (1993) used goniometric instrumentation from the Biodynamics Laboratory at Ohio State University and quantified wrist kinematic variables, like range of motion (ROM), velocity, and acceleration. Industrial workers involved in high repetition, hand-intensive tasks were selected from eight participating companies and divided into high- and low-cumulative trauma disorder risk groups based on the median incidence rate of claims and average lost work days to injury. The high-risk group had 18.4 reported claims and 111.5 lost days per 200,000 hours of worker exposure and the low-risk group had zero reported claims and zero lost days per 200,000 hours of worker exposure. High- and low-cumulative trauma disorder risk for wrist flexion-extension, radial-ulnar deviation, and forearm pronation-supination ROM (°), angular velocity (°/second), and angular acceleration (°/second^2) are conveyed in Table 1.1. Kinematic measurements greater than the high-risk value indicate high-risk for cumulative trauma disorder and vice versa. Using the methodology from Marras and Schoenmarklin (1993), Schoenmarklin et al. (1994) studied the predictability of each kinematic variable for determining high- and low-cumulative trauma disorder risk. Wrist flexion-extension angular acceleration was found to best discriminate level of risk.

Potentially, investigators could compare the wrist and forearm ROM, velocity, and acceleration of signers to that of industrial workers to categorize level of injury-risk. The demands on industrial workers, though similar, are not an exact comparison to the demands on signers, therefore more specific values to measure injury-risk in signers are needed.

Table 1.1. High- and low-cumulative trauma disorder risk for wrist and forearm motion (Marras and Schoenmarklin 1993).

	high-risk	low-risk
ROM (°)		
wrist flexion-extension	35.63	27.95
wrist radial-ulnar deviation	23.65	17.64
forearm supination-pronation	86.63	69.91
average angular velocity (°/sec)		
wrist flexion-extension	42.2	28.7
wrist radial-ulnar deviation	25.9	17
forearm supination-pronation	91.3	67.7
average angular acceleration (°/sec^2)		
wrist flexion-extension	824	494
wrist radial-ulnar deviation	494	301
forearm supination-pronation	1824	1222

1.6. Ergonomic risk assessment tools

Like the high- and low-cumulative trauma disorder risk values, ergonomic risk assessment tools also allow investigators to categorize level of injury-risk. Use of ergonomic risk measures as a method of hazard control is associated with reduced MSK disorders and injury-risk in manufacturing production and maintenance workers (Cantley et al. 2014). Various ergonomic risk measures focusing on the repetitive high-risk UE tasks in industry workers have been studied. Such measures include the Rapid Upper Limb Assessment (RULA), Strain Index (SI), concise exposure index (OCRA), Rapid Entire Body Assessment (REBA), and American Conference of Governmental Industrial Hygienists Threshold Limit Values (ACGIH TLV). No composite ergonomic measure of injury-risk presently exists for signers. Jones and Kumar (2007) performed a comparison of these five ergonomic risk assessment tools with 15 saw-filers, workers responsible for maintaining the condition of the various saws and knives, from four sawmill facilities. They found that only the SI and OCRA were sensitive to measuring differences across facilities in posture and in measures of frequency, such as hours per day, repetitions per day, and total exposure. A SI score threshold of less than or equal to three is considered safe, greater than or equal to seven is considered hazardous, and greater than three, but less than seven is considered at increased risk (Moore and Garg 1995). For example, the mean SI score for the saw-filers was 14 (Jones and Kumar 2007), thus indicating hazardous work.

1.7. Research aims and hypotheses

The goal of this study was twofold and will be presented in two separate manuscripts: 1) to examine differences in biomechanical measures between natives and non-natives and 2) upon creating a composite measure of injury-risk unique to signers, to compare differences in scores between natives and non-natives.

The overall objective for the first manuscript was attained by pursuing the following specific aim: quantify upper extremity strength, ‘micro’ rest breaks, muscle tension, ballistic signing, non-neutral joint position, and work envelope in native and non-native signers. *Hypothesis:* Non-natives will have less favorable biomechanical outcomes compared to natives.

The overall objective for the second manuscript was attained by pursuing the following specific aim: quantify self-reported MSK pain and composite injury-risk scores in native and non-native signers. *Hypothesis:* Non-natives will have less favorable composite injury-risk scores compared to natives and scores will be associated with self-reported MSK pain.

CHAPTER 2

UPPER EXTREMITY BIOMECHANICS IN NATIVE AND NON-NATIVE SIGNERS

(FIRST MANUSCRIPT)

Abstract

Over 30% of sign language interpreters are physically injured on the job. This study's goal was to identify indicators of injury-risk by measuring upper extremity isometric strength, 'micro' rest breaks, muscle tension, ballistic signing, non-neutral joint angle, and work envelope in 10 native and 15 non-native signers. Non-natives were hypothesized to have less favorable (i.e. worse) biomechanical outcome measures compared to natives. Dynamometry, surface electromyography, and optical motion capture were used to respectively quantify strength, rest, tension, ballistic signing, non-neutral joint angle, and work envelope. There was no difference with shoulder and wrist strength between natives and non-natives. Non-natives had less rest ($p=0.002$ with false discovery rate, FDR, correction) and more tension ($p=0.008$ with FDR correction) in non-dominant upper trapezius than natives. For ballistic signing, natives had greater jerk along the y-axis ($p=0.03$) than non-natives and for non-neutral joint angle, natives demonstrated greater wrist flexion-extension range of motion ($p=0.04$) than non-natives. Lastly, for work envelope, natives demonstrated greater relative maximum ($p=0.015$) and greater relative minimum ($p=0.019$) position along the x-axis, and greater relative minimum position along the z-axes ($p=0.027$). This work suggests that associated rest, tension, jerk, and maximum and minimum segment positions are potential indicators of injury-risk and should be prioritized in the development of protocols for reduction and prevention of musculoskeletal dysfunction in signers.

Keywords

sign language; ‘micro’ rest breaks; muscle tension; ballistic signing; non-neutral joint angle; work envelope

2.1. Introduction

Over 30% of sign language interpreters are physically injured on the job with 57% of primary complaints from repetitive motion. Of those injured, 33% express concern about returning to work and 32% are unable to undergo regular treatment because of time and money constraints (Kroeger 2014). Demand for interpreters and translators is anticipated to grow 18% by 2026 (BLS 2018), suggesting higher numbers of sign language interpreters will suffer from musculoskeletal (MSK) pain, equating to lost workdays and decreased availability of interpreting services.

Deaf or hearing individuals who have at least one deaf parent are considered native signers (Mitchell et al. 2006; Bishop and Hicks 2008) and are an overlooked demographic within the sign language research (Williamson 2015). Most interpreters are born to non-signing, hearing parents and considered non-native signers. Musculoskeletal pain secondary to high occupational health risks of sign language interpreting is more common from non-natives than natives (Podhorodeck and Spielholz 1993), but the reasons underpinning this disparity in risk between native and non-native signers are unclear.

Preserving the health and reducing injury-risk and pain in those who use their hands and upper extremities (UEs) to communicate is not only paramount for the well-being and livelihood of interpreters, but also for those deaf and hearing individuals fluent in sign language. A survey of signers reported that upper extremity (UE) MSK dysfunction is most prevalent in the neck (28%) and right shoulder (17%) (Woodcock and Fisher 2008). Another study found 81% of signers experienced varying intensities of MSK pain, reporting the highest pain prevalence at the neck (34%), wrist-hand (11%), elbow-forearm (10%), and shoulder (10%; Roman and Samar 2015). Durand et al. (2001) found 81% of signers reported shoulder pain, 79% reported neck pain, and 74% reported forearm-wrist-hand pain over a 12-month period. Physical exertion in sign language interpreters is similarly elevated across video relay, educational, freelance, and staff interpreting settings, however is significantly greater compared to other professions (e.g. medicine, education; Dean et al. 2010). Identification of the underlying factors among native and non-native signers is needed, so interventions can be developed to lower the risk of non-natives developing MSK symptoms.

Little work has examined the specific contribution of UE biomechanics to the high percent of MSK pain and injury in signers. Fisher et al. (2012) suggests that increased mechanical exposure, increased speaker pace, and increased psychological, psychosocial, and environmental stress in signers were the strongest factors associated with MSK disorders. The seminal work of Feuerstein and Fitzgerald (1992) examined of the work style and demands of 29 interpreters (24 females and five males) at the National Technical Institute for the Deaf (NTID, Rochester, NY) and revealed five UE biomechanical considerations: insufficient 'micro' rest breaks, muscle tension, forceful or ballistic signing, excessive hand and wrist deviations, and movement outside the normal interpreting work envelope (RIT 2005). Based upon clinical examination, these participants were sub-grouped into those working with pain (n=16; 55%) and those working with no pain or minimal discomfort (n=13; 45%). An isokinetic dynamometer was used to measure wrist and forearm range of motion (ROM) and endurance, and video recordings of the participants while interpreting were used to measure the biomechanical variables of rest breaks per minute, high impact hand contacts, pace and smoothness of finger and hand movements, hand and wrist deviations from neutral, and work envelope excursions. There were no strength or flexibility differences between sub-groups, however their findings suggest that interpreters with pain have fewer rest breaks, and more deviations from neutral joint position, lateral excursions from the work envelope and rapid finger and hand movements. This prior work was based on visual observation, and ratings of frequency and scale. Little quantitative information is available to describe these biomechanical considerations or their influence on the increased MSK symptoms reported by non-natives.

In a study of novice (less than two years of professional interpreting experience) and experienced (greater than or equal to five years) interpreters, Fisher et al. (2014) used an electromagnetic motion capture system to measure mean ROM, mean angular velocity, the number of kinematic 'micro' breaks, and time spent in 'micro' breaks for bilateral wrist flexion-extension, radial-ulnar deviation, and elbow flexion-extension during one hour of interpreting. 'Micro' breaks were defined as the time spent not in motion, or any period of more than 0.2 seconds with a velocity equal or less than 5°/sec. Comparing the first and last 15 minute increments, experienced interpreters increased their right elbow flexion-extension ROM. Novice interpreters reduced right wrist radial-ulnar deviation and right elbow flexion-extension velocity and demonstrated increased number of breaks in right elbow flexion-extension. Both novice and experienced interpreters demonstrated increased right wrist flexion-extension 'micro' breaks during the latter increment. Reduced velocity and greater 'micro' breaks of novice interpreters were attributed to higher fatigue, but whether non-native and native signers demonstrate comparable levels of fatigue and rest is unknown.

Delisle et al. (2005) used surface electromyography (EMG) to the bilateral upper trapezius to quantify time at rest and a biaxial dominant wrist goniometer to measure wrist flexion-extension and radial-ulnar deviation ROM, and angular velocity and acceleration. Nine sign language interpreters were studied over the course of four 30 to 90-minute educational interpreting sessions. Greater EMG-based rest in non-dominant than dominant upper trapezius (12.4% and 8.1% proportion of the total time at rest, respectively) was found. The mean upper minus the lower confidence interval measurements for dominant wrist flexion-extension and radial-ulnar deviation ROM were 66 and 36 degrees. The dominant peak (90th percentile) angular velocity and acceleration were 145°/sec and 1694°/sec^2 for wrist flexion-extension and 74°/sec and 851°/sec^2 for radial-ulnar deviation, respectively. Delisle et al. (2005) reported gender, height, weight, and a range of experience, but did not report native or non-native status. The use of EMG to quantify muscle activation and rest in non-native and native signers in the work presented here could inform why non-natives report greater MSK symptoms than natives.

In investigations comparing early- (learned sign language before graduating from high school) and late- (learned sign language after graduating from high school) signing interpreters (Donner 2012; Donner et al. 2016), biaxial bilateral electrogoniometers were used to measure wrist flexion-extension and radial-ulnar deviation displacement, mean angular velocity and acceleration, and pause percentage during a 20-minute interpreting task. No differences in mean wrist position, velocity, acceleration, or kinematic pause percentage were observed. However, a within-participant comparison of interpreters revealed, greater wrist position, faster wrist velocity, lower acceleration, and less pause percentage time when interpreting compared to when conversing. Between-participant comparison of interpreters and deaf college-aged students conversing revealed that deaf students sign with 16% greater right wrist displacement, and interpreters with an average pause percentage time of 50% compared to 33% for the deaf students (Donner et al. 2013). Early- and late-signing interpreters in Donner (2012) and Donner et al. (2016), and interpreters and deaf students in Donner et al. (2013) can be compared, respectively, to natives and non-natives in this study.

Previous literature assessing the biomechanical considerations of 'micro' rest breaks, muscle tension, ballistic signing, non-neutral joint angle, and work envelope identified by NTID in signers has yet to reach a consensus, and existing literature is sparse with inconsistent methods and participant groupings. Feuerstein and Fitzgerald (1992) visually measured and scored hand and wrist deviations from a neutral position, high-impact hand contacts, and pace and smoothness of finger and hand movements, while Donner (2012), Donner et al. ([2013] 2016), Fisher et al. (2014) and Delisle et al. (2005) measured wrist position, angular velocity and acceleration, and Fisher et al. (2014) additionally measured elbow joint kinematic variables. Feuerstein and Fitzgerald (1992) visually counted the number of times the dominant signing hand was lowered to constitute rest-break frequency, Donner (2012) and Donner et al. ([2013] 2016) measured kinematic pause percentage of the wrist using biaxial bilateral electrogoniometers, Fisher et al. (2014) measured kinematic wrist and elbow 'micro' breaks and time spent in 'micro' breaks using an electromagnetic motion capture system, while Delisle et al. (2005) measured EMG-based 'micro' rest breaks of the upper trapezius. These studies did not assess 'micro' rest breaks in the shoulder, such as the upper and middle trapezius or anterior and middle compartments of the deltoid. Some work has shown no differences in mean wrist position, velocity, acceleration, or the kinematic pause percentage time of early- compared to late-signing interpreters (Donner 2012; Donner et al. 2016), while other work demonstrated that novice interpreters had reduced angular velocity and increased number of breaks compared to experienced interpreters (Fischer et al. 2014), and interpreters had greater pause percentage time when conversing compared to deaf students (Donner et al. 2013). The task being performed has been shown to influence wrist position, velocity, and pause percentage time. Specifically, interpreters had reduced position and velocity, and greater pause percentage time when conversing compared to interpreting (Donner et al. 2013). To the best of this author's knowledge, the work of Feuerstein and Fitzgerald (1992) is the only previous work to quantify muscle tension and work envelope. Muscle tension was visually rated on a 10cm visual analog scale with 10 being analogous to overt tension with signs of muscular contraction or elevation of one or both shoulders and zero being no visible muscle tension, however values across sub-groups were not analyzed because of low inter-rater reliability. A transparent grid based on the 25cm^2 work envelope norm (Feuerstein and Fitzgerald 1992; Woodcock and Fisher 2008) was placed over the video-viewing monitor screen and deviations outside of the work envelope were visually assessed. More work is needed on the quantification of muscle tension and work envelope. While NTID clearly identified the biomechanical considerations of rest, muscle tension, ballistic signing, non-neutral joint position, and work envelope, little structure was provided on how they should be evaluated. The above research has helped to reach a foundational basis for these biomechanical considerations, however the various sub-groupings of signers and a lack of standardization limits application to further understand existing results.

The goal of this study was to examine biomechanical measures of native and non-native signers. Specifically, this study sought to quantify UE isometric strength, 'micro' rest breaks, muscle tension, ballistic signing, non-neutral joint position, and work envelope in natives and non-natives. It was hypothesized that non-natives will have less favorable (i.e. worse) biomechanical outcomes compared to natives.

2.2. Materials and methods

This study was approved by the Institute Review Board at Arizona State University.

2.2.1. Participants

Non-natives were defined as having non-signing, hearing parents; natives were defined as having at least one signing, deaf parent. A study population representing the surrounding community of native and non-native signers was obtained. Participants were recruited from local associations (Registry of Interpreters for the Deaf, Association for the Deaf, Children of Deaf Adults International), local schools, colleges and universities, the local Commission for the Deaf and Hard of Hearing, and a local video relay service. Fifteen non-natives (mean age 43.9±11.4 years; 9 females/6 males; 11 deaf/4 hearing; 12 right hand-dominant) and 10 natives (mean age 32.7±10.9 years; 7 females/3 males; 6 deaf/4 hearing; 9 right hand-dominant) were studied (Table 2.1). All participants voluntarily provided written informed consent to participate. Sample size calculations were based on acceleration, the primary outcome for ballistic signing, as indicated by the work of Schoenmarklin et al. (1994). Power analysis (power=0.80 and alpha=0.05) using GPower 3.1.9.2 software (Dusseldorf, Germany) from the preliminary work of Qin et al. (2008) provided a total sample size of 12 participants equally distributed into stressed and non-stressed groups with a left wrist flexion-extension angular acceleration mean difference of 99°/second^2 (stressed=713°/second^2; non-stressed=614°/second^2) and respective standard deviations of 76°/second^2 and 74.5°/second^2. A small (.2), medium (.5), or large (.8) effect size would achieve significance with an estimated 790, 120, and 22 total participants, respectively (Appendix B; Fig. B.1.). To bolster the likelihood of an effect between groups, a conservative total sample recruitment size of 25-30 participants was estimated.

Table 2.1. Participant demographics (n=25).

	natives	**non-natives**	**total**
	n (%)	**n (%)**	**n (%)**
	10 (40)	**15 (60)**	**25 (100)**
age (mean±SD)	**43.9±11.4**	**32.70±10.9**	**39.4±12.3**
18-19	**1 (10)**	**0 (0)**	**1 (4)**
20-29	**3 (30)**	**1 (6.7)**	**4 (16)**
30-39	**4 (40)**	**5 (33.3)**	**9 (36)**
40-49	**1 (10)**	**4 (26.7)**	**5 (20)**
50-59	**1 (10)**	**4 (26.7)**	**5 (20)**
60-69	**0 (0)**	**1 (6.7)**	**1 (4)**
sex			
male	**3 (30)**	**6 (40)**	**9 (36)**
female	**7 (70)**	**9 (60)**	**16 (64)**
hearing status			
hearing	**4 (40)**	**4 (26.7)**	**8 (32)**
deaf	**6 (60)**	**11 (73.3)**	**17 (68)**
hand-dominance			
right	**9 (90)**	**12 (80)**	**21 (84)**
left	**1 (10)**	**3 (20)**	**4 (16)**

All participants were ostensibly healthy, deaf or hearing adult participants greater than or equal to 18 years of age. Sign language fluency of hearing participants was measured by standards set forth by RID (RID 2015). At least one RID certification was required from all hearing participants. Acceptable certifications included: Comprehensive Skills Certificate, Certificate of Transliteration, Certificate of Interpreting, National Interpreter Certification, Educational Certificate: K-12 with greater than or equal to level four on the Educational Interpreter Performance Assessment, or a Specialist Certificate: Legal or Performing Arts. Use of sign language as primary language of communication either since birth, or during primary or secondary education equated to fluency for deaf participants. While formal RID certification for deaf participants was not required, one participant was a Certified Deaf Interpreter and others were preparing to become certified. Exclusion criteria included those enrolled in interpreter preparatory or training program, those with pacemakers, those who were pregnant, and/or those diagnosed with a neuromuscular disorder (e.g. Parkinson's Disease).

2.2.2. Data collection

Isometric joint moment was used to assess UE strength and measured with a Humac Norm (CSMI, Stoughton, MA) isokinetic dynamometer (Fig. 2.1.). Measurements were taken in standard postures: supine for shoulder internal-external rotation, and sitting for shoulder abduction-adduction, flexion-extension, and wrist flexion-extension and radial-ulnar deviation (Holzbaur et al. 2007; Vidt et al. 2012). A hydraulic hand dynamometer (Jamar Technologies, Hatfield, PA) was used to measure grip strength. Three five-second trials were performed for each test; one minute rest was given between trials and two-minutes rest was given between tests to offset fatigue (Chaffin 1975).

Figure 2.1. Isometric a) shoulder internal-external rotation, b) shoulder flexion-extension, c) shoulder abduction-adduction, d) wrist flexion-extension, and e) wrist radial-ulnar deviation strength assessment using an isokinetic dynamometer.

At a self-selected pace, deaf and hearing participants interpreted three trials of seven-minute video source, which involved a deaf leader sharing her background and experience as a part of Deaf History Month. The video source was in sign language with audio overlay and closed-captioning (Fig. 2.2.a). Participants were encouraged to interpret the video source into their own sign language and not simply echo the signs produced by the presenter. At least five minutes rest was given between trials. For all trials, a 16-channel, wireless Noraxon DTS system (Noraxon, Inc., Scottsdale, AZ) was used to measure surface EMG. Skin was prepped by shaving, light abrasion, and cleansing with alcohol; two 2cm Ag/AgCl electrodes were placed over each muscle belly or muscle group. Measures were acquired bilaterally from upper, middle compartments of trapezius, anterior, middle compartments of deltoid, and wrist extension-flexion and radial-ulnar deviation muscle groups at 1000Hz (Fig. 2.2.b-c). Prior to data collection, maximal voluntary contraction (MVC) measures were acquired from each muscle compartment using postures that elicit maximal activity (Cram et al. 1998).

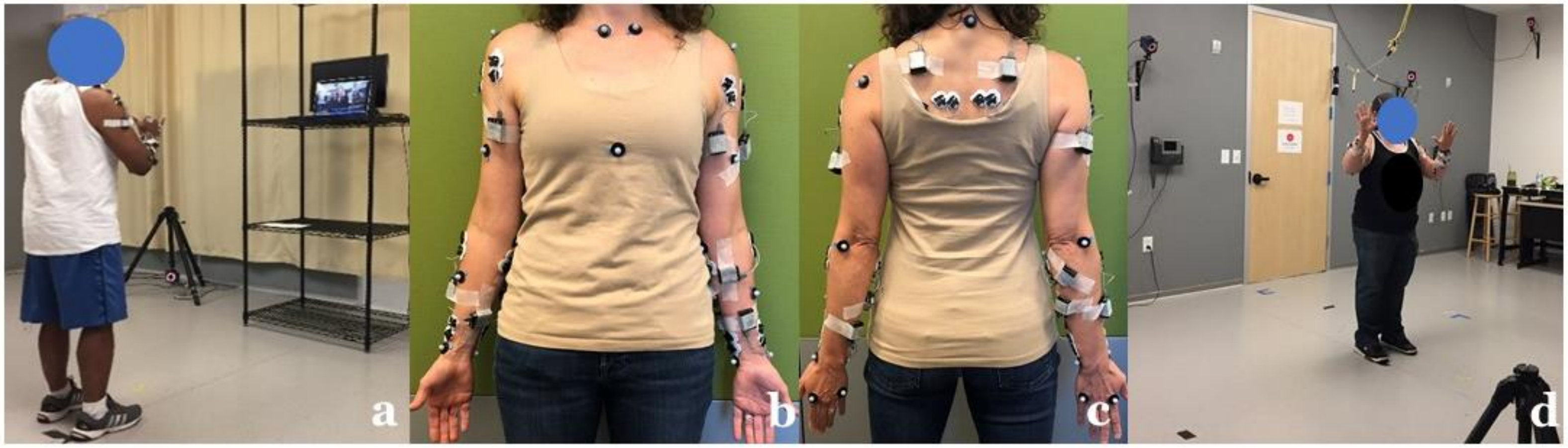

Figure 2.2. a) Participants signed from a video source in sign language with audio and closed captioning. b) Anterior and c) posterior views of electrode placement for surface EMG and surface marker placement for motion capture. d) A motion capture system tracking surface markers on upper limb segments.

An eight Kestrel camera motion capture system (Motion Analysis Corporation, Santa Rosa, CA) tracked 9mm reflective surface markers on the upper limb segments during sign production (Fig. 2.2.d). Prior to beginning the interpretation, a static recording was obtained for use in marker definition. A total of 23 surface markers were placed bilaterally on the second and fifth metacarpophalangeal (MCP) joints, the radial and ulnar styloids, medial and lateral epicondyles, posterolateral acromions, sternoclavicular joints, spinous process of the seventh cervical vertebra, xiphoid process, anterior midpoint of the proximal UEs, anterior midpoint of the forearms, and an offset marker on the left posterior shoulder (Fig. 2.2.b-c).

2.2.3. Data processing

Dynamometry

Shoulder and wrist strength were quantified by identifying the maximum joint moment maintained for at least 0.5 seconds during each trial with a custom Matlab (MathWorks, Inc., Natick, MA) script (Holzbaur et al. 2007; Vidt et al. 2012). The maximum value across the three trials was considered the participant's maximum. Hand grip strength was quantified by identifying the maximum grip strength value across the three trials.

Electromyography

Because an induced training effect was intended in effort to gather a natural capture of the participant's motion, surface EMG data from the third trial was analyzed. Raw EMG signals were band-pass filtered from 10-490Hz with a fourth order Butterworth filter, rectified, and enveloped with a second order low-pass Butterworth filter with 3Hz cutoff frequency using a custom Matlab program. Signals were normalized by each muscle's corresponding MVC. 'Micro' rest breaks were defined as a temporal delay greater than or equal to 0.2565 seconds between sequential signs with activation less than 18% MVC over the first minute of the trial (Delisle et al. 2005). 'Micro' rest breaks were identified in the processed EMG signal and represented as the total percentage of time spent in rest (%rest). Mean muscle activation across the first minute of the third trial and from the start to the stop of the signs for 'again' (Fig. 2.3.a) and 'principal' (Fig. 2.3.b) was used, respectively, for quantifying the primary outcome for muscle tension (%MVC), and secondary outcomes for ballistic signing and non-neutral joint angle.

Motion capture and computational modeling

The first minute of motion capture data from the third trial was post-processed and smoothed using Cortex software (Motion Analysis Corporation, Santa Rosa, CA). Custom MatLab codes were used to quantify ballistic signing and work envelope. The C3D model builder module of the Motion Monitor (Innovative Sports Training, Inc., Chicago, IL) software was used to quantify non-neutral joint position. Dominant absolute maximum resultant instantaneous linear segment acceleration (change of velocity per unit of time or the second time derivative of position) during the participants production of the sign for 'again' (Fig. 2.3.a) was calculated as the primary outcome for ballistic signing, and segment force (segment mass via anthropometric tables multiplied by segment acceleration; Winter 2009), jerk (change of acceleration per unit of time or the third time derivative of position), and muscle tension served as secondary outcomes. Inverse kinematics in the Motion Monitor modeling environment calculated the maximum, minimum, and average wrist flexion-extension position during the participants production of the sign for 'principal' (Fig. 2.3.b). The maximum minus the minimum was used to represent total wrist flexion-extension ROM. Average wrist flexion-extension position and ROM served as the primary outcomes for non-neutral joint angle. The maximum and minimum positions, average wrist radial-ulnar deviation position and ROM, and muscle tension served as secondary outcomes. Work envelope was identified in the post-processed motion capture data and represented by the boundary or the area of hand movement across the first minute of the third trial (Fig. 2.3.c). The boundary of the hand movement was calculated by taking the absolute value of the dominant maximum linear segment motion minus minimum linear segment motion of the relative difference between the dominant second MCP joint and ipsilateral acromion surface markers. Average position in space, two-dimensional (2D) area, and three-dimensional (3D) volume were calculated as secondary outcomes for work envelope.

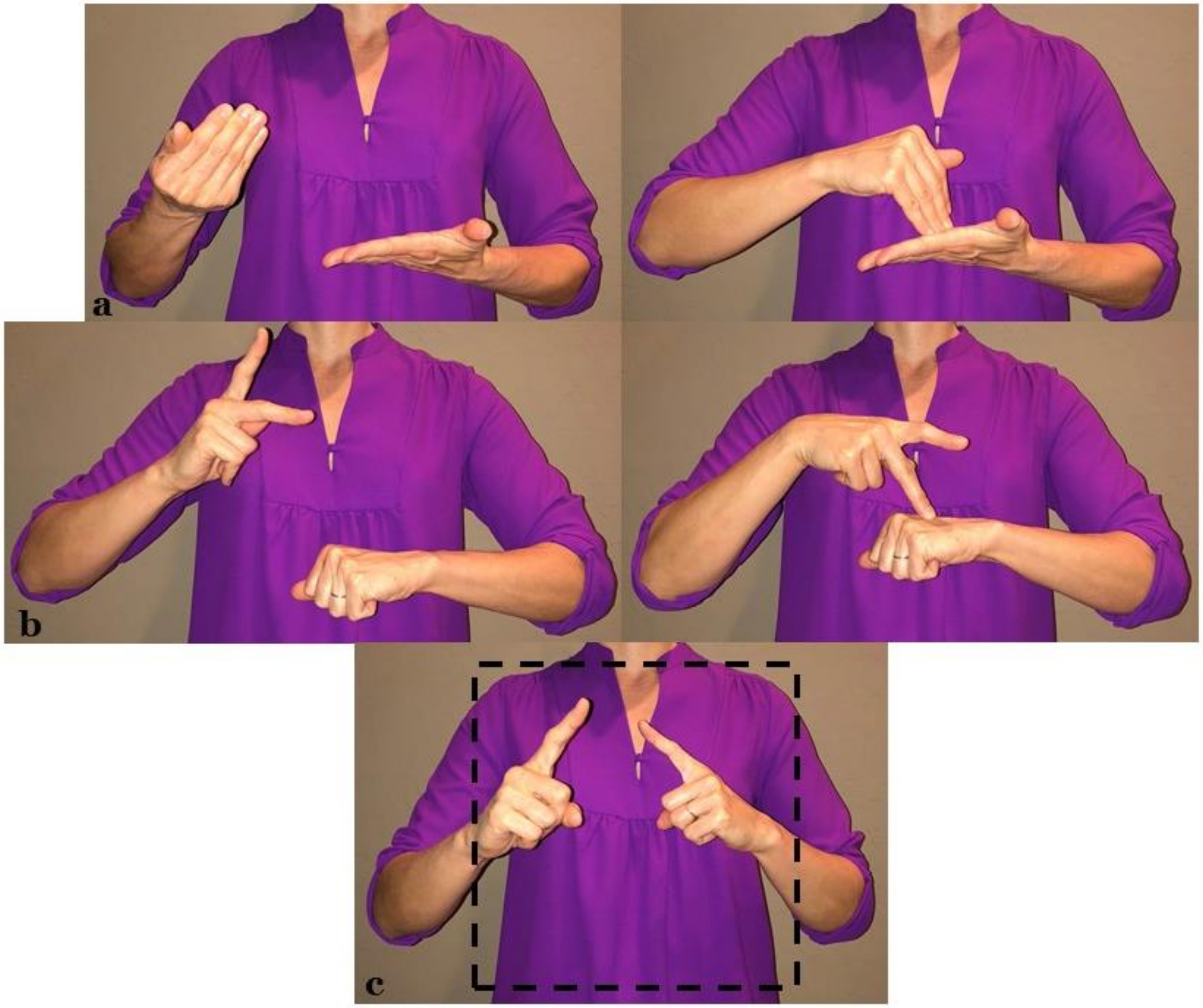

Figure 2.3. a) Sign for ‘again.’ b) Sign for ‘principal.’ c) Visualization of work envelope.

2.2.4. Data analysis

With statistical significance ($\alpha<0.05$), all statistical analyses were performed using SPSS (v.24, IBM Corp., Armonk, NY).

Strength, 'micro' rest breaks, and muscle tension

Separate Mann Whitney U tests were used to evaluate differences between natives and non-natives for 'micro' rest breaks, muscle tension, and strength. Outcomes were evaluated separately for dominant and non-dominant sides. A false discovery rate (FDR) correction by way of a custom MatLab code was used to control for type I errors (the probability that one or more null hypotheses are mistakenly rejected) across the multiple comparisons of rest, muscle tension, and strength (Benjamini and Hochberg 1995; Benjamini and Yekutieli 2001).

Ballistic signing, non-neutral joint position, and work envelope

Upon achieving normality assumption (Shapiro-Wilk $p\geq0.05$), a univariate general linear model was used to separately analyze group differences for native and non-native signers for the outcome variables representing ballistic signing, non-neutral joint position, and work envelope while adjusting for the covariates of gender, age, hearing status (deaf or hearing), and hand dominance. Dominant absolute maximum instantaneous linear segment acceleration when signing 'again' (Fig. 2.3.a) represented the primary outcome measure for ballistic signing. Mean dominant wrist flexion-extension position and ROM when signing 'principal' (Fig. 2.3.b) represented the primary outcome measures for non-neutral joint position. Lastly, dominant maximum linear segment motion minus minimum motion represented the primary outcome measure for work envelope and was compared to the established norm of $25cm^2$ (Feuerstein and Fitzgerald 1992; Woodcock and Fischer 2008).

2.3. Results

2.3.1. Isometric upper extremity strength

A FDR correction was applied to the p-values across the multiple comparisons of shoulder and wrist isometric joint moments and there were no significant differences (all $p \geq 0.22$ with FDR correction) between native and non-native signers (Fig. 2.4.).

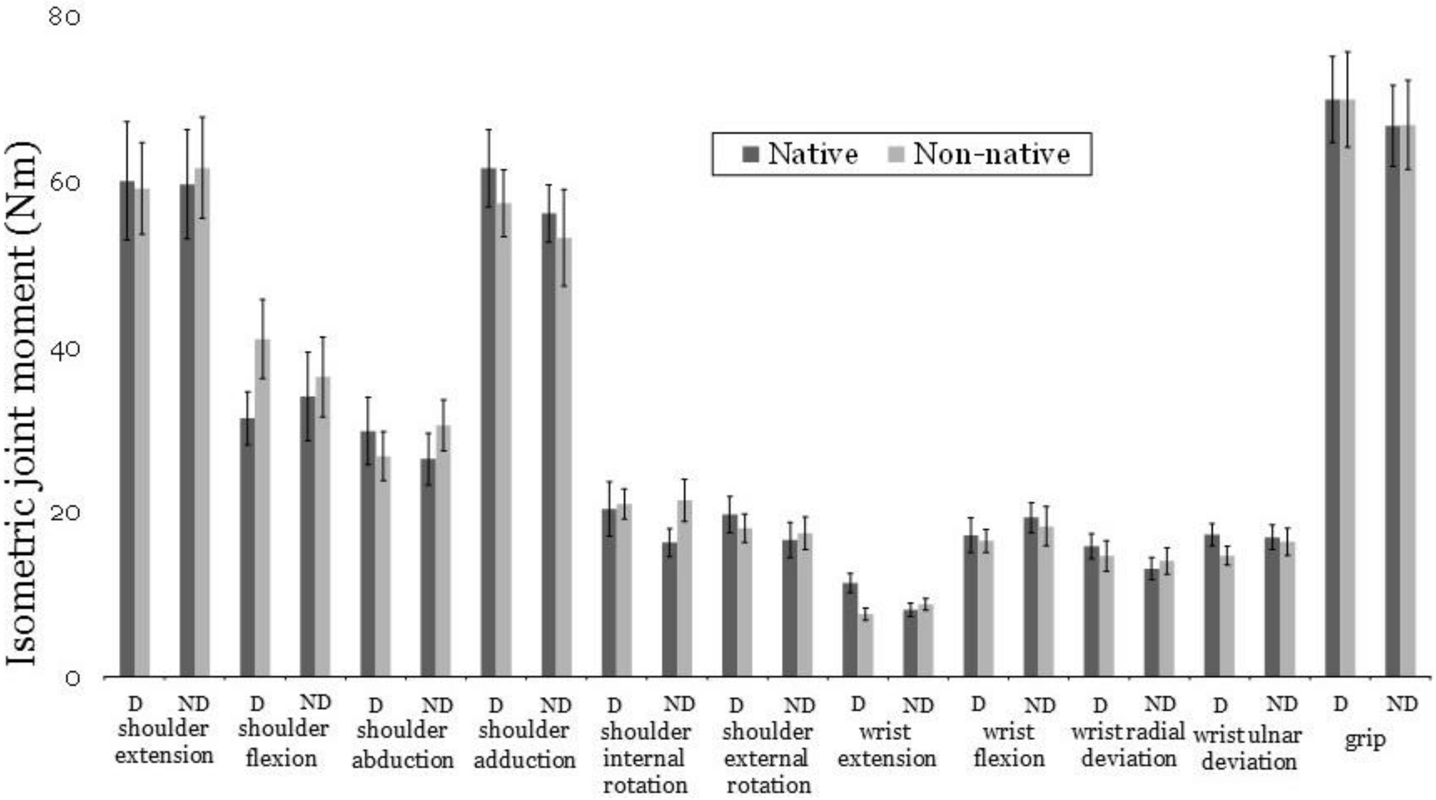

Figure 2.4. Mean (±SE) dominant (D) and non-dominant (ND) shoulder and wrist isometric joint moment for native and non-native signers.

2.3.2. 'Micro' rest breaks

Natives (mean±SE; 76.38±6.02%) had more 'micro' rest breaks for non-dominant upper trapezius (p=0.002 with FDR correction; Fig. 2.5.) than non-natives (26.86±7.41%).

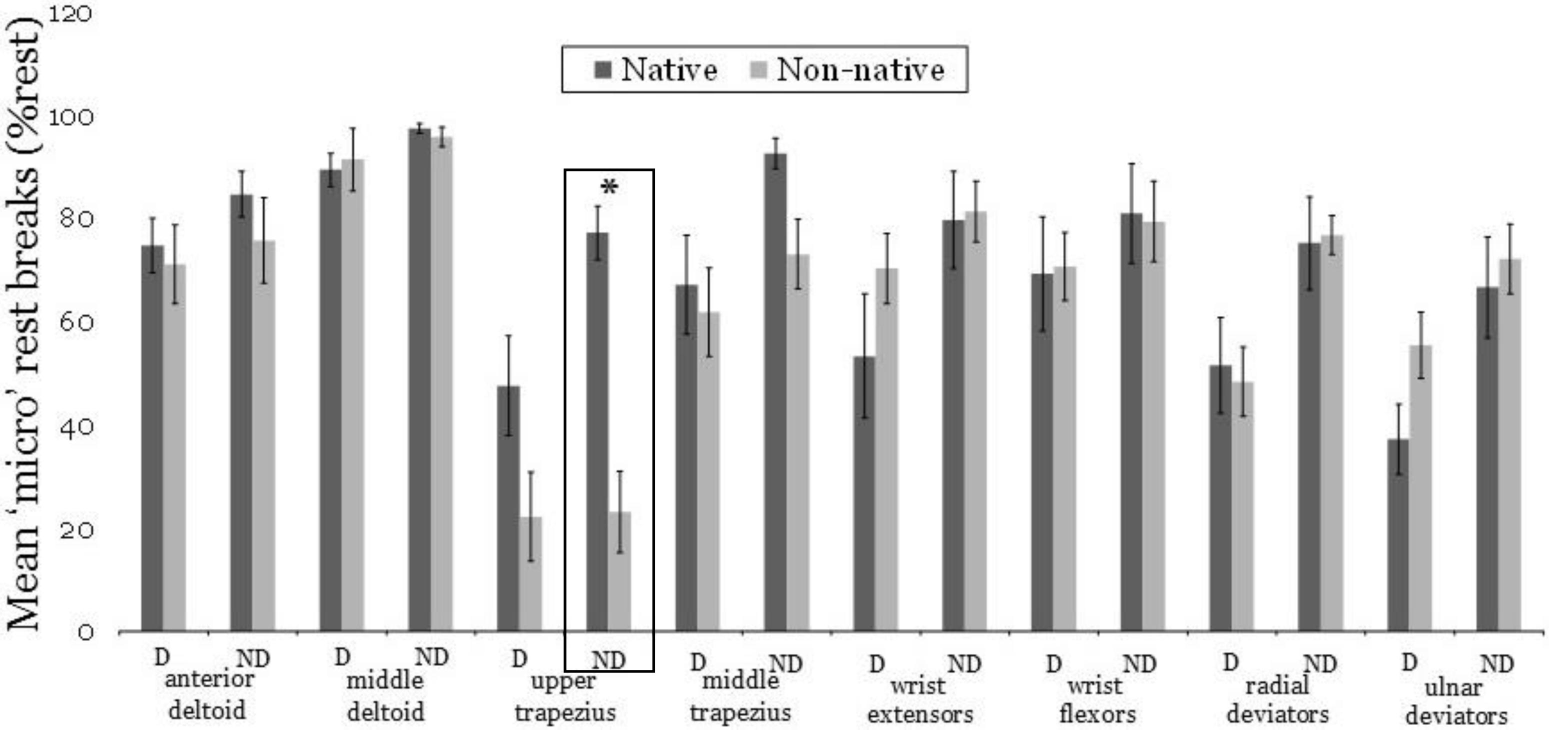

Figure 2.5. Mean (±SE) dominant (D) and non-dominant (ND) shoulder and wrist 'micro' rest breaks for natives and non-natives over the first minute of the trial.

2.3.3. Muscle tension

The variability of muscle tension was greatly impacted by participants who presented with muscle tension values in a non-physiological range of 227-1122 %MVC. It is presumed there was increased noise from the participants' forearm, wrist, and hand segments contacting their bodies or the wrist MVCs were elicited incorrectly, neither of which could be corrected for by filtering and smoothing the surface EMG data; therefore, descriptive data for muscle tension are presented here with those outliers removed. Natives (11.53±1.28%) had less non-dominant upper trapezius muscle tension ($p=0.008$ with FDR correction; Fig. 2.6.) than non-natives (48.60±11.00%).

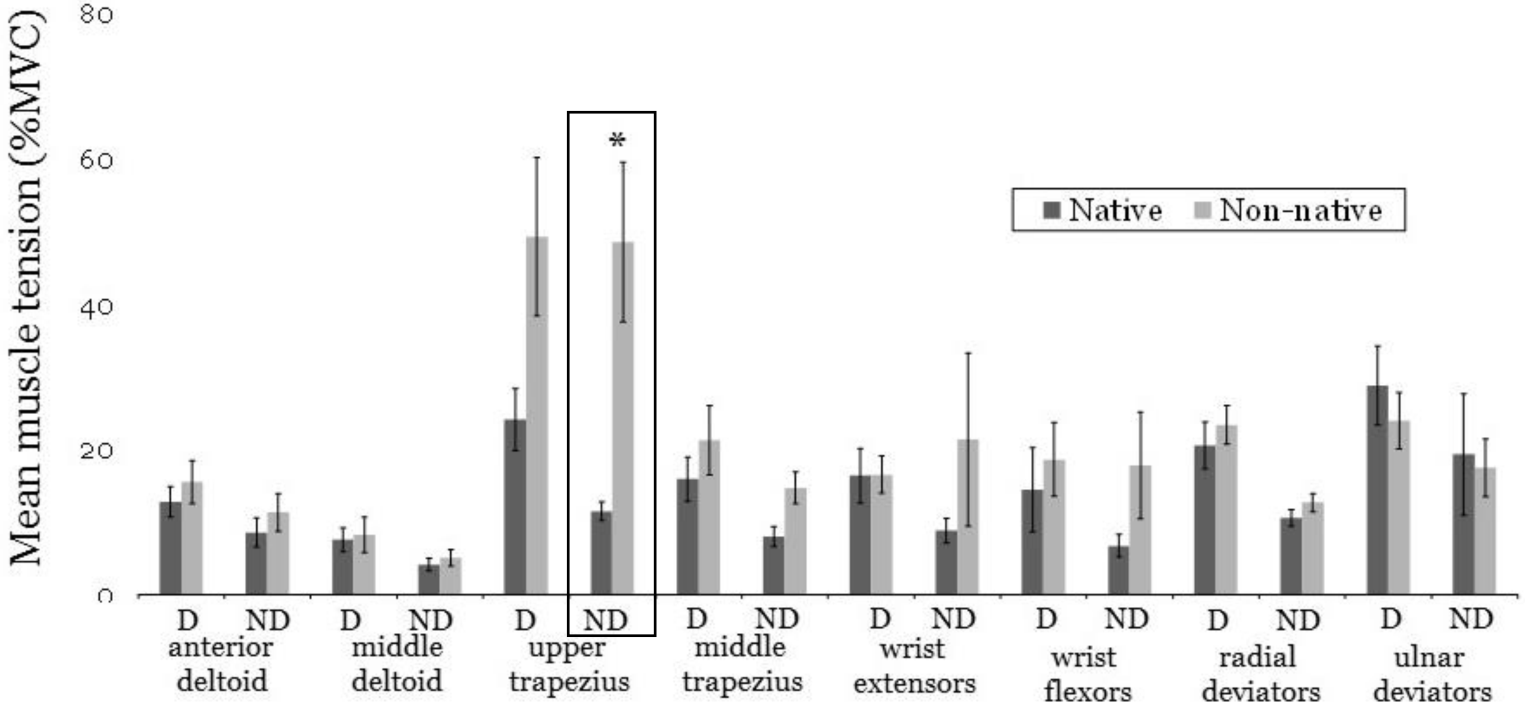

Figure 2.6. Mean (±SE) dominant (D) and non-dominant (ND) shoulder and wrist muscle tension for natives and non-natives over the first minute of the trial.

2.3.4. Ballistic signing

Mean dominant absolute maximum instantaneous linear segment acceleration (Fig. 2.7.a) produced during the sign for ‘again’ represented the primary outcome measure for ballistic signing. Mean dominant segment force, mean dominant maximum segment jerk (Fig. 2.7.b-c), and muscle tension during the sign for ‘again’ (Fig. 2.8.) represented secondary outcomes. No statistically significant differences were found in the maximum resultant instantaneous linear segment acceleration (p=0.20) between natives (27.59±2.93m/s^2) and non-natives (21.91±2.39m/s^2), nor for maximum instantaneous linear segment acceleration along the respective 3D planes (x: natives 17.43±1.34m/s^2 and non-natives 14.46±1.36m/s^2, p=0.59; y: natives 17.19±2.88m/s^2 and non-natives 12.63±2.02m/s^2, p=0.06; z: natives 10.72±1.92m/s^2 and non-natives 9.77±1.27m/s^2, p=0.86). No statistically significant differences were found in the resultant segment force (p=0.31) between natives (14.60±1.44N) and non-natives (11.61±1.67N), nor for segment force along the respective 3D planes (x: natives 9.42±0.93N and non-natives 7.64±0.97N, p=0.36; y: natives 8.99±1.40N and non-natives 6.89±1.39N, p=0.19; z: natives 5.49±0.88N and non-natives 5.05±0.64N, p=0.65). There was a main effect between natives and non-natives for jerk along the y-axis when producing the sign for ‘again’ (natives 319.71±50.86m/s^3 and non-natives 257.34±35.15m/s^3, p=0.03; Fig. 2.7.c). Natives (6.87±2.16%) also had less non-dominant upper trapezius muscle tension from the start to the stop of the sign for ‘again’ (p=0.016 with FDR correction; Figure 2.8.a) than non-natives (43.23±14.84%). Additionally, there was an effect of hearing status for maximum acceleration along the y-axis (hearing 20.54±3.64m/s^2 and deaf 11.59±1.43m/s^2, p=0.012), for maximum jerk along the y-axis (hearing 388.73±52.09m/s^3 and deaf 232.20±29.10m/s^3, p=0.006), and maximum resultant jerk (hearing 622.16±44.96m/s^3 and deaf 454.68±40.99m/s^3, p=0.015). As well, there was an effect of hand dominance (right-hand dominant 262.34±30.16m/s^3 and left-hand dominant 387.04±m/s^3, $p=0.047$) for maximum jerk along the y-axis.

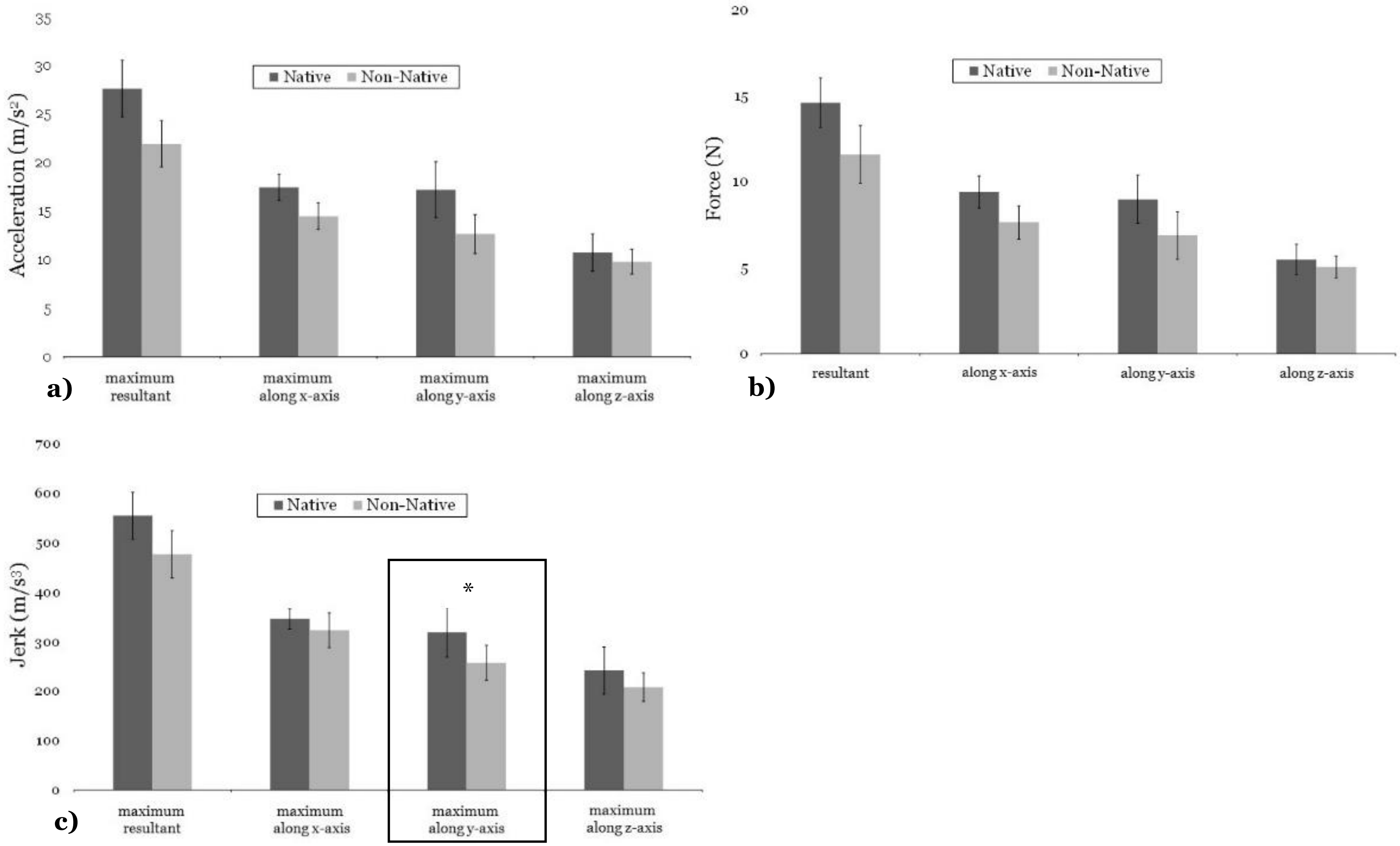

Figure 2.7. Maximum resultant and respective maximum values along the x-, y- and z-axes for a) mean (±SE) maximum linear segment acceleration b) segment force (±SE), and c) mean (±SE) maximum linear segment jerk for natives and non-natives from the start to the stop of the sign for 'again.'

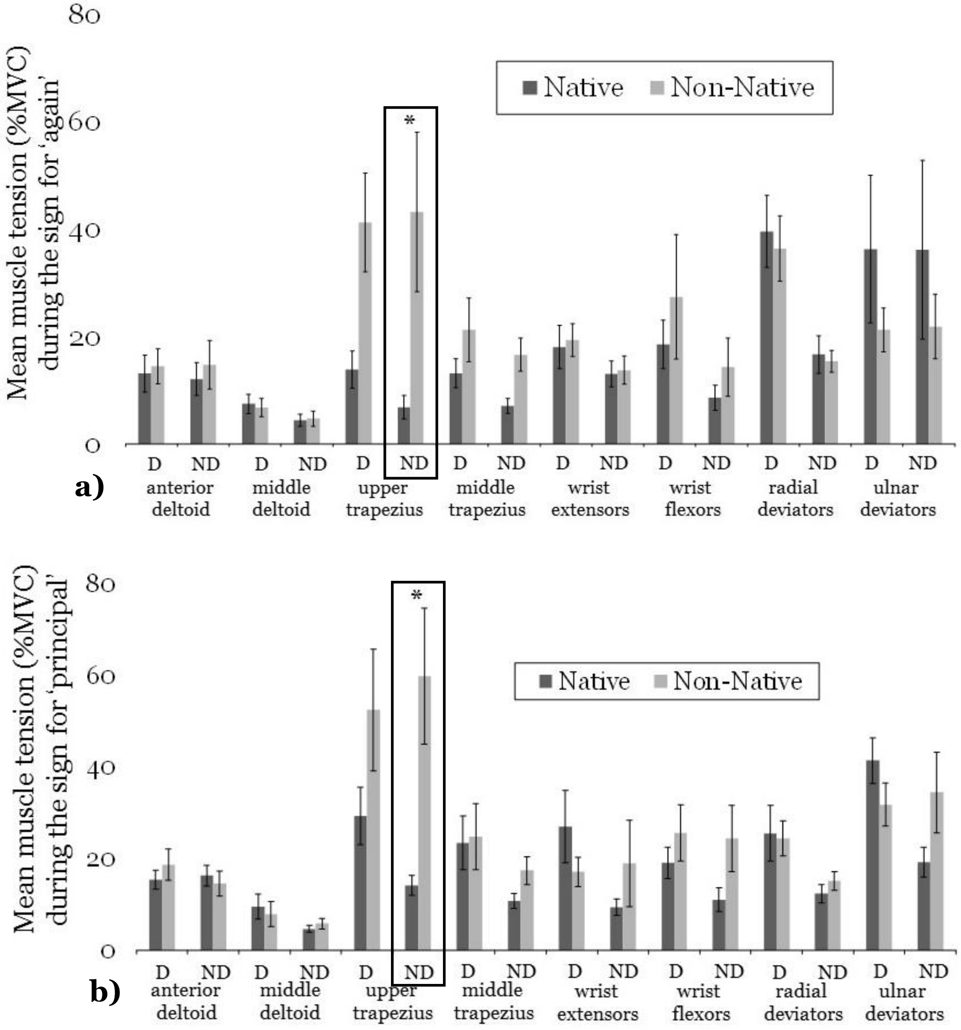

Figure 2.8. Mean (±SE) dominant (D) and non-dominant (ND) shoulder and wrist muscle tension with outliers removed for natives and non-natives during the sign for a) 'again' and the sign for b) 'principal.'

2.3.5. Non-neutral joint angle

Average wrist flexion-extension position and ROM (maximum – minimum position) represented the primary outcomes for non-neutral joint position. Maximum and minimum positions, average wrist radial-ulnar deviation position and ROM, and muscle tension during the sign for 'principal' represented secondary outcomes. When considering average wrist joint position, positive values indicated wrist flexion and ulnar deviation, and negative values indicated wrist extension and radial deviation. There was a main effect between natives and non-natives for wrist flexion-extension ROM when producing the sign for 'principal' (natives 54.93±6.41° and non-natives 46.23±3.79°; p=0.04; Fig. 2.9.). Natives (14.18±2.19%; non-natives 59.76±14.81%) also had less non-dominant upper trapezius muscle tension during the sign for 'principal' (p=0.016 with FDR correction; Fig. 2.8.b). Additionally, there was an effect of hearing status for wrist flexion-extension ROM (hearing 39.71±5.44° and deaf 54.41±3.99°; p=0.006), radial-ulnar deviation ROM (hearing 18.01±3.26° and deaf 39.42±5.75°; p=0.23), and minimum wrist flexion-extension position (hearing -35.29±7.98° and deaf -55.77±4.37°; p=0.21). As well, there was an effect of sex for average wrist flexion-extension joint position (female -28.52±5.87° and male -33.24±3.33°; p=0.029).

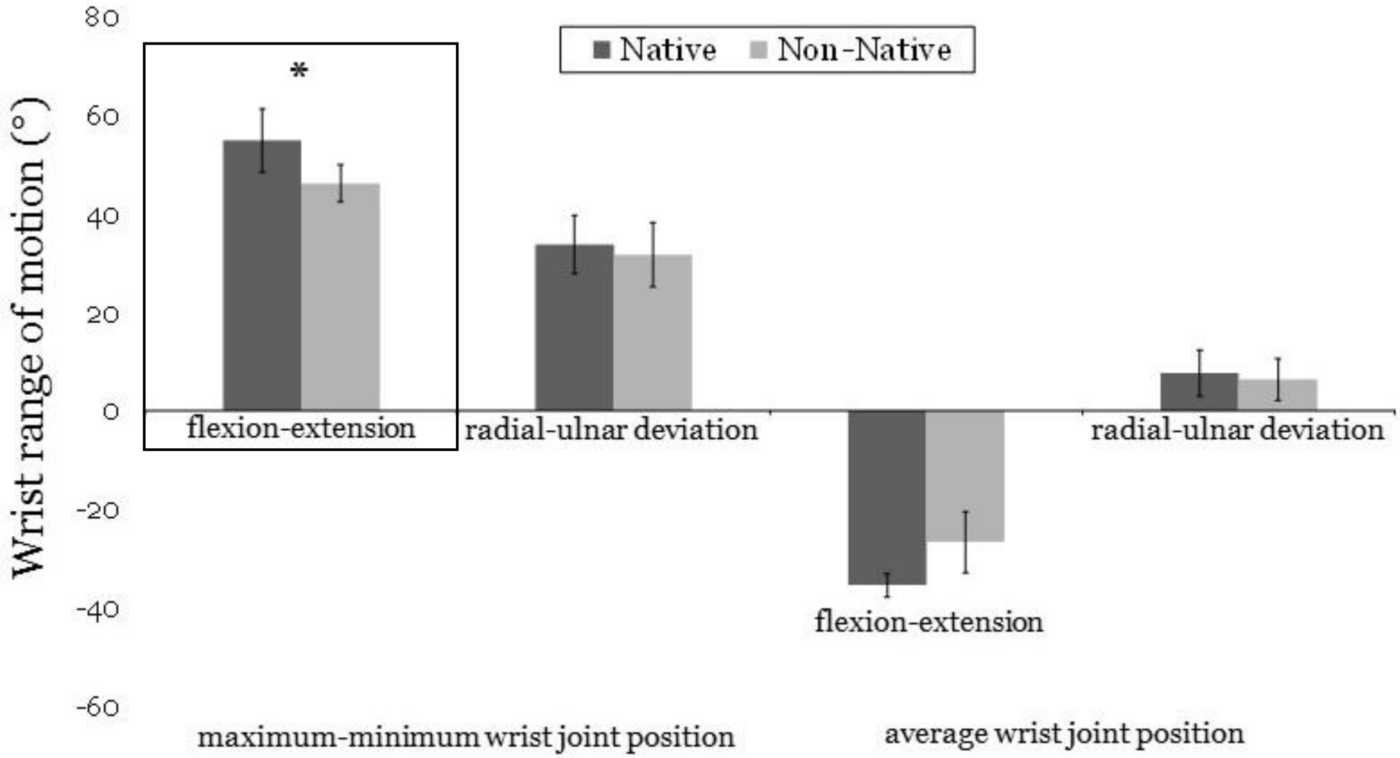

Figure 2.9. Mean (±SE) wrist flexion-extension and radial-ulnar deviation range of motion (maximum-minimum wrist joint position) and average wrist joint position for natives and non-natives from the start to the stop of the sign for 'principal.'

2.3.6. Work envelope

Natives and non-natives had a work envelope along the x-axis (medial-lateral) of 58.08±4.11cm (132% greater than the recommended norm) and 45.32±2.67 (81% greater), and a work envelope along the z-axis (superior-inferior) of 35.80±2.09cm (43% greater) and 30.84±1.36cm (23% greater), respectively, compared to the 25cm x 25cm recommended norm (Table 2.2.). There was a main effect between natives and non-natives for maximum (natives 32.08±3.20cm and non-natives 26.88±2.08cm; p=0.015; Table 2.2.; Fig. 2.10.) and minimum position (natives -26.02±2.45cm and non-natives -18.44±2.01cm; p=0.019; Table 2.2.; Fig. 2.10.) along the x-axis, and for minimum position along the z-axis (natives 9.30±1.44cm and non-natives 10.80±1.01cm; p=0.027; Table 2.2.; Fig. 2.10.). Natives had a marginally greater work envelope along the z-axis (p=0.051; Table 2.2.; Appendix B, Fig. B.2.) compared to non-natives. Additionally, there was an effect of hand dominance for work envelope along the z-axis (right-hand dominant 34.22±1.25cm and left-hand dominant 25.49±1.19cm; p=0.018), maximum position along the x-axis (right-hand dominant 31.35±1.53cm and left-hand dominant 16.44±4.73cm; p=0.003), maximum position along the y-axis (right-hand dominant 17.66±0.94cm and left-hand dominant 11.15±2.20cm; p=0.024), and minimum position along the x-axis (right-hand dominant -19.97±1.72cm and left-hand dominant -29.33±4.05cm; p=0.009). As well, there was an effect of age for minimum position along the z-axis (participants greater than or equal to 40 years 11.84±1.15cm and participants less than 40 years 8.91±1.09cm; p=0.038).

Table 2.2. Mean (±SE) relative work envelope and %difference from the 25cm x 25cm norm for non-natives and natives (*p<0.05).

	relative		**│relative max - relative min│**	**mean**
	max	**Min**		
x-axis (medial-lateral; cm)				
non-natives	**26.88 ± 2.08**	**-18.44 ± 2.01**	**45.32 ± 2.67; 81%**	**5.18 ± 1.80**
natives	**32.08 ± 3.20**	**-26.02 ± 2.45**	**58.08 ± 4.11; 132%**	**7.02 ± 2.23**
p-value	**0.015***	**0.019***	**0.102**	**0.567**
y-axis (anterior-posterior; cm)				
non-natives	**14.92 ± 1.03**	**-30.63 ± 2.75**	**45.55 ± 3.11**	**-5.29 ± 1.16**
natives	**19.16 ± 1.64**	**-32.98 ± 2.22**	**52.15 ± 3.36**	**-4.72 ± 1.09**
p-value	**0.056**	**0.238**	**0.555**	**0.935**
z-axis (superior-inferior; cm)				
non-natives	**41.64 ± 1.26**	**10.80 ± 1.01**	**30.84± 1.36; 23%**	**24.81 ± 0.78**
natives	**45.10 ± 1.23**	**9.30 ± 1.44**	**35.80± 2.09; 43%**	**25.05 ± 1.09**
p-value	**0.260**	**0.027***	**0.051**	**0.271**

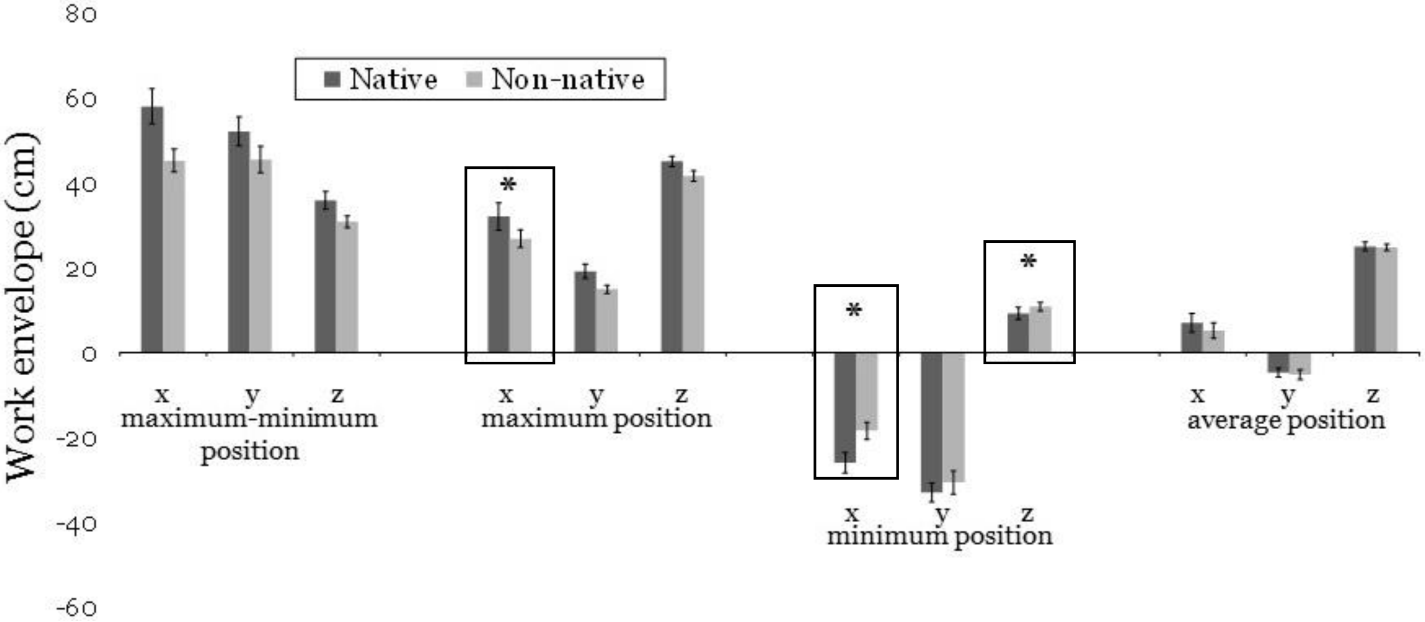

Figure 2.10. Mean (±SE) relative work envelope measures for natives and non-natives.

The calculated 2D area was 128% greater in non-natives and 240% greater in natives than the recommended 625cm^2 norm. There were no significant differences in the calculated 2D area and 3D volume between natives and non-natives (Table 2.3.; Appendix B, Fig. B.3.).

Table 2.3. Mean (±SE) relative 2D area, %difference from the 25cm x 25cm norm, and 3D volume for non-natives and natives.

	2D area using $\lvert$relative max-relative min$\rvert$ (cm^2)	**3D volume using $\lvert$relative max – relative min$\rvert$ (cm^3)**
non-natives	**1422.87±127.21; 128%**	**67582.85±8535.61**
natives	**2126.20±241.16; 240%**	**116252.45±18387.37**
p-value	**0.59**	**0.143**

2.4. Discussion

2.4.1. Isometric upper extremity strength

Outcomes for shoulder and wrist strength were hypothesized to be different between natives and non-natives, however no significant differences were found. While findings from this current work were not in support of this study's hypothesis, they were consistent with past literature. Using an isokinetic dynamometer, Feuerstein and Fitzgerald (1992) studied wrist and forearm ROM and endurance of interpreters with and without pain and found no significant differences.

In the ergonomics literature, automobile assembly line workers with lateral epicondylitis demonstrated greater muscle activity ratios of the extensor carpi radialis and the extensor carpi ulnaris compared to those workers without lateral epicondylitis (Choung et al. 2016). This suggests that overuse injuries in industry and in signers may be attributed to muscle activity imbalance rather than strength deficits.

2.4.2. 'Micro' rest breaks

'Micro' rest breaks are brief periods during the interpreting task when one or both hands are lowered (RIT 2005). Outcomes in the biomechanical measures for 'micro' rest breaks were hypothesized to be less favorable (i.e. worse) for non-natives compared to natives. Natives had more rest for non-dominant upper trapezius, demonstrating support of this study's hypothesis as greater rest was thought to be more favorable.

The significant 'micro' rest breaks found in this work were compared with the respective number of 'micro' breaks, time spent in 'micro' breaks, pause percentage, rest breaks, and time spent in rest found in previous literature. During an hour long interpreting task, Fisher et al. (2014) found an increased number of 'micro' breaks during the latter time increment for right elbow flexion-extension and right wrist flexion-extension of novice interpreters, which was attributed to fatigue. Novice interpreters in Fisher et al.'s study (2014) were all children of hearing parents, which is comparable to this study's non-native signers. During the seven-minute interpreting task used here, non-natives compared to natives had decreased rest for non-dominant upper trapezius, rather than increased rest found by Fisher (2014). These different findings may be attributed to the different durations of the interpreting task studied.

Donner et al. (2013) found an increased pause percentage in right wrist flexion-extension and left radial-ulnar deviation for interpreters compared to deaf students when conversing. Comparisons can be made between these findings for interpreters and deaf students with the current study's findings of rest for non-natives and natives, respectively. Natives in this study had more non-dominant upper trapezius rest compared to the less right wrist flexion-extension and less left wrist radial-ulnar deviation rest of the deaf students in Donner et al. (2013). Although comparisons across sub-groups can be drawn between current and prior work (Donner et al. 2013), interpretation and conversation are not equivalent tasks. Interpreting, particularly when interpreting from English to American Sign Language, is often simultaneous and ongoing, such as during a lecture. Conversation is interactive, allowing for back-and-forth exchange, and therefore more inherent opportunities for rest. In this study, the task required continuous signing for the duration of three trials, which was more consistent with interpreting a lecture. In addition to performing a comparison of interpreters and deaf students, Donner et al. (2013) also performed a within-participant comparison of interpreters across interpretation and conversation tasks. Interpreters were found to have less pause percentage time when interpreting compared to when conversing.

In the work of Feuerstain and Fitsgerald (1992), participants were asked to interpret a 20-minute audiotape of a classroom lecture. Rest breaks were defined as placing the dominant hand on the non-dominant hand, the abdomen, or in the lap. Observation of rest break frequency demonstrated good inter-rater reliability (*Pi*=0.96). Interpreters with pain had significantly fewer rest breaks per minute (mean±SD; 0.8±1.0 rest breaks/minute) when compared to interpreters without pain (1.7±1.0 rest breaks/minute), and a significant association between increased post-interpreting fatigue and decreased rest frequency was appreciated. Since the three trials of a seven-minute interpreting task were similar in duration to the 20-minute interpreting task, comparisons can be made between the findings of rest break frequency for interpreters with and without pain reported in the work of Feuerstain and Fitsgerald (1992) with the current study's findings of 'micro' rest breaks for non-natives and natives, respectively. 'Micro' rest breaks in this research were consistent with rest breaks reported by Feuerstain and Fitsgerald (1992). Non-natives had less rest of the non-dominant upper trapezius compared to natives and interpreters with pain demonstrated fewer rest breaks than interpreters without pain.

Delisle et al. (2005) measured lower average time spent in rest for the dominant (8.1%) and non-dominant upper trapezius (12.4%), than the average time spent in rest for dominant and non-dominant upper trapezius across the different sub-groups in this study. Dominant and non-dominant upper trapezius rest in all signers was measured as 35.8% and 46.7%, all natives as 49.3% and 76.4%, and all non-natives as 26.8% and 26.9%, respectively. Natives had significantly more non-dominant upper trapezius rest than non-natives, which was a favorable outcome and consistent with this study's hypothesis. The work of Delisle et al. (2005) examined rest across four sessions of a 30 to 90-minute educational interpreting task in the field, whereas the current study evaluated three trials of a seven-minute interpreting task in the lab. The difference in values could relate to difference in duration of the task studied or the variety of factors associated with the presence of MSK disorders identified by Fisher et al. (2012) (mechanical exposure, speaker pace, and stress) across the different interpreting settings. Qin et al. (2008) found faster speaker pace (fast 5.54±0.93%; slow 6.88±1.23%) resulted in less wrist pause. There was no significant difference in the time spent in wrist pause between the stressed and non-stressed (stressed 6.00±1.09%; non-stressed 6.41±1.06%) groups. Studies of additional independent variables and their implications on 'micro' rest breaks are needed. This study controlled for the effect of speaker pace by using a standardized video source. While participants may have perceived the same testing environment with varying stress levels, stress levels were not captured in this study. Future research should further evaluate the influence of speaker pace and stress on rest across different interpreting settings (e.g. field versus lab; video relay versus educational versus freelance versus staff).

2.4.3. Muscle tension

Muscle tension is prolonged muscle contraction because of an awkward position or a physiological reaction to stress (RIT 2005). Outcomes in biomechanical measures for muscle tension were hypothesized to be less favorable (i.e. worse) for non-natives compared to natives. Natives had less muscle tension in the non-dominant upper trapezius than non-natives, which was in support of this study's hypothesis as less muscle tension was thought to be more favorable.

To the best of this author's knowledge, Feuerstein and Fitzgerald (1992) is the only previous literature that aimed to quantify muscle tension in signers. They defined muscle tension as the elevation of one or both shoulders or blatant muscular contraction of the hands, neck, or face while interpreting. Participants were visually observed via video recordings and muscle tension was measured across the entire 20-minute interpreting task and across a five-minute portion of the task when the instructor used direct quotes and spoke quickly. Raters used a one to 10cm visual analog scale (zero signifying no muscle tension and 10 equating to extreme muscle tension). Muscle tension was not included in their statistical analysis because the scale demonstrated poor interrater reliability (*Pi*=0.36), therefore no comparable findings for this work are available. Additional studies on the implications of bilateral muscle tension are needed. Future research will help establish the influence of muscle tension on risk of MSK symptoms in signers.

2.4.4. Ballistic signing

Ballistic signing is defined as consistently hard, forceful, or abrupt production of signs (RIT 2005). Outcomes in biomechanical measures for ballistic signing were hypothesized to be less favorable (i.e. worse) for non-natives compared to natives. No statistically significant differences were found in the maximum instantaneous linear segment acceleration between natives and non-natives, however natives did demonstrate greater jerk along the y-axis than non-natives. The greater jerk measured in natives was not in support of this study's hypothesis as less acceleration, less force, and less jerk were thought to be more favorable. While there was no significant difference between the dominant arm length of natives and non-natives (p=0.123), the arm length of natives (54.35±1.18cm) was slightly longer than non-natives (52.07±0.86cm) possibly influencing the greater jerk along the y-axis.

This work was compared to the velocity and acceleration of wrist flexion-extension, wrist radial-ulnar deviation, forearm pronation-supination and elbow flexion-extension, high-impact hand contacts, pace of finger and hand movements, and smoothness of finger and hand movements found in previous literature. Much of the past work has studied angular velocity (°/s) and acceleration ($°/s^2$), whereas this study quantified ballistic signing by way of linear acceleration (m/s^2) and jerk (m/s^3). In a comparison of novice and experienced interpreters, Fisher et al. (2014) found slower velocity during the latter time increment for right wrist radial-ulnar deviation and right elbow flexion-extension of novice interpreters, which was attributed to fatigue. The novice and experienced interpreters in Fisher et al.'s (2014) work and this study's non-native and native signers are comparable, respectively, however the hour long interpreting task cannot be compared to this study's three trials of a seven-minute interpreting task. Experienced interpreters demonstrated a trend toward greater velocity in right wrist flexion-extension and right elbow flexion-extension compared to novice interpreters and this is consistent with this study's findings of native signers demonstrating a trend toward greater resultant and respective 3D acceleration, force, and jerk compared to non-natives.

Upon studying the variables of speaker pace and induced stress across a sample of 12 interpreters, Qin et al. (2008) found faster speaker pace resulted in greater mean velocity and acceleration. Using biaxial bilateral electrogoniometers, wrist kinematics were measured while interpreting a videotaped lecture. Speaker pace was augmented by digitally speeding up or slowing down the audio and video footage, and stress was measured before and after the experiment by using the Stress-Arousal Checklist (Mackay et al. 1978). Being stressed had no significant impact on the velocity or acceleration of the right or dominant wrist (all interpreters were right-hand dominant), however stress did result in greater left or non-dominant wrist velocity and acceleration (except for left wrist radial-ulnar acceleration). The need for greater emphasis while interpreting when stressed was the hypothesized rationale for this finding. The highest mean velocities and accelerations, therefore when interpreters exhibit ballistic signing, were found in the stressed-fast paced condition, whereas the lowest were found in the non-stressed-slow paced condition. As previously mentioned when discussing 'micro' rest breaks, this study eliminated the effect of speaker pace by using a standardized video source and did not capture stress levels. The previous work of Qin et al. (2008) indicates that the stress levels of native signers in this study may have been higher than the non-natives, thereby contributing to their greater biomechanical outcomes for ballistic signing. Four of the 10 natives in this study worked as sign language interpreters. While this study's aim was to examine the differences between native and non-native signers and the third trial was analyzed for purposes of inducing a training effect, the interpretation of the video source may have been more stressful for the natives who were not sign language interpreters, thereby causing them to sign more ballistically. However, in the work of Qin et al. (2008), stress only influenced greater velocity and acceleration on the non-dominant side, whereas all biomechanical outcomes for ballistic signing in this study were gathered on the dominant side.

Consistent with the findings of this work, Donner (2012) and Donner et al. (2016) found no differences in the mean angular velocity and acceleration for wrist flexion-extension and radial-ulnar deviation in early- (n=8) and late-signing (n=8) interpreters. However, in a comparison across the tasks of interpreting and conversing (Donner 2012; Donner et al. 2013), interpreters had decreased left wrist flexion-extension (p=0.002) and radial-ulnar deviation (p=0.001) mean velocity, and increased left wrist radial-ulnar deviation (p=0.032) acceleration and right wrist flexion-extension (p=0.021) and radial-ulnar deviation (p=0.001) mean acceleration when conversing compared to interpreting. In a comparison of interpreters to deaf students (Donner et al. 2013), no significant differences were found in mean angular velocity or acceleration when conversing. Sub-group comparisons can be drawn between the early- and late-signing interpreters, and interpreters and deaf students with the current work on non-native and native signers, respectively. The lack of significance upon comparing the acceleration and force between natives with non-natives was consistent with past findings when comparing angular velocity and acceleration between early- and late-signing interpreters and interpreters and deaf students. Outcomes for ballistic signing, specifically quantification of jerk along the y-axis, did demonstrate a trend toward ballistic signing in natives compared to non-natives, which was not consistent with prior work.

Delisle et al.'s (2005) work was a cross-sectional study that provided angular velocity and acceleration values for nine interpreters (n=9). When referencing the high- and low-cumulative trauma disorder risk established by Marras and Schoenmarklin (1993), the median angular velocity and acceleration of the participants in Delisle et al.'s (2005) work are all considered low-risk. Participants were included in Delisle et al.'s (2005) work because they reported frequent pain, therefore it can be extrapolated that the low-risk quantification of angular velocity and acceleration in these participants did not play a role in their pain presentation. The work of Delisle et al. (2005) reported median angular velocity and acceleration, and the work of Marras and Schoenmarklin (1993) reported mean angular velocity and acceleration, so median and mean values are not an exact comparison. The current work was the first to calculate jerk in signers, however the linear calculations do limit this study's comparability to the angular calculations of other studies.

The measurements of the number of high-impact hand contacts, the pace of finger and hand movements, and the smoothness of finger and hand movements found in the work of Feuerstein and Fitzgerald (1992) can be used as additional quantifications of ballistic signing. Like 'micro' rest breaks and muscle tension, participants were visually observed via video recordings. High-impact hand contacts were defined as an audible slapping sound produced by high velocity movement of the dominant hand against the non-dominant hand. Raters used a zero to 10cm visual analog scale for pace of finger and hand movements (zero signifying slow pace, five signifying moderate pace, and 10 equating to rapid pace) and for smoothness of finger and hand movements.

Although somewhat subjective in their assessment, there was good inter-rater reliability for the number of high-impact hand contacts (*Pi*=1.0), pace of finger and hand movements (*Pi*=0.99), and smoothness of finger and hand movements (*Pi*=0.89). There was no significant difference between interpreters with pain and interpreters without pain for the number of high-impact hand contacts and smoothness of finger and hand movements, however interpreters with pain had greater pace of finger and hand movements (mean±SD; 6.1±1.7cm along the 10cm visual analog scale) compared to interpreters without pain (3.8±2.0cm). Out of the seven biomechanical measures assessed and six that were analyzed, Feuerstein and Fitzgerald (1992) found pace of finger and hand movements achieved the greatest significance between interpreters with and without pain. The lack of significance across interpreters with and without pain in the number of high-impact hand contacts and smoothness of finger and hand movements was similar to the lack of significance across native and non-native signers in this study for segment acceleration and force. The significance of interpreters with pain having a greater pace of finger and hand movements was not consistent when compared with native signers demonstrating greater jerk along the y-axis as natives are presumed to have less pain from signing when compared to non-natives. Greater ballistic signing in non-natives would have been more comparable to the greater pace measured in interpreters with pain and in support of this study's hypothesis. Interestingly, the finding of greater jerk in native signers may perhaps be indicative of a counterintuitive self-preservation response against injury-risk. For example, greater jerk in native signers, may lend itself to providing greater clarity and effectiveness in communicating thereby lessening the need for repetition and reiteration when signing; subsequently, improving efficiency, and reducing fatigue and injury-risk.

Upon adjusting for the covariates of gender, age, hearing status (deaf or hearing), and hand dominance, hearing participants (n=8) had greater maximum acceleration and jerk along the y-axis, and greater maximum resultant jerk than deaf participants (n=17). The significance of these ballistic signing measures begs to question the sub-grouping of participants in this work. Would a comparison of hearing status (sub-groups of hearing and deaf), rather than language acquisition status (natives and non-natives) be better apt to distinguish the biomechanical measures indicative of injury-risk? Natives presented with greater jerk along the y-axis than non-natives, only one of the 12 measures used to quantify ballistic signing, and hearing participants presented with a significant difference compared to deaf participants in three of the 12 measures. Categorization into hearing and deaf sub-groups when studying biomechanical measures indicative of injury-risk should be considered with future research.

Approximately ten percent of the population is left-hand dominant (Hardyck and Petrinovich 1977). There were four left-hand dominant participants in this study (16%), demonstrating a larger representation here than in the general population. Left-hand dominant participants (n=4, three of whom were non-natives) had greater jerk along the y-axis than right-hand dominant participants (n=21). Fisher et al.'s (2014) work had a total sample of 18 sign language interpreters and all self-identified as being right-hand dominant. Donner (2012) and Donner et al. (2016) had a total sample of 16 early- and late- signing interpreters with only one being left-hand dominant and in Donner et al. (2013), all nine deaf students were right-hand dominant. Although Delisle et al. (2005) coded their rest analysis of the upper trapezius as dominant and non-dominant, we do not know how many of the nine interpreters in that study were right- or left-hand dominant. Past evidence from Qin et al. (2008) conveyed higher values of right wrist velocity and acceleration when compared with the left wrists of 12 right-hand dominant interpreters. Since Qin et al.'s (2008) sample was all right-hand dominant interpreters, their findings could not be compared to left-hand dominant signers, like in this work. The work of Feuerstein and Fitzgerald (1992) did not differentiate based on hand dominance. While the p-value from this work indicating significantly greater jerk along the y-axis for left-hand dominant participants was marginal (p=0.047), the relatively large representation of left-hand dominant participants in this sample beckons attention. The past evidence does not convey any significant findings when comparing right- and left-hand dominance, so this finding is unsubstantiated. As for anecdotal rationale, the person signing in the video source was right-hand dominant. This may have factored into this study's left-hand dominant participants' 'jerkiness' when providing their own rendition of the video source.

2.4.5. Non-neutral joint angle

Neutral joint positions are considered the midpoint of opposing motions within the same cardinal plane (e.g. midpoint between wrist flexion-extension in the sagittal plane), therefore non-neutral joint positions are deviations from neutral (RIT 2005). Outcomes in biomechanical measures for non-neutral joint angle were hypothesized to less favorable (i.e. worse) for non-natives compared to natives. Natives had greater wrist flexion-extension ROM than non-natives, which was not in support of this study's hypothesis as less wrist ROM and a closer to neutral mean wrist position were thought to be more favorable.

This research was compared to the wrist joint minimum, maximum and mean position, and range of displacement or ROM found in previous literature. In Fisher et al.'s (2014) comparison of novice and experienced interpreters, there were no significant differences in wrist flexion-extension, radial-ulnar deviation, or elbow flexion-extension ROM between novice and experienced interpreters when examining each of the four 15-minute time segments of an hour long interpreting task. However, upon examining experience by time interactions, experienced interpreters were found to increase their right elbow flexion-extension ROM from the first to the second 15-minute time segment.

The novice and experienced interpreters in Fisher et al.'s (2014) work and this study's non-native and native signers are comparable, respectively. This study did not analyze elbow joint ROM to compare with Fisher et al.'s (2014) findings. However, we did find natives demonstrated greater wrist flexion-extension ROM while Fisher et al. (2014) did not find any significance between novice and experienced groups with wrist ROM. The experienced interpreters in Fisher et al.'s (2014) work and the native signers in this work increased their ROM in comparison to novice sign language interpreters and non-native signers, respectively. This contrasted with the work of Feuerstein and Fitzgerald (1992) where interpreters with pain (mean±SD; 10.2±3.4 hand and wrist deviations/minute) were found to have greater mean hand and wrist deviations per minute than interpreters without pain (7.5±3.3 hand and wrist deviations/minute). Anecdotally, natives are known to have less pain from signing when compared to non-natives. More wrist flexion-extension ROM from non-natives, rather than natives, would be in support of this study's hypothesis and more in line with the greater mean hand and wrist deviations per minute in interpreters with pain found by Feuerstein and Fitzgerald (1992). Similar to greater jerk in native signers, this increase in ROM with the experienced interpreters and native signers may be indicative of a counterintuitive self-preservation response against injury-risk. Greater ROM may lend itself to greater clarity, thus improving efficiency by lessening the need for repetition when signing.

Although there was no difference in minimum, maximum and mean position, and overall range of displacement with wrist flexion-extension and radial-ulnar deviation between early- and late-signing interpreters the work of Donner (2012) and Donner et al. (2016), a significant difference in the wrist flexion-extension ROM between natives and non-natives was realized in this work. When comparing interpreters' performance across interpretation and conversation tasks, Donner et al. (2013) discovered significant differences in mean range of wrist displacement (upper minus lower confidence interval) for right wrist flexion-extension and right wrist radial-ulnar deviation. Interpreters demonstrated greater range of wrist displacement when interpreting, 22% greater on average, compared to when conversing. Donner et al. (2013) also compared the range of wrist displacement between interpreters and deaf students when conversing and found that deaf students demonstrated greater right wrist flexion-extension and right radial-ulnar deviation displacement. Upon comparing non-native and native signers to interpreters and deaf students in Donner et al. (2013), respectively, we see that both the natives and deaf students demonstrated greater wrist flexion-extension wrist range of displacement. As seen in the comparison with ROM findings from Fisher et al. (2014), comparison of the increased dominant wrist flexion-extension ROM in natives with the increased right wrist flexion-extension and radial-ulnar deviation ROM in deaf students (Donner et al. 2013) may somehow demonstrate a counterintuitive effect on self-preservation against injury-risk.

Marras and Schoenmarklin (1993) created high- and low-cumulative trauma disorder risk values for wrist and forearm ROM. High- and low-risk mean wrist flexion-extension ROM were established at 35.63° and 27.95°, and high- and low-risk mean radial-ulnar deviation ROM were established at 23.65° and 17.64°, respectively (Table 1.1.). Descriptive statistics from Delisle et al. (2005) for mean ROM (90th – 5th percentile) of wrist flexion-extension and wrist radial-ulnar deviation were reported as 66° and 36°, respectively. Both of which are considered high-risk when referencing Marras and Schoenmarklin (1993). Qin et al. (2008) found no significant main effect of pace or stress on mean wrist position and did not compare wrist position with the established low- and high-risk values (Marras and Schoenmarklin 1993). The mean wrist flexion-extension ROM (mean±SE; 54.93±6.41°) and radial-ulnar deviation ROM (33.81±5.96°) for natives and the mean wrist flexion-extension ROM (46.23±3.79°) and radial-ulnar deviation ROM (31.74±6.50°) for non-natives in this work are lesser ROM values when compared to Delisle et al. (2005), although still considered high-risk for cumulative trauma disorders when referencing Marras and Schoenmarklin (1993). Measures from this study were gathered during the production of a sign ('principal') that was intended to differentiate between signers who deviate compared to signers who do not deviate from neutral wrist joint position. Mean ROM values over the course of one sign compared to over the course of an entire task may not be equivalent.

Upon adjusting for the covariates of gender, age, hearing status, and hand dominance, this work found deaf participants (n=17) had greater mean wrist flexion-extension ROM (mean±SE; deaf 54.41±3.99° and hearing 39.71±5.44°), greater mean radial-ulnar deviation ROM (deaf 39.42±5.75° and hearing 18.01±3.26°), and greater minimum wrist flexion-extension position (deaf -55.77±4.37° and hearing -35.29±7.98°) than hearing participants (n=8). These secondary outcomes are consistent with the work of Donner et al. 2013 who reported that deaf students demonstrated greater right wrist flexion-extension and right radial-ulnar deviation displacement compared to interpreters when conversing. Findings for the non-neutral joint angle echo the same sentiment mentioned in the ballistic signing discussion. Categorization into hearing and deaf sub-groups when studying biomechanical measures indicative of injury-risk is something that should be considered with future research.

This work also found males (n=9) had a lesser average wrist flexion-extension joint position (mean±SE; -33.24±3.33°), indicating a greater deviation from neutral into wrist extension, than females (n=16; -28.52±5.87°) during the sign for 'principal.' This may simply be a stylistic difference across the sexes, however it does highlight a mean wrist flexion-extension position further from, rather than closer to neutral. Based on the work of Feuerstein and Fitzgerald 1992, hand and wrist deviations were found to be significantly greater in interpreters with pain making this is a less favorable outcome for males.

2.4.6. Work envelope

Work envelope is defined as movement in front of the chest within a boundary of 25cm^2 (Feuerstein and Fitzgerald 1992; Woodcock and Fisher 2008). Outcomes in biomechanical measures for work envelope were hypothesized to be less favorable (i.e. worse) for non-natives compared to natives. Similar to the results for non-neutral joint position, natives had a greater maximum position along the x-axis, greater minimum positions along the x- and z-axes, and marginally greater work envelope along the z-axis compared to non-natives, which were not in support of this study's hypothesis. Minimum and maximum positions, and work envelope measurements closer to the recommended 25cm x 25cm norm (Feuerstein and Fitzgerald 1992; Woodcock and Fischer 2008) were thought to be more favorable. The slightly longer dominant arm length of natives compared to natives (though not significant; p=0.123) may have influenced the greater work envelope values.

Compared to the 25cm x 25cm recommended norm, natives and non-natives were 132% and 81% greater along the x-axis (medial-lateral), and 43% and 23% greater along the z-axis (superior-inferior), respectively. This recommended norm was originally proposed by Feuerstein and Fitzgerald (1992) and was based on seated work space design specifications of Hagberg (1984). Data for this study were gathered in standing; therefore, use of the mean values along the x- (mean±SE; 50.42±2.85cm), y- (48.19±2.35cm), and z-axes (32.82±1.24cm) from this study should help inform the development of 2D and 3D work envelope norms for signers while standing.

To the best of this author's knowledge, the study by Feuerstein and Fitzgerald (1992) is the only prior work available analyzing work envelope of signers. Like 'micro' rest breaks, muscle tension, ballistic signing, and non-neutral joint angle, participants were visually observed via video recordings. The frequency of excursions outside of the

$25 cm^2$ recommended work envelope norm were counted. There was good inter-rater reliability of this quantification for work envelope (*Pi*=0.95). Interpreters with pain (mean±SD; 2.7±3.1 excursions outside of the optimal work envelope per minute) had greater excursions outside of the optimal work envelope per minute than interpreters without pain (1.0±0.8 excursions outside of the optimal work envelope per minute). Sub-group comparisons can be drawn between interpreters with and without pain with the current work on non-native and native signers, respectively. These findings of natives with greater maximum and minimum positions along the x-axis, greater minimum position along the z-axis, and marginally greater work envelope along the z-axis compared to non-natives are inconsistent with the larger excursion measurements outside of the optimal work envelope for interpreters with pain in the work of Feuerstein and Fitzgerald (1992). Anecdotally, there is some thought that a larger work envelope is safer and less injury-risk prone because it relies on the larger muscle groups of the shoulders and elbows, and therefore induces less repetitive motion to the smaller muscle groups of the wrists and hands.

Upon adjusting for the covariates of gender, age, hearing status, and hand dominance, this work found right-hand dominant participants (34.22±1.25cm) had a larger work envelope along the z-axis (superior-inferior), a greater maximum position along the x-axis (medial-lateral; 31.35±1.53cm), and a greater maximum position along the y-axis (anterior-posterior; 17.66±0.94cm) compared to left-hand dominant participants (25.49±1.19cm, 16.44±4.73cm, 11.15±2.20cm, respectively). The greater maximum value along the x-axis for right-hand dominant participants is clear because the positive x-axis denotes the right side of the body where right-hand dominant participants presumably conduct much of their motion. The greater maximum motion along the z- and y-axes by right-hand dominant participants may simply relate to the larger representation of right-hand dominant participants in this study (n=21) compared to left-hand dominant participants (n=4). While there was no significant difference between the dominant arm length of right- and left-hand dominant participants (p=0.136), the arm length of right-hand dominant participants (53.45±0.80cm) was slightly longer than left-hand dominant participants (50.50±0.96cm) possibly influencing the greater work envelope values along the z- and y-axes. Left-hand dominant participants (-29.33±4.05cm) had a greater minimum position along the x-axis compared to right-hand dominant participants (-19.97±1.72cm). The greater minimum value along the x-axis for left-hand dominant participants is clear because the negative x-axis denotes the left side of the body where left-hand dominant participants presumably conduct much of their motion.

Participants greater than or equal to 40 years of age did not have as great of a minimum position along the z-axis (11.84±1.15cm) as participants less than 40 years of age (8.91±1.09cm). While there was no significant difference between the arm length of participants greater than or equal to 40 years of age compared to participants less than 40 years of age (p=0.140), the arm length of participants less than 40 years of age (53.71±0.96cm) was slightly longer than participants greater than or equal to 40 years of age (52.05±1.08cm) possibly influencing the greater minimum work envelope values. This lack of extreme minimum motion in the superior to inferior plane may relate to employment of greater energy conservation tactics with increased age.

2.4.7. Study limitations

There were a few limitations to this study. The observational cross-sectional design limits the ability to detect any cause and effect relationships between the variables. Dynamometry, EMG, and optical motion capture were used to quantify biomechanical outcomes in this work, however past work has used dynamometry, visual observation with ratings of frequency and scale, biaxial unilateral and bilateral electrogoniometers, and electromagnetic motion capture. EMG-based rest and linear segment acceleration were used to quantify 'micro' rest breaks and ballistic signing in this work, whereas other work has used kinematic-based rest and angular joint acceleration. Inconsistent methods used to collect biomechanical outcomes and participant groupings make it difficult to compare across studies. Participant sampling targeted natives and non-natives, but did not match age, gender, or hearing status across sub-group comparisons. The typical interpreting demographic is approximately 75% female to 25% male (Brunson 2017). While the groups in this study were unbalanced between males and females (60% to 40% of native females to males and 70% to 30% of non-native females to males; Table 2.1.), these group distributions are consistent with the distribution of sex in the interpreting profession. The aim of this study was to compare differences between natives and non-natives. Participants were encouraged to interpret the video source into their own sign language and not simply echo the signs produced by the presenter. Although the third trial was analyzed for purposes of inducing a training effect, those participants who were not sign language interpreters may have felt more stressed or uncomfortable with this methodology, thereby affecting the investigators ability to gather a natural capture their sign language expression. Measuring participant stress before and after the experiment may have helped to taper the influence of interpreting the video source, or comparing across the task of conversing, rather than the task of interpreting may have served as a better approach in capturing differences between natives and non-natives. Additionally, comparing native and non-native sub-groups based on hearing status would offer additional insight into the biomechanical considerations unique to signers and should be considered in future investigations. This study was powered to detect wrist acceleration as the primary outcome for ballistic signing, thus other analyses of UE strength, 'micro' rest breaks, muscle tension, non-neutral joint angle, and work envelope may be underpowered. These data can now be used to power and design future studies exploring similar factors. Assessment of scapular muscle strength was not conducted in the current work. This would be a useful correlate measure to tension and rest found in the scapular musculature. EMG measures targeted the entire shoulder complex, whereas dynamometry targeted only the glenohumeral joint. Future work should include assessments of scapular muscle strength to further explore the implications of non-dominant upper trapezius found in this study. Investigators used RID certification to ascertain sign language fluency for hearing participants, but no standard assessment was used to determine sign language fluency for deaf participants. Use of sign language as a primary language of communication either since birth, or during primary or secondary education was deemed sufficient evidence to prove fluency for deaf participants, but this could introduce possible discrepancies in future comparisons. Future work will include use of American Sign Language Proficiency Assessment to assess individual ability to communicate using sign language as a standard fluency measure with all hearing and deaf participants (Maller et al. 1999).

2.5. Conclusions

Sub-group comparisons demonstrated consistent results implicating non-dominant upper trapezius in the identified ‘micro’ rest breaks and muscle tension (across the first minute of the trial, and from the start to the stop of the signs for ‘again’ and ‘principal’) findings. Results from this work for rest and tension demonstrated more significance on the non-dominant, rather than the dominant side. The non-dominant upper trapezius of natives demonstrated significantly more rest and less tension, which was thought to be favorable. Given these results, biomechanists and clinicians alike should not be surprised by non-dominant symptom presentation in non-natives.

Use of dynamometry for strength, EMG for quantification of ‘micro’ rest breaks and muscle tension, and optical motion capture for ballistic signing, non-neutral joint angle, and work envelope will help to inform a composite measure of injury-risk specific to signers. This complete description of all the UE biomechanics unique to signers will help to deepen our understanding of their collective role as indicators of MSK symptoms. Natives in this study demonstrated favorable outcomes compared to non-natives for less muscle tension and more rest. If rest is notably decreased or increased, then the inverse for tension should be examined. Non-natives in this study demonstrated favorable outcomes compared to natives for ballistic signing, non-neutral joint angle, and work envelope. Since natives are, anecdotally, known to have less pain from signing when compared to non-natives, investigation of their greater jerk, increased wrist flexion-extension ROM, and larger work envelope findings warrants further examination. Originally thought to be indicative of injury-risk, ballistic signing, greater non-neutral joint angle, and a larger work envelope may actually be indicative of a counterintuitive self-preservation response against injury-risk while signing. Increased jerk and greater non-neutral joint angle may improve clarity and effectiveness while signing, thus lessening the need for repetition and reiteration; subsequently, improving efficiency, and reducing fatigue and injury-risk. Additionally, a larger work envelope may be safer and less prone to injury because it relies on the larger muscle groups of the shoulders and elbows, thereby reducing repetitive motion of the smaller muscle groups of the wrists and hands.

While consistency in methodology and participant groupings is needed to compare across studies with more ease, this work helps to build upon the UE biomechanics of signers in the available literature. To promote safe practices while signing, emulating the rest and tension of natives, and the ballistic signing, non-neutral joint angle, and work envelope of non-natives is suggested.

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2.7. References

Benjamini, Y. and Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J Royal Statistical Society*, Series B (Methodological). 57(1): 289-300.

Benjamini, Y. and Yekutieli, D. (2001). The control of the false discovery rate in multiple testing under dependency. *Annals of Stats*. 29(4): 1165-1188.

Bishop, M. and Hicks, S. (2008). Hearing, mother father deaf: hearing people in deaf families. Washington, D.C.: Gallaudet University Press.

Brunson, J.L. Sign language interpreting: moving towards professionalism. Available at *faculty.maxwell.syr.edu/mdevault/JeremyBrunson.pdf. Accessed on October 19, 2017.*

BLS (Bureau of Labor and Statistics). Occupational Outlook Handbook. Media and Communication > Interpreters and Translators. Available at https://www.bls.gov/ooh/media-and-communication/interpreters-and-translators.htm. September 11, 2018.

Chaffin, D. (1975). Ergonomics guide for the assessment of human static strength. *American Industrial Hygiene Association Journal*. 36(7): 505-511.

Choung, S.D., Park, K.N., Kim, S.H., and Kwon, O.Y. (2016). Comparison of muscle activity of wrist extensors and kinematics of wrist joint during wrist extension in automobile assembly line workers with and without lateral epicondylitis. *Work*. 55(1): 241-247.

Cram, J.R., Kasman, G.S., and Holtz, J. (1998). Introduction to Surface Electromyography. Gaithersburg, MD: Aspen Publishers.

Dean, R., Pollard, R., and Samar, V. (2010). RID research grant underscores occupational health risks: VRS and K-12 settings most concerning. *RID Views*. 27(1): 41-43.

Delisle, A., Lariviere, C., Imbeau, D., and Durand, M.J. (2005). Physical exposure of sign language interpreters: baseline measures and reliability analysis. *European J of App Phys*. 94: 448-460.

Donner, A. (2012). A biomechanical assessment of early and late sign language learners: impact on work style and musculoskeletal disorder risk. Thesis. Rochester Institute of Technology.

Donner, A. Marshall, M., and Mozrall, J. (2013). Biomechanical comparison of American Sign Language interpretation and conversation. Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting.

Donner, A., Marshall, M., and Mozrall, J. (2016). Effects of early exposure to sign language on the biomechanics of interpreting. *J of Interpretation*. 25(1): article 4.

Durand, M-J., Delisle, A., and Imbeau, D. (2001). A program to reduce occupational upper extremity symptoms in sign language interpreters. Step 1: descriptive study. In: Fourth international scientific conference on prevention of work-related musculoskeletal disorders (PREMUS2001), Amsterdam, p 186.

Feuerstein, M. and Fitzgerald, T. E. (1992). Biomechanical factors affecting upper extremity cumulative trauma disorders in sign language interpreters. *J of Occ and Environmental Med*. 34(3): 257-264.

Fisher, S.L., Marshall, M.M., and Woodock, K. (2012). Musculoskeletal disorders in sign language interpreters: a systematic review and conceptual model of musculoskeletal disorder development. *Work*. 42(2): 173-184.

Fischer, S., Johnson, R., Abdoli-Eramaki, M., and Woodcock, K. (2014). Investigating the effect of experience and duration on kinematics during 1 hour of sign language interpreting. *IIE Transactions on Occupational Ergonomics and Human Factors*. 2(2): 60-70, DOI: 10.1080/21577323.2014.948694

Hagberg, M. (1984). Occupational musculoskeletal stress and disorders of the neck and shoulder: a review of possible pathophysiology. *Int Arch Occup Environ Health*. 53:269-278.

Holzbaur, K.R., Delp, S.L., Gold, G.E., and Murray, W.M. (2007). Moment-generating capacity of upper limb muscles in healthy adults. *J of Biomech*. 40(11):2442-2449.

Kroeger, M. (2014). Findings from the video interpreter member section survey on injuries. *RID Views*. 31(1): 42-43.

Mackay, C., Cox, T., Burrows, G., and Lazzerini, T. (1978). An inventory for the measurement of self-reported stress and arousal. *British J of Social and Clin Psychol*. 17: 283-284.

Maller, S., Singleton, J., Supalla, S., and Wix, T. (1999). The development and psychometric properties of the American sign language proficiency assessment (ASL-PA). *J Deaf Studies Deaf Edu*. 4(4):249-269.

Marras, W.S. and Schoenmarklin, R.W. (1993). Wrist motions in industry. *Ergonomics*. 36(4): 341-351.

Mitchell, R.E., Young, T.A., Bachleda, B., and Karchmer, M. (2006) How many people use ASL in the United States? Why estimates need updating. *Sign Language Studies*. 6(3): 306-335.

Podhorodecki, A.D. and Spielholz, N.I. (1993). Electromyographic study of overuse syndromes in sign language interpreters. *Arch Phys Med Rehabil*. 74(3):261-2.

Qin, J., Marshall, M.M., Mozrall, J., and Marschark, M. (2008). Effects of pace and stress on upper extremity kinematic responses in sign language interpreters. *Ergonomics*. 51(3): 274-89.

RID (Registry of Interpreters for the Deaf). Certification Overview. Available at http://www.rid.org/rid-certification-overview/. 2015.

RIT (Rochester Institute of Technology), National Technical Institute for the Deaf. (2005). Cumulative Trauma Disorder. Rochester, NY: RIT Publishers.

Roman, G. and Samar, V. (2015). Workstation ergonomics improves posture and reduces musculoskeletal pain in video interpreters. *J of Interpretation*. 24(1): article 7.

Schoenmarklin, R. W., Marras, W.S. and Leurgans, S.E. (1994). Industrial wrist motions and incidence of hand/wrist cumulative trauma disorders. *Ergonomics*. 37(9): 1449-1459.

Vidt, M.E., Daly, M., Miller, M.E., Davis, C.C., Marsh, A.P., and Saul, K.R. (2012). Characterizing upper limb muscle volume and strength in older adults: A comparison with young adults. *J of Biomech*. 45(2):334-341.

Williamson, A. (2015). Heritage learner to professional interpreter: Who are deaf-parented interpreters and how do they achieve professional status? Master of Arts in Interpreting Studies (MAIS) Theses. *Paper 22*. http://digitalcommons.wou.edu/theses/22

Winter, D.A. (2009). Biomechanics and motor control of human movement. 4th Ed. Hoboken, NJ: John Wiley & Sons, Inc.

Woodcock, K. and Fisher, S. (2008). Occupational Health and Safety for Sign Language Interpreters. (Workplace Safety and Insurance Board Research Advisory Council Grant #0523). Toronto ON: Ryerson University.

CHAPTER 3

COMPOSITE MEASURE OF INJURY-RISK FOR SIGNERS

(SECOND MANUSCRIPT)

Abstract

Self-reported musculoskeletal (MSK) pain ranges from 31-81% in signers. The goal of this study was to take a wider view of previously identified biomechanical tasks that may contribute to injury-risk in signers. A composite injury-risk measure (the modified Strain Index) specific to the biomechanics of signers was created, examined across the entire cohort of signers, and compared across the sub-groups of natives (participants with at least one signing, deaf parent) and non-natives (participants with non-signing, hearing parents). Non-natives were hypothesized to have less favorable (i.e. worse) modified Strain Index (SI) scores when compared to natives. It was also hypothesized that non-natives will have a greater self-report of MSK pain, and that pain will be associated with the modified SI score and its respective biomechanical tasks. Fifteen non-natives (mean age 43.9±11.4 years; 11 deaf/4 hearing; 9 females/6 males; 12 right hand-dominant) and 10 natives (mean age 32.7±10.9 years; 6 deaf/4 hearing; 7 females/3 males; 9 right hand-dominant) used a numeric pain rating scale to rate whether they experience pain while signing. Modified SI methodology was developed and tested from a previously collected dataset. Tasks contained within the modified SI were: 1) duration of exertion, 2) muscle tension, 3) ballistic signing, 4) non-neutral joint angle, and 5) two-dimensional work envelope. Descriptive statistics and normative values from the Occupational Health and Safety for Sign Language Interpreters helped to create categorical ratings and a principal component analysis helped to establish multiplier weights. Participant performance was ranked, and the product of the multipliers for each task created a modified SI score. Modified SI scores across the entire cohort indicated a mild increased injury-risk

(3.71±3.16 points). There were no differences when comparing modified SI scores across the sub-groups of natives (4.70±3.2 points) and non-natives (3.06±3.05 points; p=0.144), however only 30% of all natives and 74% of the non-natives had safe modified SI scores. This was inconsistent with natives' and non-natives' subjective report of MSK pain. Native signers (30%) presented with a lower self-reported MSK pain prevalence than non-natives (40%). Pain intensity while signing was comparable across all natives (0.90±1.91 out of 10) and all non-natives (0.87±1.30), however natives with pain (3.00±2.65) had a slightly greater pain intensity report than non-natives with pain (2.17±1.17). Presence of pain and pain intensity were not associated with the modified SI score, and pain intensity was not associated with any of the biomechanical tasks reflected on the modified SI. Use of the modified SI for signers demonstrates promise as a more global assessment of the biomechanical factors that contribute to injury-risk, however further investigation of non-biomechanical contributors to pain and injury-risk in signers is needed.

Keywords

modified Strain Index; composite measure of injury-risk; native signers; non-native signers; biomechanics

3.1. Introduction

Self-reported musculoskeletal (MSK) pain ranges from 31-81% in signers (Feuerstein and Fitzgerald 1992; Podhorodecki and Spielholz 1993; Kroeger 2014; Roman and Samar 2015). Durand et al. (2001) found 81% of signers reported shoulder pain, 79% reported neck pain, and 74% reported forearm-wrist-hand pain over a 12-month period. Roman and Samar (2015) found 81% of signers experienced varying intensities of MSK pain, reporting the neck with the highest pain prevalence (34%), followed by the wrist-hand (11%), elbow-forearm (10%), and shoulder (10%). Johnson and Feuerstein (2005) found that signers reported symptoms in the neck (73.6%), hand and wrist (69.6%), shoulder (60.0%), low back (48.6%), forearm (44.2%), upper back (44.1%), and/or elbow (33.6%). The preeminent work of Feuerstein and Fitzgerald (1992) on upper extremity biomechanical factors affecting signers informed a text published by the Rochester Institute of Technology, National Technical Institute for the Deaf in Rochester, NY on cumulative trauma disorders (RIT 2005). Since Feuerstein and Fitzgerald's (1992) seminal work, researchers continue to investigate joint position, velocity, acceleration and jerk, rest, muscle tension, and work envelope of the upper extremity (UE), in attempt to discern why signers report such a high prevalence of pain (Delisle et al. 2005; Donner 2012; Donner et al. 2013; Fisher et al. 2014; Donner et al. 2016). While the study of individual biomechanical factors further informs the literature, it is important to keep in mind that work-related musculoskeletal (MSK) disorders in signers are multi-factorial. (Johnson and Feuerstein 2005; Delisle et al. 2007)

Use of ergonomic risk assessment tools as a method of hazard control is associated with reduced MSK disorders and injury-risk in manufacturing production and maintenance workers (Cantley et al. 2014). No composite injury-risk measure presently exists for signers. Various ergonomic risk measures for repetitive high-risk UE tasks have been studied, however many focus on the assessment of industry workers. The Rapid Upper Limb Assessment (RULA) uses diagrams of body postures to evaluate exposure to risk factors and was designed for occupations, like the garment-making, where upper limb disorders are commonly reported (McAtamney and Corlett 1993). The Strain Index (SI) is a multiple task analysis tool used to measure risk of distal upper extremity disorders in industry workers including manufacturing, meat and poultry processing, and manual material handling (Moore and Garg 1995). The concise exposure index (OCRA) is a proposed measure for occupations with repetitive movements of the upper limbs and considers an array of technical actions performed during a shift divided by a corresponding number of recommended actions during that shift, in effort to glean a measure of risk (Occhipinti 1998). The Rapid Entire Body Assessment (REBA) was developed to measure unpredictable work postures in the health care or service industry (Hignett and McAtamney 2000). The quantified version of the American Conference of Governmental Industrial Hygienists Threshold Limit Values for mono-task hand work (ACGIH TLV) estimates a normalized peak force relative to individual's percent maximal voluntary contraction (MVC) divided by their hand activity level measured on a visual analog scale from zero to ten (zero signifying no regular exertions and 10 equating to rapid steady motion; ACGIH 2001). Jones and Kumar (2007) performed a comparison of these five ergonomic risk assessment tools with 15 saw-filers, workers responsible for maintaining the condition of the various saws and knives, from four sawmill facilities. They found that only the SI and OCRA were sensitive to measuring differences across facilities in posture and in measures of frequency, such as hours per day, repetitions per day, and total exposure. Since the SI demonstrated increased sensitivity compared to other ergonomic risk assessment tools (Jones and Kumar 2007), good test-retest reliability (Stephens et al. 2006), the tasks assessed (Moore and Garg 1995) were similar to the ones within this study, a modified SI specific to the biomechanics of signers was created.

The multiple tasks analyzed within the original SI are intensity of exertion, duration of exertion, efforts per minute, hand and wrist posture, speed of work, and duration of task per day (Table 3.1.). Intensity of exertion is an estimate of the strength required to perform the task. Duration of exertion is calculated by measuring the duration of all exertions during the observation period divided by the duration of the observation period and multiplied by 100. Efforts per minute are measured by counting the number of exertions that occur during an observation period divided by the duration of the observation period. Hand and wrist posture estimates the position of the hand or wrist in degrees of motion relative to neutral. Posture estimates for wrist flexion, extension, and ulnar deviation are available. Speed of work is an estimate of how fast the worker is working relative to a previously determined predicted pace. Lastly, duration of the task per day is obtained from plant personnel and measured in hours (Moore and Garg 1995).

Table 3.1. Quantitative and qualitative indicators for the original Strain Index (SI)

task	**rating**				
	1	**2**	**3**	**4**	**5**
intensity of exertion (% of muscle strength)	**<10 light**	**10-29 somewhat hard**	**30-49 hard**	**50-79 very hard**	**≥80 near maximal**
multiplier	**1.00**	**3.00**	**6.00**	**9.00**	**13.00**
duration of exertion (% of total time)	**<10**	**10-29**	**30-49**	**50-79**	**≥80**
multiplier	**0.50**	**1.00**	**1.50**	**2.00**	**3.00**
efforts per minute (minutes)	**<4**	**4-8**	**9-14**	**15-19**	**≥20**
multiplier	**0.50**	**1.00**	**1.50**	**2.00**	**3.00**
hand and wrist posture (°) (i.e. wrist extension)	**0-10 very good**	**11-25 good**	**26-40 fair**	**41-55 bad**	**≥60 very bad**
multiplier	**1.00**	**1.00**	**1.50**	**2.00**	**3.00**
speed of work (observed pace/predicted pace; %)	**≤80 very slow**	**81-90 slow**	**91-100 fair**	**101-115 fast**	**>115 very fast**
multiplier	**1.00**	**1.00**	**1.00**	**1.50**	**2.00**
duration of task per day (hours)	**≤1**	**1-2**	**2-4**	**4-8**	**≥8**
multiplier	**0.25**	**0.50**	**0.75**	**1.00**	**1.50**

Semi-quantitative participant performance during each task of the SI is ranked from one to five. Each rating category is associated with a multiplier. The higher the rating category, the higher the multiplier, and the greater the injury-risk. The product of the respective task multipliers provides a composite measure of injury-risk or what is known as the SI score (i.e. SI score=intensity of exertion multiplier* duration of exertion multiplier*efforts per minute multiplier*hand and wrist posture multiplier*speed of work multiplier*duration of task per day multiplier). A SI score threshold of less than or equal to three is considered safe, greater than or equal to seven is considered hazardous, and greater than three, but less than seven is considered at increased risk (Moore and Garg 1995). For example, the mean SI score for the previously mentioned saw-filers was 14 (Jones and Kumar 2007), thus indicating hazardous work.

The goal of this study was to take a wider view of the previously identified biomechanical tasks that may contribute to injury-risk in signers (Feuerstein and Fitzgerald 1992; RIT 2005). Specifically, this study sought to 1) quantify self-reported MSK pain, 2) modify the SI to make it appropriate for signers by establishing relevant tasks, rating values and multiplier weights, 3) calculate modified SI scores across a cohort of signers and compare across the sub-groups of natives (participants with at least one deaf, signing parent) and non-natives (participants with hearing, non-signing parents) signers, and 4) determine any associations of self-reported MSK pain with modified SI score and its respective biomechanical tasks. Non-natives were hypothesized to have greater self-reported MSK pain than natives. It was also hypothesized that non-natives will have less favorable (i.e. worse) composite injury-risk scores when compared to natives and that self-reported MSK pain will be associated with the modified SI score and its respective biomechanical tasks.

3.2. Materials and methods

This study was approved by the Institute Review Board at Arizona State University.

3.2.1. Participants

Non-natives were defined as having hearing, non-signing parents; natives were defined as having at least one deaf, signing parent. A study population representing the surrounding community of native and non-native signers was obtained. Participants were recruited from local associations (Registry of Interpreters for the Deaf, Association for the Deaf, Children of Deaf Adults International), local schools, colleges and universities, the local Commission for the Deaf and Hard of Hearing, and a local video relay service. Fifteen non-natives (mean age 43.9±11.4 years; 11 deaf/4 hearing; 9 females/6 males; 12 right hand-dominant) and 10 natives (mean age 32.7±10.9 years; 6 deaf/4 hearing; 7 females/3 males; 9 right hand-dominant) were studied (Table 3.2.).

Table 3.2. Participant demographics (n=25).

	natives	**non-natives**	**total**
	n (%)	**n (%)**	**n (%)**
	10 (40)	**15 (60)**	**25 (100)**
age (mean±SD)	**43.9±11.4**	**32.70±10.9**	**39.4±12.3**
hearing status			
hearing	**4 (40)**	**4 (26.7)**	**8 (32)**
deaf	**6 (60)**	**11 (73.3)**	**17 (68)**
sex			
male	**3 (30)**	**6 (40)**	**9 (36)**
female	**7 (70)**	**9 (60)**	**16 (64)**
hand-dominance			
right	**9 (90)**	**12 (80)**	**21 (84)**
left	**1 (10)**	**3 (20)**	**4 (16)**

All participants voluntarily provided written informed consent to participate and were ostensibly healthy, deaf or hearing adult participants greater than or equal to 18 years of age. Fluency of hearing participants was measured by standards of Registry of Interpreters for the Deaf (RID) (RID 2015). Use of sign language as primary language of communication either since birth, or during primary or secondary education equated to fluency for deaf participants. While formal RID certification for deaf participants was not required, one participant was a Certified Deaf Interpreter and others were preparing to become certified. Exclusion criteria included those enrolled in interpreter preparatory or training programs, those with pacemakers, those who were pregnant, and/or those diagnosed with a neuromuscular disorder (e.g. Parkinson’s Disease).

3.2.2. Data collection

During the initial intake, participants were asked to self-report MSK pain using a numeric pain rating scale (Castarlenas et al. 2016; Kahl and Cleland 2005). Not focused to a specific body region, participants rated whether they typically experience pain while signing on a zero to 10 scale (zero signifying no pain and 10 equating to the worst imaginable pain).

The modified SI was developed and tested from previously collected data (refer to Chapter 2). Variables extracted from this data set included values for ‘micro’ rest breaks, muscle tension, ballistic signing, non-neutral joint angle, and work envelope. ‘Micro’ rest breaks are brief periods during the interpreting task when one or both hands are lowered. Muscle tension is prolonged muscle contraction because of an awkward position or a physiological reaction to stress (RIT 2005). Participants watched and interpreted three trials of a seven-minute video source. ‘Micro’ rest breaks and muscle tension were quantified using a 16-channel, wireless Noraxon DTS system (Noraxon, Inc., Scottsdale, AZ) to measure surface electromyography (EMG). Measures were acquired bilaterally from upper, middle compartments of trapezius, anterior, middle compartments of deltoid, and wrist extension-flexion and radial-ulnar deviation muscle groups at 1000Hz. Prior to data collection, a MVC measure was acquired from each muscle compartment using postures that elicit maximal activity (Cram, Kasman, and Holtz 1998). ‘Micro’ rest breaks were identified in the processed EMG signal, measured as a temporal delay greater than or equal to 0.2565 seconds between sequential signs with activation less than 18% MVC over the first minute of the third trial (Delisle and Lariviere 2005), and represented as the total percentage of time spent in rest (%rest). Muscle tension was quantified by taking the mean muscle activation across the first minute of the third trial (%MVC).

Ballistic signing, non-neutral joint angle, and work envelope were quantified using an eight Kestrel camera motion capture system (Motion Analysis Corporation, Santa Rosa, CA), which tracked 9mm reflective surface markers on the upper limb segments during sign production. Ballistic signing is defined as a consistently hard, forceful, or abrupt production of signs. Neutral joint positions are considered the midpoint of opposing motions within the same cardinal plane (e.g. midpoint between wrist flexion-extension in the sagittal plane), therefore non-neutral joint positions are deviations from neutral. Work envelope is defined as the area in which signs can be produced with a minimal amount of exertion (RIT 2005). The Occupational Health and Safety for Sign Language Interpreters describes ideal work envelope as hand movement in front of the chest within a boundary of 25cm^2 (Feuerstein and Fitzgerald 1992; Woodcock and Fischer 2008). Prior to beginning the interpretation, a static recording was obtained for use in marker definition. A total of 23 surface markers were placed bilaterally on the second and fifth metacarpophalangeal (MCP) joints, the radial and ulnar styloids, medial and lateral epicondyles, posterolateral acromions, sternoclavicular joints, spinous process of the seventh cervical vertebra, xiphoid process, anterior midpoint of the proximal UEs, anterior midpoint of the forearms, and an offset marker on the left posterior shoulder. By way of tracking the dominant second MCP joint surface marker, ballistic signing was measured as the dominant absolute maximum resultant instantaneous linear segment acceleration from the start to the stop of the sign for 'again' (Fig. 3.1.a) Inverse kinematics using the C3D model builder module of the Motion Monitor (Innovative Sports Training, Inc., Chicago, IL) software calculated the average wrist flexion-extension position during the participants' production of the sign for 'principal' (Fig. 3.1.b) and the absolute value was used as the primary outcome for non-neutral joint position. Work envelope was measured across the first minute of the third trial by tracking the maximum minus the minimum linear motion of the dominant second MCP joint surface marker relative to the ipsilateral posterolateral acromion surface marker along the respective two-dimensional (x-, medial to lateral, and z-, superior to inferior, axes) planes.

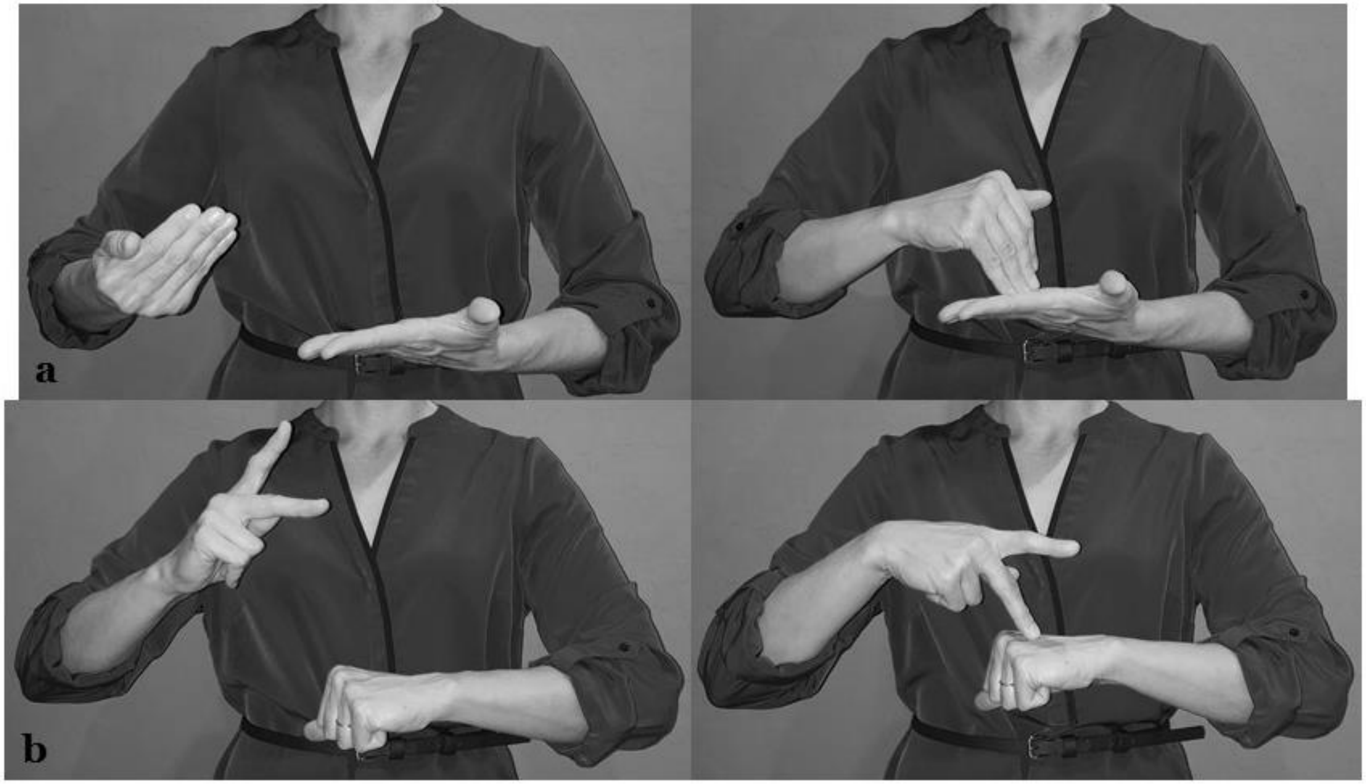

Figure 3.1. a) Sign for ‘again.’ b) Sign for ‘principal.’

3.2.3. Data processing

Self-reported MSK pain was compiled as a dichotomous variable (participants with pain had a rating greater than zero and participants without pain had a rating equal to zero). Pain intensities were also complied across the entire cohort of signers, and across the sub-groups of natives and non-natives.

Upon comparing the tasks contained within the original SI to the proposed tasks to be contained within the modified SI for signers, the inverse of 'micro' rest breaks (%total - %rest time), muscle tension, ballistic signing, and non-neutral joint angle were analogous, respectively, to duration of exertion, intensity of exertion, speed of work, and hand and wrist posture. Work envelope along the x-axis and work envelope along the z-axis were newly introduced tasks in to the modified SI, as efforts per minute or duration of task per day were not assessed.

Like the original SI, participant performance during each task of the modified SI was ranked one to five. Each rating category was assigned a multiplier. The higher the rating category, the higher the multiplier, and the greater the injury-risk. The product of the respective task multipliers was calculated, providing a composite injury-risk measure or a modified SI score (i.e. modified SI score=duration of exertion multiplier*muscle tension multiplier*ballistic signing multiplier*non-neutral joint angle multiplier*work envelope along the x-axis multiplier*work envelope along the z-axis multiplier; Table 3.3.). The same thresholds used for the original SI (less than or equal to three considered as safe, greater than or equal to seven considered as hazardous, greater than three, but less than seven indicating increased risk; Moore and Garg 1995) were used to deduce the indications of the modified SI score for signers.

Table 3.3. Example procedure for calculating the modified SI score for signers.

	duration of exertion (%)	muscle tension (%)	ballistic signing (m/s^2)	non-neutral joint angle (°)	work envelope	
					along the x-axis (cm)	along the z-axis (cm)
raw data	**31.44**	**25.31**	**34.21**	**36.62**	**49.47**	**75.54**
rating	**2**	**3**	**3**	**3**	**3**	**5**
multiplier	**0.75**	**1**	**1.75**	**0.75**	**2**	**3**
modified SI score calculation	**0.75*1*1.75*0.75*2*3=5.91 (signifying at increased risk)**					

3.2.4. Data analysis

With statistical significance ($\alpha<0.05$), all statistical analyses were performed using SPSS (v.24, IBM Corp., Armonk, NY).

Modified SI rating values for signers

Descriptive statistics from the total sample and norms from the Occupational Health and Safety for Sign Language Interpreters (Woodcock and Fisher 2008) were used to determine the categorical rating values for each biomechanical task in the modified SI.

Modified SI multiplier weights for signers

Upon achieving normality assumption (Shapiro-Wilk $p\geq0.05$), principal component analysis was performed to determine multiplier weights in the modified SI. A scree plot was created with the principal components along the x-axis and the eigenvalues along the y-axis. The bend in the curve on the scree plot helped to determine the number of principal components to consider for analysis. A cut-off for the significance of the factor loadings was set to ±0.6. Only the factor loadings within the principal components that explained the most amount of variance were considered when establishing the multiplier weights. Analysis of the constructs surrounding each principal component was beyond the scope of this work.

Additionally, in effort to confirm correct assignment of multiplier weights in the modified SI, Spearman correlation analyses were performed between self-reported pain intensities while signing and the respective biomechanical tasks.

Comparison of modified SI scores for natives and non-natives

A Mann Whitney U test was used to analyze group differences in the modified SI score between native and non-native signers.

Association of modified SI scores for signers with self-report of MSK pain

Spearman correlation analyses were used to evaluate associations between presence of self-reported MSK pain and modified SI scores, and intensities of self-reported MSK pain and modified SI scores.

3.3. Results

3.3.1. Musculoskeletal pain

Self-reported MSK pain was examined across the entire cohort of signers and compared across the sub-groups of non-natives and natives. Nine out of 25 signers (36%), three out of 10 (30%) natives, and six out of 15 (40%) non-natives self-reported pain (Fig. 3.2.). The (mean±SD) reported pain intensities for all signers, all natives, and all non-natives were 0.88±1.54, 0.90±1.91, and 0.87±1.30 out of 10, respectively. The reported pain intensities for signers, natives, and non-natives with reported MSK pain were 2.44±1.67, 3.00±2.65, and 2.17±1.17 out of 10, respectively.

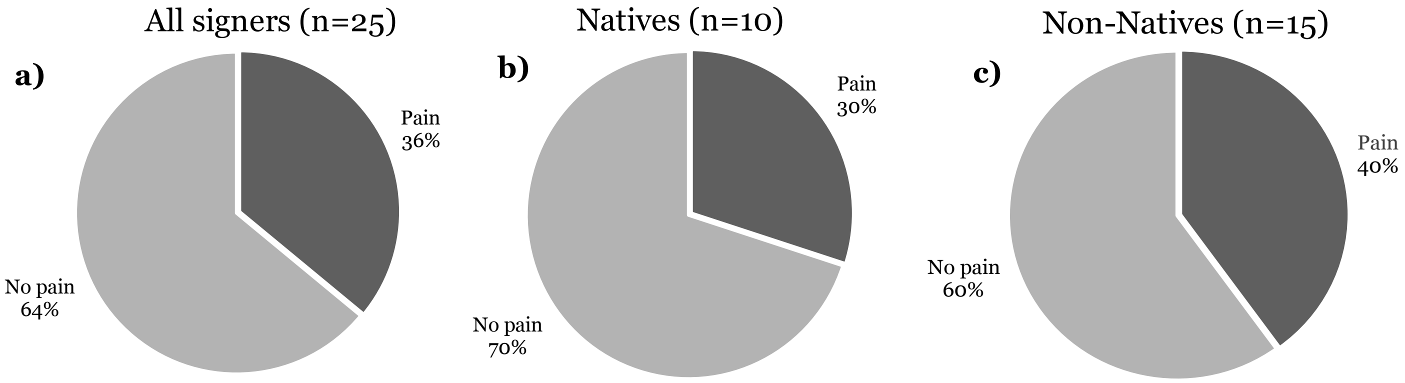

Figure 3.2. Self-reported musculoskeletal pain in a) all signers, b) native, and c) non-native signers.

3.3.2. Modified SI rating values for signers

Descriptive statistics (mean±SD) were gathered for each biomechanical task (Table 3.4.). The variability of muscle tension was greatly impacted by participants who presented with muscle tension values in a non-physiological range of 227-1122 %MVC. It is presumed there was increased noise from the participants' forearm, wrist, and hand segments contacting their bodies or the wrist MVCs were elicited incorrectly, neither of which could be corrected for by filtering and smoothing the surface EMG data; therefore, descriptive data for muscle tension are presented here with these outliers removed.

Table 3.4. Descriptive statistics (mean±SD) from the total sample for ‘micro’ rest breaks, duration of exertion, muscle tension, ballistic signing, non-neutral joint angle, and two-dimensional work envelope.

biomechanical task	
‘micro’ rest breaks (%rest)	**68.79±15.02**
duration of exertion (%total-%rest)	**31.21±15.02**
muscle tension (%MVC)	**18.46±7.43**
ballistic signing (m/s^2)	**24.19±9.49**
non-neutral joint angle (°)	**33.74±12.17**
work envelope along the x-axis (medial-lateral; cm)	**50.42±12.90**
work envelope along the z-axis (superior-inferior; cm)	**48.19±11.75**

Based on these findings and the norms from the Occupational Health and Safety for Sign Language Interpreters (Woodcock and Fisher 2008), the categorical ratings from one to five for the modified SI for signers were established (Table 3.7.).

3.3.3. Modified SI multiplier weights for signers

Upon entering the variables of duration of exertion (the inverse of 'micro' rest breaks), muscle tension (intensity of exertion), ballistic signing (speed of work), non-neutral joint angle (hand and wrist posture), and the new task of work envelope along its two-dimensional x- (medial-lateral) and z- (superior-inferior) axes into a principal component analysis, the scree plot (Fig. 3.3.) indicated that principal components one through three were worthy of analysis as they collectively explained 83.99% of the total variance (Table 3.5.).

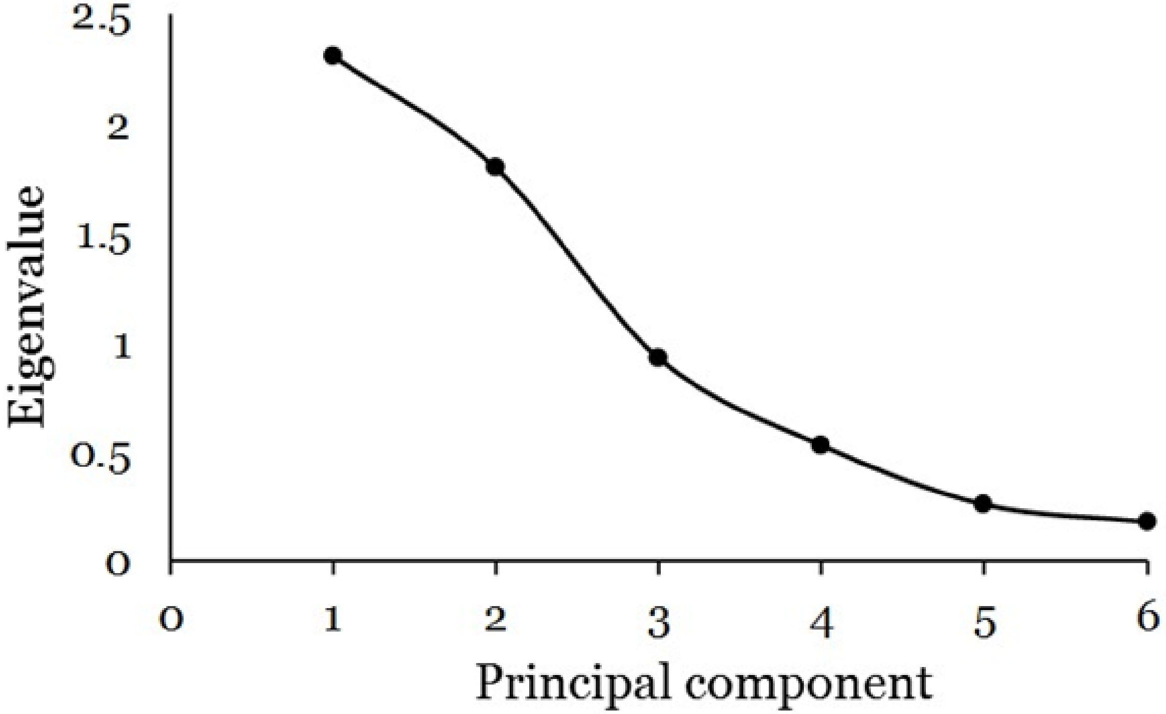

Figure 3.3. Scree plot for the biomechanical factors of duration of exertion, muscle tension, ballistic signing, non-neutral joint angle, and work envelope along the x- (medial-lateral) and z- (superior-inferior) axes.

Table 3.5. Eigenvalues for each principal component and percent of variance explained.

principal component	**eigenvalue**	**percent variance explained (%)**
1	**2.31**	**38.43**
2	**1.80**	**30.05**
3	**0.93**	**15.51**
4	0.53	8.76
5	0.26	4.25
6	0.18	3.01

Table 3.6. Factor loadings for principal components one through three.

biomechanical task	**principal component**		
	1	**2**	**3**
duration of exertion	0.07	**0.95**	-0.03
muscle tension	0.26	**0.90**	-0.04
ballistic signing	**0.77**	-0.30	-0.11
non-neutral joint angle	0.37	0.03	**0.93**
work envelope along the x-axis	**0.84**	-0.07	-0.03
work envelope along the z-axis	**0.89**	-0.02	-0.24

The first principal component explained 38.43% of the variance (Table 3.5.) and the highest factor loadings, respectively, were work envelope along the z-axis, work envelope along the x-axis, and ballistic signing (Table 3.6.). The second principal component explained 30.05% of the variance (Table 3.5.) and the highest factor loadings, respectively, were duration of exertion and muscle tension (Table 3.6.). Lastly, the third principal component explained 15.51% of the variance (Table 3.5.) and its highest factor loading was non-neutral joint angle (Table 3.6.). Based on these findings, modified SI multipliers were assigned from greatest to least amount of weight as follows: work envelope along the z-axis, work envelope along the x-axis, ballistic signing, duration of exertion, muscle tension, and non-neutral joint angle.

Spearmen correlation analyses demonstrated no association between self-reported MSK pain intensity during the initial intake and duration of exertion (r=0.267; p=0.196), self-reported MSK pain intensity and muscle tension (r=0.105; p=0.625), self-reported MSK pain intensity and ballistic signing (r=0.103; p=0.652), self-reported MSK pain intensity and non-neutral joint angle (r=-0.144; p=0.494), self-reported MSK pain intensity and work envelope along the x-axis (r=0.001; p=0.997), and self-reported MSK pain intensity and work envelope along the z-axis (r=-0.061; p=0.774). In support of the reflected factor loadings from the principal component analysis, work envelope along the x-axis with work envelope along the z-axis (r=0.773; p=0.001), ballistic signing with work envelope along the z-axis (r=0.552; p=0.004), and duration of exertion with muscle tension (r=0.775; p=0.001) were associated.

Based on the factor loadings, the correlational analyses, and previous multiplier framework of the original SI (Moore and Garg 1995), the multiplier weights for each biomechanical task in the modified SI for signers were established (Table 3.7.).

Table 3.7. Modified SI for signers.

	rating				
biomechanical task	**1**	**2**	**3**	**4**	**5**
muscle tension (%MVC)	**<9.99 very light**	**10-19.99 light**	**20-29.99 medium**	**30-39.99 somewhat hard**	**≥40 hard**
multiplier	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**
duration of exertion (%total - %rest)	**<19.99**	**20-39.99**	**40-59.99**	**60-79.99**	**≥80**
multiplier	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**
ballistic signing (m/s^2)	**<14.99 very slow**	**15-24.99 slow**	**25-34.99 fair**	**35-44.99 fast**	**≥45 very fast**
multiplier	**0.75**	**1.25**	**1.75**	**2.25**	**2.75**
non-neutral joint angle (°)	**<9.99 very good**	**10-24.99 good**	**25-39.99 fair**	**40-54.99 bad**	**≥55 very bad**
multiplier	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**
work envelope along the x-axis (cm)	**<24.99**	**25-39.99**	**40-54.99**	**55-69.99**	**≥70**
multiplier	**1.00**	**1.50**	**2.00**	**2.50**	**3.00**
work envelope along the z-axis (cm)	**<24.99**	**25-39.99**	**40-54.99**	**55-69.99**	**≥70**
multiplier	**1.00**	**1.50**	**2.00**	**2.50**	**3.00**

3.3.4. Examination of modified SI scores across the entire cohort of signers, and between natives and non-natives

Overall (n=25), modified SI scores ranged from 0.75 to 10.94 points and on average (mean±SD; 3.71±3.16 points), indicated a mild increased injury-risk. The modified SI scores for 14 out of 25 (56%) signers were considered safe (less than or equal to three), seven out of 25 (28%) were at increased risk (greater than three, but less than seven), and four out of the 25 (16%) were hazardous (greater than or equal to seven; Fig. 3.4.). Forty-four percent of the modified SI scores for signers in this overall participant sample reflected an increased injury-risk.

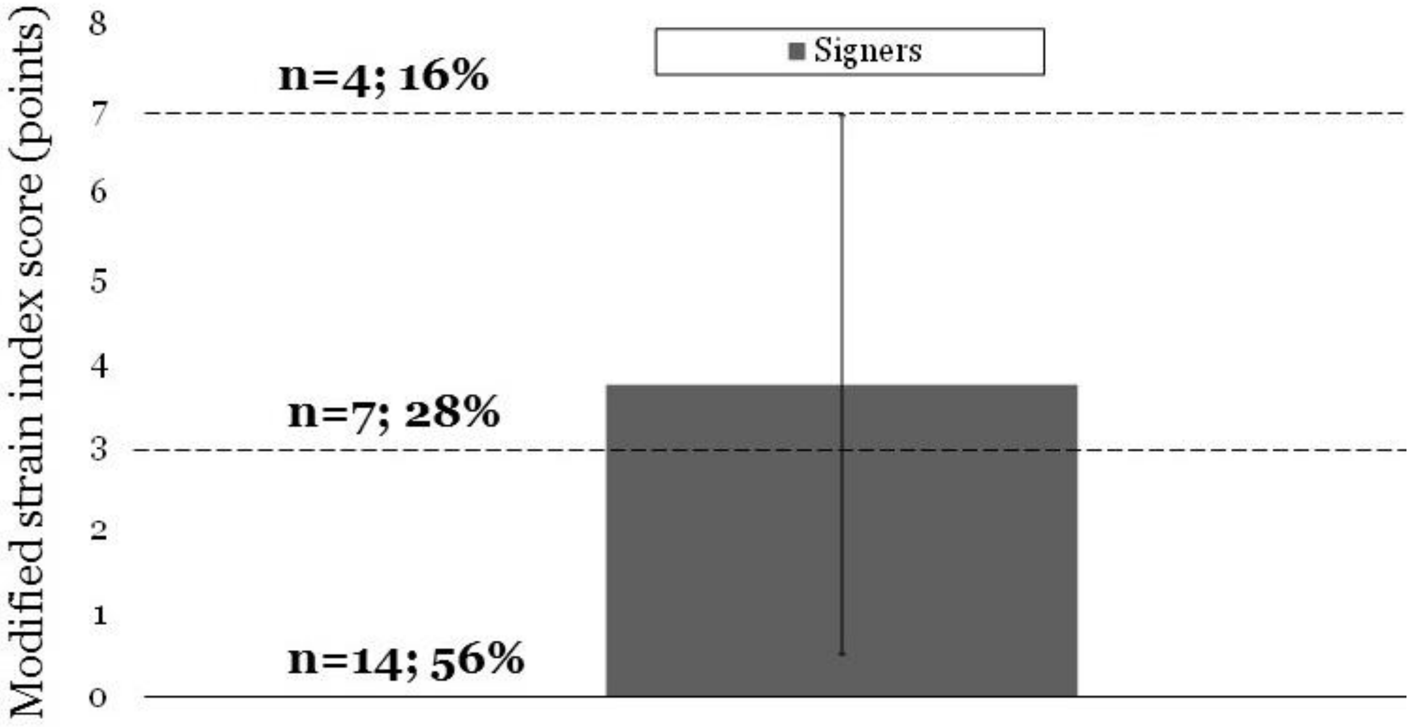

Figure 3.4. Mean (±SD) modified SI scores for signers (n=25) with modified SI score thresholds indicated by the dashed lines (less than or equal to three considered as safe, greater than or equal to seven considered as hazardous, and greater than three, but less than seven considered at increased risk).

There was no statistical difference in the modified SI scores (mean±SD) of natives (4.70±3.2 points) and non-natives (3.06±3.05 points; $p=0.144$). Of the natives, the modified SI scores of three out of the 10 (30%) were considered safe, five out of the 10 (50%) were at increased risk, and two out of the 10 (20%) were hazardous. Of the non-natives, the modified SI scores of 11 out of the 15 (73%) were considered safe, two out of the 15 (13%) were at increased risk, and two out of the 15 (13%) were hazardous (Fig. 3.5.). Seventy percent of the natives' and 26% of the non-natives' modified SI scores reflected an increased injury-risk.

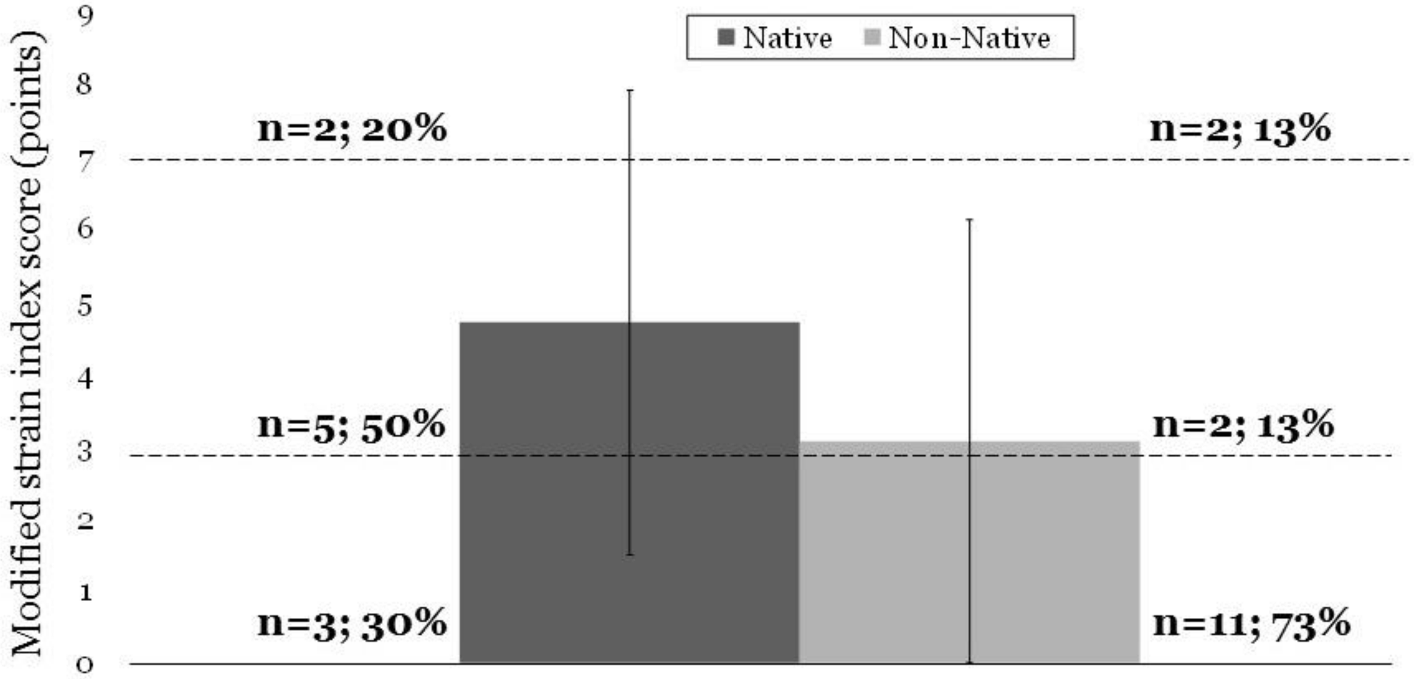

Figure 3.5. Mean (±SD) modified SI scores for natives (n=10) and non-natives (n=15) with modified SI score thresholds indicated by the dashed lines (less than or equal to three considered as safe, greater than or equal to seven considered as hazardous, and greater than three, but less than seven considered at increased risk).

3.3.5. Association of modified SI scores for signers with self-reported MSK pain

Spearmen correlation analysis demonstrated no association between presence of self-reported of MSK pain and modified SI score (r=0.087; p=0.680), nor was there an association between intensity of self-reported MSK pain and modified SI score (r=-0.035; p=0.869). On average, natives reporting pain had a pain intensity of 3.00 out of 10 and a modified SI score of 5.60 points indicating at increased risk and non-natives reporting pain had a pain intensity of 2.17 out of 10 and a modified SI score of 2.54 points indicating safe practice (Fig. 3.6.).

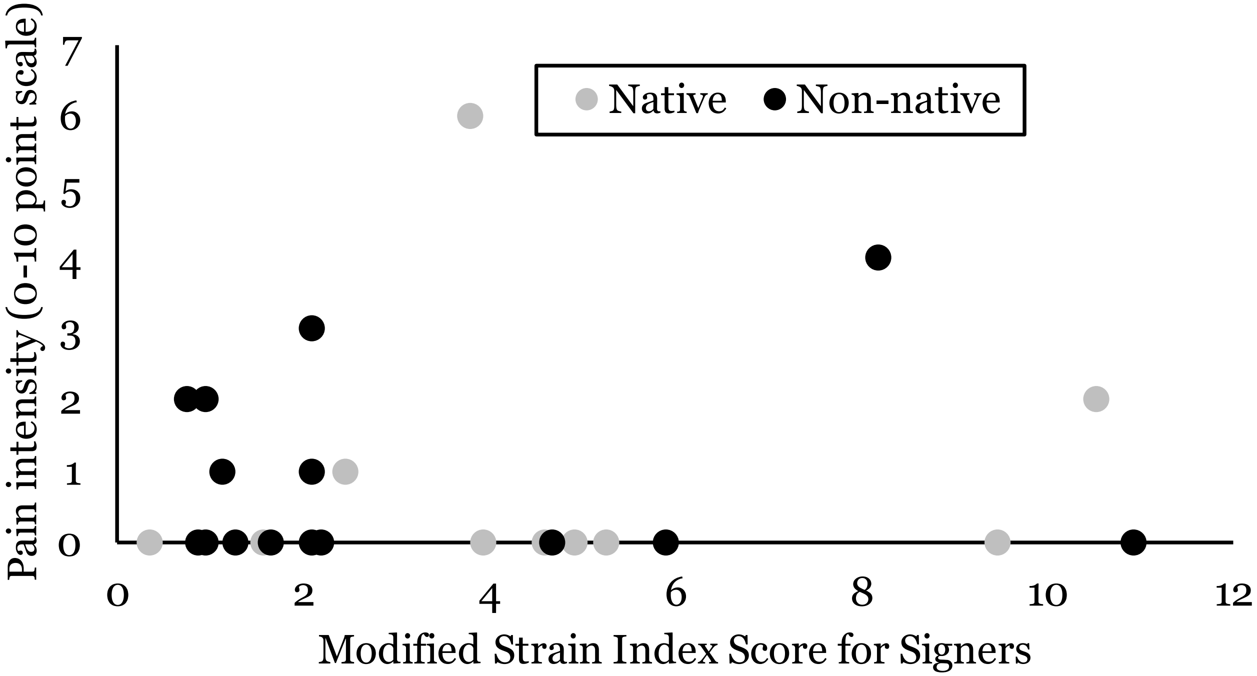

Table 3.6. Musculoskeletal pain intensities and modified SI scores of natives and non-natives.

3.4. Discussion

The overall 36% prevalence of self-reported MSK pain across all signers in this study was fairly consistent with the 31-81% reported in the literature (Feuerstein and Fitzgerald 1992; Podhorodecki and Spielholz 1993; Kroeger 2014; Roman and Samar 2015). There was a 55% and 81% prevalence of pain reported by the signers studied in the work of Feuerstein and Fitzgerald (1992) and Roman and Samar (2015), respectively. In Podhorodecki and Spielholz (1993), 48.5% of signers had pain with zero percent of the deaf-parented (native or deaf participants signing since childhood) sub-group and 67% of the non-native sub-group reporting pain. The deaf-parented and non-native sub-groups in Podhorodecki and Spielholz's (1993) work were, respectively, comparable with this study's native and non-native signers. Based on the findings from Podhorodecki and Spielholz (1993), greater MSK pain from non-natives than natives was anticipated in this study. Forty percent of non-natives reported MSK pain from sign language use compared to 30% of natives. While this was consistent with the past literature (Podhorodecki and Spielholz 1993) and clinical observation of non-natives presenting with greater self-reported MSK pain over natives, the disparity between was expected to be greater than the 10% observed. Misalignment in the categorization of natives and non-natives across studies may explain the observed difference being smaller than anticipated.

Across the entire cohort of signers in this study, pain intensity while signing on the numeric pain rating scale was (mean±SD) 0.88±1.54 out of 10 points at initial intake and this was comparable to the 10cm visual analogue scale measuring baseline pain of all interpreters (0.78±1.25cm) in the work of Feuerstein and Fitzgerald (1992). The sub-grouping of interpreters working with pain and interpreters working without pain or minimal/transient discomfort in Feuerstein and Fitzgerald's (1992) work and this study's non-native and native signers were, respectively, comparable. A rating of greater than zero was considered pain in this work, therefore signers without pain reported a zero for pain intensity and signers with pain reported a pain intensity of 2.44±1.67 out of 10 points during the initial intake. Natives with pain reported a pain intensity of 3.00±2.65 out of 10 points and non-natives with pain reported a pain intensity of 2.17±1.17 out of 10 points. The interpreters working with no pain or minimal/transient discomfort in Feuerstein and Fitzgerald's (1992) work had slightly higher pain intensities at baseline (0.46±1.4cm) and post-interpreting (0.65±1.7cm) than the signers without pain (0 out of 10 points) in this work, however were comparable to the reported pain of 0.90±1.91 out of 10 points while signing across all natives. The interpreters working with pain in Feuerstein and Fitzgerald's (1992) work had comparable pain intensities at baseline (1.09±1.1cm) and post-interpreting (3.44±2.0cm) with the signers with pain (2.44±1.67 points), natives with pain (3.00±2.65 points), and non-natives with pain (2.17±1.17 points) in this work; however, the same could not be said when comparing interpreters with pain at baseline and post-interpreting in the work of Feuerstein and Fitzgerald (1992) with all non-natives (0.87±1.30 points) in this work. This begs to question the potentially unfair assumption that non-native signers will report similarly to interpreters with pain. This study's hypothesis was that non-natives will have greater reported MSK pain than natives. Indeed, the prevalence of self-reported pain was greater in non-natives (40%) than natives (30%), however pain intensity was slightly greater in all natives (0.90±1.91 points) and natives with pain (3.00±2.65 points) compared to all non-natives (0.87±1.30 points) and non-natives with pain (2.17±1.17 points).

Feuerstein and Fitzgerald (1992) also considered associations across all interpreters between post-interpreting pain and the biomechanical factors of rest, hand and wrist deviations, work envelope, and pace of finger and hand movements. This study did not find any association between presence of pain or pain intensity with the modified SI score, nor were associations found between pain intensity with any of the biomechanical tasks reflected on the modified SI. Feuerstein and Fitzgerald (1992), however, found a significant correlation between post-interpreting pain with hand and wrist deviations ($r=0.47$; $p<0.01$) indicating that a greater pain intensity after interpreting was associated with greater hand and deviations. This significant association in the work of Feuerstein and Fitzgerald (1992) highlights the importance of hand and wrist deviations, unlike in this study's correlation analysis of pain with non-neutral joint angle where no association was found and in the principal component analysis where non-neutral joint angle helped to explain the least amount of variance. These differences can likely be explained by the differences in quantifying hand and wrist deviations and non-neutral joint angle across the two studies. Feuerstein and Fitzgerald (1992) used a visual assessment method to measure collective deviations from optimal wrist extension-flexion, radial-ulnar deviation, and forearm pronation-supination position across a 20-minute interpreting task, whereas this work considered the average wrist flexion-extension position from the start to the stop of the sign for 'principal.' The sign for 'principal' was elected for analysis, rather than average wrist flexion-extension and radial-ulnar deviation joint position across the first minute of the trial or the entire trial because, anecdotally, 'principal' allows for easy observation of gross deviations from neutral wrist position in signers who tend to sign with more hand and wrist deviations.

The lack of association between presence of pain and pain intensity with the modified SI score, and between pain intensity and any of the biomechanical tasks was not in support of this study's hypotheses. The assessment of various biomechanical tasks to explain a signer's report of MSK pain, rather than an individual task, was a step in the right direction toward developing a more global assessment of pain; however, this lack of association confirms that pain encompasses other variables in addition to a signer's biomechanics. The non-native and deaf-parented sub-groups' subjective pain and presence of objective abnormalities from Podhorodecki and Spielholz (1993) helps to inform the discrepancies found between the subjective report of MSK pain in signers and the objective findings on the modified SI in this work. Podhorodecki and Spielholz (1993) used motor and sensory nerve conduction studies to investigate the presence of symptomatic and occult ulnar and median nerve entrapment. There was no significant difference in the action potential latencies between the interpreter (n=33; 24 non-native and nine deaf-parented) and control (n=21) groups, however within the interpreter group, five participants had findings suggestive of mild median neuritis (carpal tunnel syndrome), three were suggestive of mild ulnar neuritis (guyon's canal syndrome), and two participants had both conditions. Seven of the 24 non-natives (29%) had mild electrophysiological abnormalities while 67% conveyed a subjective report pain (16 of 24) and three of the nine deaf-parented participants (33%) demonstrated mild electrophysiological abnormalities while zero percent (zero of the nine) reported pain. Unlike the greater abnormal electrophysiological in non-natives reported by Podhorodecki and Spielholz (1993), more natives had at risk or hazardous objective findings on the modified SI compared to non-natives in this work. Of the four non-natives who had at risk or hazardous modified SI scores, one reported MSK pain and of the seven natives who had at risk or hazardous modified SI scores, two reported MSK pain. The remaining signers with reported MSK pain all had safe modified SI scores. Forty-four percent of the overall participant sample had at risk modified SI scores and 36% reported pain. While these measures were not associated, the composite injury-risk measure seemed to be in line with the reported pain prevalence. Seventy percent of the native sub-group had at risk or hazardous modified SI scores while only 30% reported pain, and 26% of non-native sub-group had an at risk or hazardous modified SI scores while 40% reported pain. These findings were consistent with Podhorodecki and Spielholz (1993). Abnormal pathoanatomical (nerve conduction studies) and at risk or hazardous biomechanical (modified SI) objective findings were less apt to translate to pain in natives, whereas abnormal pathoanatomical and biomechanical objective findings, or lack thereof were more apt to translate to pain in non-natives. Use of the modified SI for signers as a more global assessment of the biomechanical factors that contribute to injury-risk demonstrates promise, however further investigation of non-biomechanical contributors to pain and injury-risk in signers is needed.

A few studies have helped to enhance our understanding of multifactorial pain in signers. Johnson and Feuerstein (2005) surveyed interpreters (n=1398) to glean their perspectives on what initiates or exacerbates symptoms related to UE MSK disorders in signers. Thirty percent felt that job content and task, and 28% felt that personal and social factors played a role in the initiation or exacerbation of symptoms, whereas only nine to 12% felt that interpreting style, ergonomic factors, and health had implications. The findings from the work of Johnson and Feuerstein (2005) support further examination of the influence of job content and task, and personal and social factors on report of MSK pain in signers. In the work of Delisle et al. (2007), seven sign language interpreters with baseline pain participated in a cross-over design study receiving a stress-management intervention for seven sessions and a workstyle intervention for five sessions, each over the course of nine weeks with a seven-week washout period in between. The stress management intervention provided an emphasis on reducing psychological distress and promoting healthy living habits, whereas the workstyle intervention aimed at reducing the number and amplitude of signs, hand impacts, and promoting micro-breaks. Both interventions demonstrated potential to reduce pain, therefore supporting the broader influences on a signer’s pain. Since one intervention was not more effective than the other on reducing pain outcomes, the authors suggest integrating both as preventative strategies with signers. Interesting to note, and potentially worthy of future investigation, that the workstyle intervention may be more efficient and cost-effective at reducing pain, as it did not meet for as many sessions as the stress management intervention but had similar effectiveness in reducing pain.

From the principal component analysis, the modified SI multipliers were assigned from greatest to least amount of weight as follows: work envelope along the z-axis, work envelope along the x-axis, ballistic signing, duration of exertion, muscle tension, and non-neutral joint angle. The biomechanical factors studied by Feuerstein and Fitzgerald (1992) can be ranked from greatest to least amount of statistical significance as follows: pace of finger and hand movement ($t=3.24$; $p<0.01$; interpreters with pain: 6.1±1.7 and interpreters without pain: 3.8±2.0cm on a 10cm visual analogue scale), rest breaks per minute ($t=2.23$; $p<0.05$; interpreters with pain: 0.8±1.0 and interpreters without pain: 1.7±1.0 rest breaks per minute), hand and wrist deviations ($t=2.18$; $p<0.05$; interpreters with pain: 10.2±3.4 and interpreters without pain: 7.5±3.3 deviations per minute), and excursions from optimal work envelope ($t=2.11$; $p<0.05$; interpreters with pain: 2.7±3.1 and interpreters without pain: 1.0±0.8 excursions per minute). In this study, work envelope along the z- and x-axes demonstrated the greatest significance when determining injury-risk and thus, were assigned the greatest multiplier weights. In Feuerstein and Fitzgerald (1992), while work envelope was significantly different across sub-groups, it was the least significant when compared to pace of finger and hand movement, rest, and hand and wrist deviations. Pace of finger and hand movement, total frequency of high-impact hand contacts, and smoothness of finger and hand movements are all analogous to ballistic signing. In this study, ballistic signing was ranked with the second highest multiplier weight, whereas in the work of Feuerstein and Fitzgerald (1992), pace of finger and hand movement had the highest significance, and total frequency of high-impact hand contacts and smoothness of finger and hand movements were not significant. In this study, rest and muscle tension were ranked with the third highest multiplier weight, whereas in the work of Feuerstein and Fitzgerald (1992) rest was ranked second and muscle tension was not analyzed. As previously mentioned, a greater pain intensity post-interpreting was previously associated with greater hand and deviations (Feuerstein and Fitzgerald 1992), however that was not realized here. There was a lack of association between self-reported MSK pain intensity and any of the biomechanical tasks. Non-neutral joint angle demonstrated the greatest factor loading in the third principal component helping to explain 15.51% of the variance compared to the 68.48% variance explained by the other four variables; therefore, it was ranked with the lowest multiplier weight. In the work of Feuerstein and Fitzgerald (1992), hand and wrist deviations were ranked third out of seven factors. More work is needed to determine which of the previously identified biomechanical considerations unique to signers (Feuerstein and Fitzgerald 1992; RIT 2005) has the greatest significance in determining injury-risk and differentiating between signers with and without pain.

Since the modified SI was developed and tested from previously collected data, there were a few limitations from that work (refer to Chapter 2). Additionally, there were a few limitations to this study regarding the small sample size. These data were powered to detect wrist acceleration as the primary outcome for ballistic signing based on the work of Qin et al. (2008) and not to determine differences in self-reported MSK pain and modified SI scores. Thus, the reader is cautioned about using these limited data to derive generalizations about pain intensities and composite injury-risk scores as the study may be underpowered. While normality assumption was achieved for all biomechanical tasks reflected on the modified SI, use of a principal component analysis is typically done with a much greater sample size and with disassociated factors. The recommended ratio of participants to factors is 10 to one (Kerlinger 1986), indicating a sample of 60 participants for this statistical analysis. Knowing this, a principal component analysis was pursued as a means to offer a more rigorous approach for discerning multiplier weights when compared with a correlation analysis alone. The generalizability of the modified SI for signers would be strengthened by a larger sample with a broader array of pain intensities.

3.5. Conclusions

Self-reported MSK pain and injury-risk in signers are multifactorial. When determining the injury-risk of signers based on their performance of various biomechanical tasks, use of the modified SI for signers as a semi-quantitative composite measure of injury-risk demonstrates promise. The following tasks contained within the modified SI reflect the biomechanics unique to signers: 1) duration of exertion (the inverse of 'micro' rest breaks), 2) muscle tension, 3) ballistic signing, 4) non-neutral joint angle, and 5) two-dimensional work envelope. The multipliers for work envelope along the z- and x-axes, ballistic signing, rest and muscle tension, and non-neutral joint angle were weighted from highest to lowest. Like the original SI (Moore and Garg 1995), participant performance on each biomechanical task is ranked from one to five and the product of the respective task multipliers is calculated providing a modified SI score. Modified SI scores less than or equal to three are considered safe, greater than or equal to seven are considered hazardous, and greater than three, but less than seven are considered at increased risk.

The modified SI scores across the entire cohort indicated only a mild increased injury-risk with 56% of signers demonstrating a safe performance (modified SI score less than or equal to three points). There were no statistically significant differences when comparing across the sub-groups of natives and non-natives, however only 30% of all natives, and 74% of the non-natives had modified SI scores indicating safe practice. This was inconsistent with natives' and non-natives' subjective report of MSK pain. Native signers presented with a lower self-reported MSK pain prevalence than non-natives.

While self-reported pain intensities (zero signifying no pain and 10 equating to the worst imaginable pain) when signing were comparable across all natives and all non-natives, natives with pain had a slightly greater pain intensity report than non-natives with pain. Presence of pain and pain intensity were not associated with the modified SI score, and pain intensity was not associated with any of the biomechanical tasks reflected on the modified SI.

Assessment of biomechanical factors using the modified SI for signers is a step in the right direction toward addressing prevention of pain in signers, however future work should consider additional correlates of pain such as psychological distress, healthy living habits (Delisle et al. 2007), job content and task, and personal and social factors (Johnson and Feuerstein 2005). Further investigation on the efficiency and effectiveness of stress management or workstyle interventions for pain prevention may also help to further enhance the health of signers. More work is needed to determine which of the previously identified biomechanical considerations unique to signers (Feuerstein and Fitzgerald 1992; RIT 2005) have the greatest significance in determining injury-risk and differentiating between signers with and without pain. The modified SI for signers demonstrates that previously established ergonomic risk assessment tools can be curtailed to the unique needs of different study populations. Use of this measure in additional research on signers will help to improve its ability to implicate injury-risk.

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3.7. *References*

American Conference of Governmental Industrial Hygienists (ACGIH). (2001). Threshold limit values for chemical substances and physical agents & biological exposure indices. Cincinnati, OH, USA: ACGIH.

Cantley, L.F., Taiwo, O.A., Galusha, D., Barbour, R., Slade, M.D., Tessier-Sherman, B., and Cullen, M.R. (2014). Effect of systematic ergonomic hazard identification and control implementation on musculoskeletal disorder and injury risk. *Scand J Work Environ Health*. 40(1): 57-65.

Castarlenas, E., de la Vega, R., Jensen, M.P., and Miro J. (2016). Self-report measures of hand pain intensity: current evidence and recommendations. *Hand Clinics*. 32(1):11-19.

Cram, J.R., Kasman, G.S., and Holtz, J. (1998). Introduction to Surface Electromyography. Gaithersburg, MD: Aspen Publishers.

Delisle, A., Durand, M-J., Imbeau, D, and Lariviere, C. (2007). The effects of two interventions on persistent pain: a multiple single-case study among sign language interpreters. *Inter J Indus Ergo*. 37(2):111-123.

Delisle, A., Lariviere, C., Imbeau, D., and Durand, M.J. (2005). Physical exposure of sign language interpreters: baseline measures and reliability analysis. *European J of App Phys*. 94: 448-460.

Donner, A. (2012). A biomechanical assessment of early and late sign language learners: impact on work style and musculoskeletal disorder risk. Thesis. Rochester Institute of Technology.

Donner, A. Marshall, M., and Mozrall, J. (2013). Biomechanical comparison of American Sign Language interpretation and conversation. Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting.

Donner, A., Marshall, M., and Mozrall, J. (2016). Effects of early exposure to sign language on the biomechanics of interpreting. *J of Interpretation*. 25(1): article 4.

Durand, M-J., Delisle, A., and Imbeau, D. (2001). A program to reduce occupational upper extremity symptoms in sign language interpreters. Step 1: descriptive study. In: Fourth international scientific conference on prevention of work-related musculoskeletal disorders (PREMUS2001), Amsterdam, p 186.

Feuerstein, M. and Fitzgerald, T. E. (1992). Biomechanical factors affecting upper extremity cumulative trauma disorders in sign language interpreters. *J of Occ and Environmental Med*. 34(3): 257-264.

Fischer, S., Johnson, R., Abdoli-Eramaki, M., and Woodcock, K. (2014). Investigating the effect of experience and duration on kinematics during 1 hour of sign language interpreting. *IIE Transactions on Occupational Ergonomics and Human Factors*. 2(2): 60-70, DOI: 10.1080/21577323.2014.948694

Hignett, S. and McAtamney, L. (2000). Rapid entire body assessment (REBA). *Appl Ergo*. 31: 201-205.

Johnson, W.L. and Feuerstein, M. (2005). An interpreter's interpretation: sign language interpreters' view of musculoskeletal disorders. *J of Occup Rehab*. 15(3): 401-415.

Jones, T. and Kumar, S. (2007). Comparison of ergonomic risk assessments in a repetitive high-risk sawmill occupation: saw-filer. *International J of Indust Ergo*. 37: 744-753.

Kahl, C. and Cleland, J. (2005). Visual analogue scale, numeric pain rating scale and the McGill pain questionnaire: an overview of psychometric properties. *Physical Therapy Reviews*. 10: 123–128.

Kerlinger, F.N. (1986). Foundations of Behavioral Research. 3rd Ed. New York, NY: Holt, Rinehart and Winston, Inc.

Kroeger, M. (2014). Findings from the video interpreter member section survey on injuries. *RID Views*. 31(1): 42-43.

McAtamney, L. and Corlett, E.N. (1993). RULA: a survey method for the investigation of work-related upper limb disorders. *Appl Ergo*. 24(2): 91-99.

Moore, J.S. and Garg, A. (1995). The strain index: a proposed method to analyze jobs for risk of distal upper extremity disorders. *Am Indus Hygiene Assoc J*. 56: 443-458.

Occhipinti, E. (1998). OCRA: a concise index for the assessment of exposure to repetitive movements of the upper limbs. *Ergonomics*. 41(9): 1290-1311.

Podhorodecki, A.D. and Spielholz, N.I. (1993). Electromyographic study of overuse syndromes in sign language interpreters. *Arch Phys Med Rehabil*. 74(3):261-2.

Qin, J., Marshall, M.M., Mozrall, J. and Marschark, M. (2008). Effects of pace and stress on upper extremity kinematic responses in sign language interpreters. *Ergonomics*. 51(3): 274-89.

RIT (Rochester Institute of Technology), National Technical Institute for the Deaf. (2005). Cumulative Trauma Disorder. Rochester, NY: RIT Publishers.

Roman, G. and Samar, V. (2015). Workstation ergonomics improves posture and reduces musculoskeletal pain in video interpreters. *J of Interpretation*. 24(1): article 7.

Stephens, J.P., Vos, G.A., Stevens, E.M., and Moore, J.S. (2006). Test-retest reliability of the Strain Index. *Appl Ergo*. 37:275-281.

Woodcock, K. and Fisher, S. (2008). Occupational Health and Safety for Sign Language Interpreters. (Workplace Safety and Insurance Board Research Advisory Council Grant #0523). Toronto ON: Ryerson University.

CHAPTER 4

CONCLUSION

The goal of this study was twofold: 1) to examine differences in biomechanical measures between natives and non-natives and 2) upon creating a composite measure of injury-risk unique to signers, to compare differences in scores between natives and non-natives.

Upon examining the differences in biomechanical measures between natives and non-natives, this study used dynamometry for strength, EMG for quantification of 'micro' rest breaks and muscle tension, and optical motion capture for ballistic signing, non-neutral joint angle and work envelope. There were no significant differences in shoulder and wrist strength between native and non-native signers. Natives had more 'micro' rest breaks and less muscle tension for non-dominant upper trapezius compared to non-natives across the first minute of the trial. Natives also had less non-dominant upper trapezius muscle tension compared to non-natives from the start to the stop of the signs for 'again' and 'principal.' An inverse relationship exists between rest and tension, and more significance was demonstrated on the non-dominant rather than the dominant side. Given these results, if a signer exhibits reduced rest, then the observer should assess for increased tension and vice versa. Also, biomechanists and clinicians alike should not be surprised by non-dominant symptom presentation in non-natives. For ballistic signing, no significant differences were found in the resultant or along the respective 3D planes for maximum instantaneous linear segment acceleration, or for segment force between natives and non-natives from the start to the stop of the sign for 'again.' However, native, hearing, and left-hand dominant participants all demonstrated greater maximum linear segment jerk along the y-axis. Additionally, hearing participants demonstrated greater maximum acceleration along the y-axis and greater maximum resultant jerk than deaf participants. Slightly longer arm lengths in natives may have influenced their greater jerk compared to non-natives, however the shorter arm lengths of hearing or left-hand dominant participants did not help explain their greater ballistic measures compared to their deaf and right-hand dominant counterparts. Of the 10 natives in this study, four were hearing and only one was left-hand dominant. While this further sub-categorization of this study's small sample does not permit generalization, a slight concern regarding injury-risk for hearing natives who are left-hand dominant presents itself in these ballistic signing results. For non-neutral joint angle, natives and deaf participants had more wrist flexion-extension ROM when producing the sign for 'principal.' Deaf participants also had more wrist radial-ulnar deviation ROM and greater minimum wrist flexion-extension position than hearing participants. Male participants demonstrated a greater absolute average wrist flexion-extension joint position than females. The findings for ballistic signing and non-neutral joint angle beckon future examination across the hearing status (hearing versus deaf) of signers, rather than hearing acquisition status (native versus non-native). For work envelope, there was a greater maximum and minimum position along the x-axis, a greater minimum position along the z-axis, and a marginally greater work envelope along the z-axis for natives. For right-hand dominant participants, there was a greater work envelope along the z-axis, and a greater maximum position along the x- and y-axes. Slightly longer arm lengths, although not significant, in natives and right-hand dominant participants may have influenced their greater work envelope measures compared to their non-native and left-hand dominant counterparts. Left-hand dominant participants demonstrated a greater minimum position along the x-axis and younger participants had a greater minimum position along the z-axis. There is some thought that a larger work envelope is safer and less injury-risk prone because it relies on the larger muscle groups of the shoulders and elbows, and therefore induces less repetitive motion to the smaller muscle groups of the wrists and hands. Since natives are known to have less pain from signing when compared to non-natives, their larger work envelope, greater non-neutral joint angle, and increased jerk while signing may somehow have a counterintuitive effect on self-preservation against injury-risk.

It is important to keep in mind that work-related MSK disorders in signers are multi-factorial (Johnson and Feuerstein 2005; Delisle et al. 2007). The examination of individual biomechanical factors of signers made it possible to inform a composite measure of injury-risk, which was a critical development of this study. The Strain Index (SI) is one of many ergonomic risk assessment tools that measure the risk of UE disorders. Since the SI demonstrated increased sensitivity compared to other ergonomic risk assessment tools (Jones and Kumar 2007), good test-retest reliability (Stephens et al. 2006), and the tasks assessed (Moore and Garg 1995) were similar to the ones within this study, a modified SI specific to the biomechanics of signers was created. Duration of exertion (or the inverse of 'micro' rest breaks; %total - %rest time), muscle tension (%MVC), ballistic signing (resultant instantaneous linear segment acceleration; m/s^2), non-neutral joint angle (mean wrist flexion-extension position; °), and work envelope along the x- (medial-lateral; cm) and z- (superior-inferior; cm) axes were the proposed tasks for the modified SI for signers. Descriptive statistics and normative values from the Occupational Health and Safety for Sign Language Interpreters (Woodcock and Fisher 2008) were used to create categorical rankings and a principal component analysis provided multiplier weights. Modified SI multipliers were assigned from greatest to least amount of weight as follows: work envelope along the z-axis, work envelope along the x-axis, ballistic signing, duration of exertion, muscle tension, and non-neutral joint angle. Participant performance during each task was ranked from one to five. Each rating category was associated with a multiplier. The higher the rating category, the higher the multiplier, and the greater the injury-risk. The product of the respective task multipliers was calculated to provide a composite injury-risk measure or a modified SI score. The same thresholds used for the original SI (less than or equal to three is considered safe, greater than or equal to seven is considered hazardous, greater than three, but less than seven is considered at increased risk; Moore and Garg 1995) were used to deduce the indications of the modified SI score.

Modified SI scores across the entire cohort ranged from 0.75 – 10.94 points and on average, indicated a mild increased injury-risk. Fifty-six percent of all signers had modified SI scores demonstrating safe practice. There were no differences when comparing modified SI scores across the sub-groups of natives and non-natives, however only 30% of all natives, and 74% of the non-natives had modified SI scores demonstrating safe practice. This was inconsistent with natives' and non-natives' subjective report of MSK pain. Natives presented with a lower self-reported MSK pain prevalence than non-natives. Although self-reported pain intensities (zero signifying no pain and 10 equating to the worst imaginable pain) while signing were comparable across all natives and all non-natives, natives with pain had a slightly greater pain intensity (3.00 out of 10) report than non-natives with pain (2.17 out of 10). At risk or hazardous modified SI scores were less apt to translate to self-reported pain in natives, whereas at risk or hazardous modified SI scores, or lack thereof were more apt to translate to self-reported pain in non-natives. There were no associations between pain intensities and the biomechanical tasks within the modified SI, nor were there any associations between presence of pain and modified SI score or pain intensity and modified SI score.

The observational cross-sectional design limits the ability to detect any cause and effect relationships between language acquisition status and UE biomechanics, and biomechanical tasks and self-reported MSK pain and injury-risk. There was a dichotomy between how the biomechanical outcomes were quantified in this research as compared to previous work. For example, dynamometry, EMG, and optical motion capture were used, whereas past work has used dynamometry, visual observation with ratings of frequency and scale, biaxial unilateral and bilateral electrogoniometers, and electromagnetic motion capture. Inconsistent methodology used to collect biomechanical measures makes it difficult to compare across studies. This study used EMG-based rest to quantify 'micro' rest breaks, where other studies have used kinematic-based rest via electrogoniometric and motion capture data. This study used linear segment acceleration to quantify ballistic signing, whereas other work has used angular. And lastly, this study defined natives as having at least one deaf, non-signing parent, where another study defined native as being deaf and signing since childhood regardless of the parents' hearing status.

Participant sampling targeted native and non-native signers, but did not match age, gender, or hearing status across sub-group comparisons. The typical demographic for professional interpreters is approximately 75% female to 25% male (Brunson 2017). While the groups in this study were unbalanced between males and females (Table 2.1.), these group distributions are consistent with the distribution of sex in the interpreting profession.

The aim of this study was to compare differences between natives and non-natives. Participants were encouraged to interpret the video source into their own sign language and not simply echo the signs produced by the presenter. Although the third trial was analyzed for purposes of inducing a training effect, those participants who were not sign language interpreters may have felt more stressed or uncomfortable with this methodology, thereby affecting the investigators ability to gather a natural capture their sign language expression. Measuring participant stress before and after the experiment may have helped to taper the influence of interpreting the video source, or comparing across the task of conversing, rather than the task of interpreting may have served as a better approach in capturing differences between natives and non-natives. Additionally, comparing native and non-native sub-groups based on hearing status would offer additional insight into the biomechanical considerations unique to signers and should be considered in future investigations.

This study was powered to detect wrist acceleration as the primary outcome for ballistic signing, thus other analyses of UE strength, ‘micro’ rest breaks, muscle tension, non-neutral joint angle, work envelope, self-reported MSK pain, and modified SI scores may be underpowered. These data can now be used to power and design future studies exploring similar factors. Assessment of scapular muscle strength was not conducted in the current work. This would be a useful correlate measure to the significant tension and rest found in the non-dominant trapezius. Electromyography measures targeted the entire shoulder complex, whereas dynamometry targeted only the glenohumeral joint. Future work should include assessments of scapular muscle strength to further explore the implications of scapular musculature found in this study.

Investigators used RID certification to ascertain sign language fluency for hearing participants, but no standard assessment was used to determine sign language fluency for deaf participants. Use of sign language as a primary language of communication either since birth, or during primary or secondary education was deemed sufficient evidence to prove fluency for deaf participants, but this could introduce possible discrepancies in future comparisons. Future work will include use of American Sign Language Proficiency Assessment to assess individual ability to communicate using sign language as a standard fluency measure with all hearing and deaf participants (Maller et al. 1999).

While normality assumption was achieved for all biomechanical tasks reflected on the modified SI, use of a principal component analysis is typically done with a much greater sample size and with disassociated factors. The recommended ratio of participants to factors is 10 to one (Kerlinger 1986), indicating a sample of 60 participants for this statistical analysis. Knowing this, a principal component analysis was pursued as a means to offer a more rigorous approach for discerning multiplier weights when compared with a correlation analysis alone. The generalizability of the modified SI for signers would be strengthened by a larger sample with a broader array of pain intensities.

This was the first study since the seminal work of Feuerstein and Fitzgerald (1992) to use current instrumentation and offer a comprehensive analysis of all the previously identified UE biomechanics unique to signers. This work fulfilled the lacking precedent for quantification and analysis of muscle tension and work envelope in signers. Two- and three-dimensional work envelope were explored and norms for work envelope in signers while standing were provided. Results made it possible to inform the first available composite measure of injury-risk specific to the biomechanical tasks of signers. Creation of the modified SI demonstrated that previously established ergonomic risk assessment tools for industry workers can be curtailed to the unique needs of different study populations.

More work is needed to determine which previously identified biomechanical consideration unique to signers (Feuerstein and Fitzgerald 1992; RIT 2005) has the greatest significance in determining injury-risk and differentiating between signers with and without pain. The findings from this study support further investigation of non-biomechanical contributors to pain and injury-risk in signers. Assessment of multiple biomechanical tasks to explain a signer’s report of MSK pain, rather than an individual task, is a step in the right direction toward developing a more global assessment of pain. Use of the modified SI for signers as a composite measure of injury-risk holds promise as a tool to predict injury-risk in signers. However, the lack of association between self-reported MSK reported pain in this sample and the modified SI clearly suggests that pain encompasses other variables in addition to a signer’s biomechanics. Future studies should include psychological distress, healthy living habits, job content and task, and personal and social factors (Delisle et al. 2007; Johnson and Feuerstein 2005) as additional variables on a composite measure of injury-risk for signers.

REFERENCES

ADA (American with Disabilities Act). (2014). Effective communication. Available at https://www.ada.gov/effective-comm.htm. Accessed on October 13, 2018.

Benjamini, Y. and Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J Royal Statistical Society*, Series B (Methodological). 57(1): 289-300.

Benjamini, Y. and Yekutieli, D. (2001). The control of the false discovery rate in multiple testing under dependency. *Annals of Stats*. 29(4): 1165-1188.

Bishop, M. and Hicks, S. (2008). Coda talk: Bimodal discourse among hearing, native signers. In M. Bishop & S. Hicks (Eds.), Hearing, mother father deaf: Hearing people in deaf families (pp. 54-98). Washington, DC: Gallaudet University Press.

BLS (Bureau of Labor and Statistics). Occupational Outlook Handbook. Media and Communication > Interpreters and Translators. Available at https://www.bls.gov/ooh/media-and-communication/interpreters-and-translators.htm. September 11, 2018.

CAD (Canadian Association of the Deaf). (2015). Statistics on Deaf Canadians. Available at http://cad.ca/issues-positions/statistics-on-deaf-canadians/. Accessed on December 24. 2017.

Cantley, L.F., Taiwo, O.A., Galusha, D., Barbour, R., Slade, M.D., Tessier-Sherman, B., and Cullen, M.R. (2014). Effect of systematic ergonomic hazard identification and control implementation on musculoskeletal disorder and injury risk. *Scand J Work Environ Health*. 40(1): 57-65.

Castarlenas E., de la Vega R., Jensen M.P. and Miro J. (2016). Self-report measures of hand pain intensity: current evidence and recommendations. *Hand Clinics*. 32(1):11-19.

Chaffin, D. (1975). Ergonomics guide for the assessment of human static strength. *Amer Indus Hyg Assoc J*. 36(7): 505-511.

Choung, S.D., Park, K.N., Kim, S.H., and Kwon, O.Y. (2016). Comparison of muscle activity of wrist extensors and kinematics of wrist joint during wrist extension in automobile assembly line workers with and without lateral epicondylitis. *Work*. 55(1): 241-247.

Compton, S. (2014). American Sign Language as a Heritage Language. In T.G. Wiley, J.K. Peyton, D. Christian, S.C. Moore, & N. Liu (Eds.), Handbook of Heritage, Community, and Native American Languages in the United States: Research, Policy, and Educational Practice. New York: Routledge and Center for Applied Linguistics.

Dean, R., Pollard, R. and Samar, V. (2010). RID research grant underscores occupational health risks: VRS and K-12 settings most concerning. *RID Views*. 27(1): 41-43.

Delisle, A., Durand, M-J., Imbeau, D, and Lariviere, C. (2007). The effects of two interventions on persistent pain: a multiple single-case study among sign language interpreters. *Inter J Indust Ergo*. 37(2):111-123.

Delisle, A., Lariviere, C., et al. (2005). Physical exposure of sign language interpreters: baseline measures and reliability analysis. *European J of App Phys*. 94: 448-460.

Donner, A. (2012). A biomechanical assessment of early and late sign language learners: impact on work style and musculoskeletal disorder risk. Thesis. Rochester Institute of Technology.

Donner, A. Marshall, M. and Mozrall, J. (2013). Biomechanical comparison of American Sign Language interpretation and conversation. Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting.

Donner, A., Marshall, M and Mozrall, J. (2016). Effects of early exposure to sign language on the biomechanics of interpreting. *J of Interpretation*. 25(1): article 4.

Durand, M-J., Delisle, A. and Imbeau, D. (2001). A program to reduce occupational upper extremity symptoms in sign language interpreters. Step 1: descriptive study. In: Fourth international scientific conference on prevention of work-related musculoskeletal disorders (PREMUS2001), Amsterdam, p 186.

Feuerstein, M. and Fitzgerald, T.E. (1992). Biomechanical factors affecting upper extremity cumulative trauma disorders in sign language interpreters. *JOM*. 34(3):257-264.

Fisher, S.L., Marshall, M.M. and Woodcock, K. (2012). Musculoskeletal disorders in sign language interpreters: a systematic review and conceptual model of musculoskeletal disorder development. *Work*. 42(2): 173-184.

Fischer, S., Johnson, R., Abdoli-Eramaki, M. and Woodcock, K. (2014). Investigating the effect of experience and duration on kinematics during 1 hour of sign language interpreting. *IIE Transactions on Occupational Ergonomics and Human Factors*. 2(2): 60-70, DOI: 10.1080/21577323.2014.948694

Fisher, S. and Woodcock, K. (2012). A cross-sectional survey of reported musculoskleletal pain, disorders, work volume and employment situation among sing language interpreters. *Int J of Indus Ergo*. 42:335-340.

Forstall, Richard L. Population of States and Counties of the United States: 1790 to 1990, U.S. Bureau of the Census, Washington, D.C., 1996.

Gallaudet University Library. (2016). Sign languages of the world by country. Available at http://libguides.gallaudet.edu/content.php?pid=114804&sid=991940. Accessed on December 24, 2017.

Hagberg, M. (1984). Occupational musculoskeletal stress and disorders of the neck and shoulder: a review of possible pathophysiology. *Int Arch Occup Environ Health*. 53:269-278.

Hardyck, C. and Petrinovich, L.F. (1977). Left-handedness. *Psych Bulletin*. 84(3):385-404.

Holzbaur, K.R., Delp, S.L., Gold, G.E., Murray, W.M. (2007). Moment-generating capacity of upper limb muscles in healthy adults. *J of Biomech*. 40(11): 2442-2449.

Johnson, W.L. and Feuerstein, M. (2005). An interpreter's interpretation: sign language interpreters' view of musculoskeletal disorders. *J of Occup Rehab*. 15(3): 401-415.

Jones, T. and Kumar, S. (2007). Comparison of ergonomic risk assessments in a repetitive high-risk sawmill occupation: saw-filer. *Int J of Indust Ergo*. 37: 744-753.

Kahl, C. and Cleland, J. (2005). Visual analogue scale, numeric pain rating scale and the McGill pain questionnaire: an overview of psychometric properties. *Physical Therapy Reviews*. 10: 123–128.

Kerlinger, F.N. (1986). Foundations of Behavioral Research. 3rd Ed. New York, NY: Holt, Rinehart and Winston, Inc.

Kroeger, M. (2014). Findings from the video interpreter member section survey on injuries. *RID Views*. 31(1): 42-43.

Mackay, C., Cox, T., Burrows, G., and Lazzerini, T. (1978). An inventory for the measurement of self-reported stress and arousal. *British J of Social and Clin Psychol*. 17: 283-284.

Mapson, R. (2014.) Who are we? *Newsli*. 87: 13-15.

Marras, W.S. and Schoenmarklin, R.W. (1993). Wrist motions in industry. *Ergonomics*. 36(4): 341-351.

Mitchell, R.E. (2005). Can you tell me how many deaf people there are in the United States? *J of Deaf Studies and Deaf Edu*. 11(1):112-119. doi: 10.1093/deafed/enn004

Mitchell, R.E. and Karchmer, M. (2004). Chasing the mythical ten percent: Parental hearing status of deaf and hard of hearing students in the United States. *Sign Language Studies*. 4(2):138-163.

Mitchell, R.E., Young, T.A., Bachleda, B. and Karchmer, M.A. (2006). How many people use ASL in the United States? Why estimates need updating. *Sign Language Studies*. 6(3):306-335.

Moore, J.S. and Garg, A. (1995). The strain index: a proposed method to analyze jobs for risk of distal upper extremity disorders. *Am Indust Hyg Assoc J*. 56: 443-458.

Podhorodecki, A.D. and Spielholz, N.I. (1993). Electromyographic study of overuse syndromes in sign language interpreters. *Arch Phys Med Rehabil*. 74(3): 261-2.

Qin, J., Marshall, M.M., Mozrall, J. and Marschark, M. (2008). Effects of pace and stress on upper extremity kinematic responses in sign language interpreters. *Ergonomics*. 51(3): 274-89.

RID (Registry of Interpreters for the Deaf). About RID. Available at https://www.rid.org/about-rid/. Accessed on December 26, 2017.

RID (Registry of Interpreters for the Deaf). (2016). Annual Report. Available at https://www.rid.org/2016-annual-report/. Accessed on December 26, 2017.

RID (Registry of Interpreters for the Deaf). (2015). Certification Overview. Available at http://www.rid.org/rid-certification-overview/. Accessed on December 26, 2017.

RID (Registry of Interpreters for the Deaf). (2009). Fiscal Year 2009 RID Annual Report. Available at https://drive.google.com/file/d/0B3DKvZMflFLdblhzaE5ibXFvNkk/view. Accessed on December 26, 2017.

RIT (Rochester Institute of Technology), National Technical Institute for the Deaf. Cumulative Trauma Disorder. Rochester, NY: RIT Publishers, 2005.

Roman, G. and Samar, V. (2015). Workstation ergonomics improves posture and reduces musculoskeletal pain in video interpreters. *J of Interpretation*. 24(1): article 7.

Schein, J.D. and Delk, M.T. (1974). The deaf population of the United States. Silver Spring, MD: National Association of the Deaf.

Schoenmarklin, R. W., Marras, W.S. and Leurgans, S.E. (1994). Industrial wrist motions and incidence of hand/wrist cumulative trauma disorders. *Ergonomics*. 37(9): 1449-1459.

Stephens, J.P., Vos, G.A., Stevens, E.M., and Moore, J.S. (2006). Test-retest reliability of the Strain Index. *Appl Ergo*. 37:275-281.

USCB (United States Census Bureau). (2017). Population. Available at https://www.census.gov/topics/population.html. Accessed on December 27, 2017.

Vidt, M.E., Daly, M., Miller, M.E., Davis, C.C., Marsh, A.P., Saul, K.R. (2012). Characterizing upper limb muscle volume and strength in older adults: A comparison with young adults. *J of Biomech*. 45(2): 334-341.

Williamson, A. (2015). Heritage learner to professional interpreter: Who are deaf-parented interpreters and how do they achieve professional status? Master of Arts in Interpreting Studies (MAIS) Theses. Paper 22. http://digitalcommons.wou.edu/theses/22

Winter, D.A. (2009). Biomechanics and motor control of human movement. 4th Ed. Hoboken, NJ: John Wiley & Sons, Inc.

Woodcock, K. and Fisher, S. (2008). Occupational Health and Safety for Sign Language Interpreters. (Workplace Safety and Insurance Board Research Advisory Council Grant #0523). Toronto ON: Ryerson University.

APPENDIX A

REVIEW OF LITERATURE

Little work has examined all the biomechanical considerations identified by NTID and whether they contribute to the high incidence of UE MSK injury in singers. The preeminent work of Feuerstein and Fitzgerald (1992) examined the work style and demands of 29 interpreters (24 females and five males) at NTID. Based upon clinical examination, these participants were sub-grouped into those working with pain (n=16; 55%) and those working with no pain or minimal discomfort (n=13; 45%). On a zero to 10cm visual analogue scale, baseline pain intensity was (mean±SD) 1.09±1.1cm and 0.46±1.4cm, and post-interpreting pain intensity was 3.44±2.0cm and 0.65±1.7cm for interpreters with and without pain, respectively. An isokinetic dynamometer was used to measure wrist and forearm ROM and endurance, and video recordings of the participants while interpreting were used to measure the biomechanical variables of rest breaks per minute, high impact hand contacts, pace and smoothness of finger and hand movements, hand and wrist deviations from neutral, and work envelope excursions. There were no flexibility or endurance differences between sub-groups, however their findings suggest that interpreters with pain have fewer rest breaks, and more deviations from neutral joint position, lateral excursions from the work envelope and rapid finger and hand movements.

Feuerstein and Fitzgerald (1992) provides the only known comparable study to have quantified muscle tension and work envelope in signers. Muscle tension was quantified by using a zero to 10cm visual analogue scale (zero signifying no muscle tension and 10 equating to extreme muscle tension). Unfortunately, since the inter-rater reliability was low, it was not included in their statistical analysis making this study the first to analyze muscle tension in signers. Work envelope, defined as the optimal signing area with minimal UE exertions (RIT 2005), was measured by aligning a transparent grid over the video-viewing monitor with the participant's midline and level with their bilateral shoulders. Work envelope deviations were defined as lateral excursions beyond the width of the participant’s shoulders and hips. The ROM (ratio of flexibility comparing involved to uninvolved UE at 180°/second) and endurance (ratio of effort comparing involved to uninvolved UE at 180°/second) in this prior work can be compared to the isometric joint moments (N) gathered in this study because both were measured using an isokinetic dynamometer. The zero to 10cm visual analogue scale in this prior work and the zero to 10 numeric pain rating scale used in this study allow for a comparison of pain prevalence and pain intensities across studies, as well.

In a study of 33 sign language interpreters (24 non-native and nine native signers) who were age-matched with 21 non-signing controls, Podhorodecki and Spielholz (1993) used motor and sensory nerve conduction studies to investigate the presence of symptomatic and occult ulnar and median nerve entrapment. Forty-nine percent (16 of 33 total sample) of the sign language interpreters reported UE pain ranging in duration. Pain intensities were not reported. All interpreters reporting pain were non-native signers. There was no significant difference in the action potential latencies between the interpreter and control groups, however within the interpreter group, five participants had findings suggestive of mild median neuritis (carpal tunnel syndrome), three were suggestive of mild ulnar neuritis (guyon’s canal syndrome), and two participants had both conditions. Twenty-nine percent of non-native signers (seven of 24 non-native signers) had mild electrophysiological abnormalities while 67% conveyed a subjective report of pain (16 of 24) and 33% of native signers (three of nine native signers) demonstrated mild electrophysiological abnormalities while zero percent (zero of nine) reported pain.

Delisle et al. (2005) used surface EMG and a biaxial dominant wrist goniometer to quantify physical exposure measures of nine sign language interpreters during three to four sessions of a 30 to 90-minute educational interpreting task. EMG measured bilateral upper trapezius frequency of rest and time at rest, and the biaxial wrist goniometer assessed dominant wrist flexion-extension and radial-ulnar deviation ROM, and angular velocity and acceleration. Descriptive statistics for mean overall ROM (95th – 5th percentile), maximum (90th percentile) angular velocity and acceleration, and median (50th percentile) angular velocity and acceleration of wrist flexion-extension and radial-ulnar deviation are conveyed in Table A.1. The mean overall wrist flexion-extension and radial-ulnar deviation ROM measures in Delisle et al.'s (2005) work indicate high-cumulative trauma disorder risk, and the median wrist flexion-extension and radial-ulnar deviation angular velocity and acceleration indicate low-risk (Marras and Schoenmarklin 1993). Mean time at rest for the dominant upper trapezius was 8.1% and non-dominant upper trapezius was 12.4%. Gender, height, weight, and a range of experience were all reported, but not native or non-native status.

Table A.1. Mean dominant ROM, angular velocity and acceleration across all conditions in the work of Delisle et al. (2005) compared to high- and low-cumulative trauma disorder risk (Marras and Schoenmarklin 1993).

		high-risk	**low-risk**
overall ROM (95th – 5th percentile; °)			
wrist flexion-extension	66	35.63	27.95
wrist radial-ulnar deviation	36	23.65	17.64
maximum angular velocity (90th percentile; °/sec)			
wrist flexion-extension	145		
wrist radial-ulnar deviation	74		
median angular velocity (50th percentile; °/sec)			
wrist flexion-extension	26	42.2	28.7
wrist radial-ulnar deviation	14	25.9	17
maximum angular acceleration (90th percentile; °/sec^2)			
wrist flexion-extension	1694		
wrist radial-ulnar deviation	851		
median angular acceleration (50th percentile; °/sec^2)			
wrist flexion-extension	329	824	494
wrist radial-ulnar deviation	171	494	301

Qin et al. (2008) used biaxial bilateral electrogoniometers to measure the effects of speaker pace and stress on wrist flexion-extension and radial-ulnar deviation position, angular velocity and acceleration, and time spent in wrist pause of 12 full-time sign language interpreters. All participants were right-hand dominant. Each performed a slow- and fast-paced interpreting segment of equal duration and was assigned to a stressed or non-stressed sub-group based on difference between their baseline and post-interpreting Stress-Arousal Checklist (Mackay et al. 1978) scores. There was no significant main effect of pace or stress on mean wrist position. Qin et al. (2008) did not compare wrist position values with the established high- and low-risk values established by Marras and Schoenmarklin (1993). There were significant differences between fast- and slow-paced groups for mean velocity on all motions of the right and left wrist flexion-extension, but not left radial-ulnar deviation. The fast-paced group demonstrated greater mean acceleration and less mean time spent in wrist pause across all wrist planes of motion compared to the slow-paced group. There was significant change between stressed and non-stressed groups for mean velocity on all motions of the left wrist, however no significant difference in the right wrist motions. The stressed group demonstrated greater left wrist flexion-extension acceleration, but no change in left wrist radial-ulnar deviation and right wrist motion acceleration. Greater involvement of the non-dominant hand only was attributed to the need for greater emphasis and clarity when stressed. There was no significant difference in the time spent in wrist pause between the stressed and non-stressed groups. The mean angular velocity across all conditions for wrist flexion-extension and radial-ulnar deviation studied by Qin et al. (2008) indicated high-cumulative trauma disorder risk when compared to the values established by Marras and Schoenmarklin (1993). The mean angular acceleration across all conditions for wrist flexion-extension and radial-ulnar deviation studied by Qin et al.

(2008) indicated between high- and low-cumulative trauma disorder risk on the left, and high-cumulative trauma disorder risk on the right (Table A.2.).

Table A.2. Mean angular velocity and acceleration across all conditions in the work of Qin et al. (2008) compared to high- and low-cumulative trauma disorder risk (Marras and Schoenmarklin 1993).

	left	right	high-risk	low-risk
mean angular velocity (°/sec)				
wrist flexion-extension	46.5	79.3	42.2	28.7
wrist radial-ulnar deviation	27.3	43.1	25.9	17
mean angular acceleration (°/sec^2)				
wrist flexion-extension	664	1219	824	494
wrist radial-ulnar deviation	376	640	494	301

In a study of eight early-signing (learned sign language before graduating from high school) interpreters and eight late-signing (learned sign language after graduating from high school) interpreters, Donner (2012) and Donner et al. (2016) used biaxial bilateral electrogoniometers to measure wrist flexion-extension and radial-ulnar deviation displacement, angular velocity and acceleration, and pause percentage during a 20-minute interpreting task. The minimum (5th percentile), mean, and maximum (95th percentile) positions, angular velocity and acceleration, and pause percentages for right wrist flexion-extension in early- and late-signing interpreters are conveyed in Table A.3. Wrist displacement, velocity, acceleration, and pause percentage values for left wrist flexion-extension and bilateral wrist radial-ulnar deviation were provided, but not conveyed here because no significant differences across all planes were observed between the early- and late-signing groups. The mean values for wrist flexion-extension and radial-ulnar deviation velocity and acceleration reported by Donner (2012) and Donner et al. (2016) exceed the high-risk values established by Marras and Schoenmarklin (1993) by 81% for wrist flexion-extension and 63% for radial-ulnar deviation velocity, and 30% for wrist flexion-extension and 20% for radial-ulnar deviation acceleration. The left hand had significantly greater pause percentage when compared to the right hand, however this was explained by all interpreters being right-hand dominant. Native and non-native status was not specifically reported, but the mean age for first use of sign language was 6.1 years in the early-signing and 24.3 years in the late-signing interpreters.

Table A.3. Right wrist position, velocity, acceleration, and pause percentage of early- and late-signing interpreters in the work of Donner (2012) and Donner et al. (2016) compared to high- and low-cumulative trauma disorder risk (Marras and Schoenmarklin 1993).

	early-signing	late-signing	high-risk	low-risk
right wrist flexion-extension position (°)				
minimum	**-26.6**	**-30.8**		
mean	**2.8**	**-0.9**		
maximum	**40.4**	**35.3**		
right wrist flexion-extension mean angular velocity (°/sec)	77	75.7	**42.2**	**28.7**
right wrist flexion-extension mean angular acceleration (°/sec^2)	**995**	**1411**	**824**	**494**
right wrist flexion-extension pause percentage (%)	**5.3**	7.4		

Donner et al. (2013) also performed a within-participant comparison of the 16 early- and late-signing interpreters (Donner 2012) across the tasks of interpreting and conversing, and a between-participant comparison with nine college-aged deaf students. Biaxial bilateral electrogoniometers were again used to measure range of wrist flexion-extension and radial-ulnar deviation displacement, mean angular velocity and acceleration, and pause percentage during a 10-minute conversational task. All the deaf students were right-hand dominant. When comparing between interpreting and conversing tasks for the interpreters, 22% greater range of wrist displacement overall was measured when interpreting compared to when conversing and significant differences were noted for right wrist flexion-extension and right radial-ulnar deviation displacement. Average wrist velocity was seven percent greater overall when interpreting compared to conversing and significant differences were measured in left wrist flexion-extension and left radial-ulnar deviation velocity. Average wrist acceleration was eight percent greater overall when conversing compared to interpreting and significant differences were measured in right wrist flexion-extension and bilateral radial-ulnar deviation acceleration. Interpreters demonstrated a greater average pause percentage when conversing compared to interpreting across all measured wrist planes of motion with an overall 50% pause average when conversing and only 13% when interpreting. When comparing between interpreters and college-aged deaf students, the students had 16% more range of wrist displacement with significant differences noted in right wrist flexion-extension and right radial-ulnar deviation displacement. No differences were noted across groups with mean wrist velocity and acceleration. An average pause percentage of 50% for interpreters compared with 33% for students with significant differences measured for right wrist flexion-extension and left radial-ulnar deviation.

In a study of nine novice (less than two years of experience) and nine experienced (greater than or equal to five years of experience) interpreters, Fisher et al. (2014) used an electromagnetic motion capture system to measure the influence of experience and interpreting duration on mean ROM, velocity, number of micro breaks, and time spent in micro-breaks for bilateral wrist flexion-extension, radial-ulnar deviation, and elbow flexion-extension during a one-hour simulated classroom interpreting session. This was the first study to examine biomechanics of the elbow in signers. All participants were right-hand dominant. All novice interpreters were non-natives and of the experienced interpreters, three were natives and six were non-natives. Experienced interpreters demonstrated increased right elbow flexion-extension ROM between the first and second 15-minute increments, however consistent ROM was maintained thereafter. Significant differences between novice and experienced interpreters were found upon on comparing the first and last 15-minute increments for the variables of mean angular velocity and number of micro-breaks. Experienced interpreters maintained consistent mean velocities throughout, while novice interpreters decreased mean angular velocities for right wrist ulnar-radial deviation and right elbow flexion-extension. In the last 15-minute increment, the novice interpreters increased right elbow flexion-extension and right wrist flexion-extension number of micro-breaks and the experienced interpreters increased right wrist flexion-extension number of micro-breaks. Time spent in micro-breaks significantly increased over each time increment for right elbow flexion-extension in novice interpreters. Greater micro-breaks of novice interpreters were attributed to higher fatigue.

In addition to high- and low-cumulative trauma disorder risk values, ergonomic risk assessment tools allow investigators to categorize level of injury-risk. Various ergonomic risk measures focus on the repetitive high-risk UE tasks in industry workers. The RULA uses diagrams of body postures to evaluate exposure to risk factors and was designed for occupations, like the garment-making, where upper limb disorders are commonly reported (McAtamney and Corlett 1993). The SI is a multiple task analysis tool used to measure risk of distal upper extremity disorders in industry workers including manufacturing, meat and poultry processing, and manual material handling (Moore and Garg 1995). The OCRA is a proposed measure for occupations with repetitive movements of the upper limbs and considers an array of technical actions performed during a shift divided by a corresponding number of recommended actions during that shift, in effort to glean a measure of risk (Occhipinti 1998). The REBA was developed to measure unpredictable work postures in the health care or service industry (Hignett and McAtamney 2000). The quantified version of the ACGIH TLV for mono-task hand work estimates a normalized peak force relative to individual's percent maximal voluntary contraction (MVC) divided by their hand activity level measured on a visual analog scale from zero to ten (zero signifying no regular exertions to 10 equating to rapid steady motion; ACGIH 2001).

The SI is sensitive to measuring differences across facilities in posture and in measures of frequency (Jones and Kumar 2007) and demonstrates good test-retest reliability (Stephens et al. 2006). The multiple tasks analyzed within the original SI are: intensity of exertion, duration of exertion, efforts per minute, hand and wrist posture, speed of work, and duration of task per day. Intensity of exertion is an estimate of the strength required to perform the task. Duration of exertion is calculated by measuring the duration of all exertions during the observation period divided by the duration of the observation period and multiplied by 100. Efforts per minute are measured by counting the number of exertions that occur during an observation period divided by the duration of the observation period. Hand and wrist posture estimates the position of the hand or wrist in degrees of motion relative to neutral. Posture estimates for wrist flexion, extension, and ulnar deviation are available. Speed of work is an estimate of how fast the worker is working relative to a previously determined predicted pace. Lastly, duration of the task per day is obtained from plant personnel and measured in hours (Moore and Garg 1995; Table A.4.).

Table A.4. Quantitative and qualitative indicators for the original Strain Index (SI).

task	**rating**				
	1	**2**	**3**	**4**	**5**
intensity of exertion (% of muscle strength)	**<10** **light**	**10-29** **somewhat hard**	**30-49** **hard**	**50-79** **very hard**	**≥80** **near maximal**
multiplier	**1.00**	**3.00**	**6.00**	**9.00**	**13.00**
duration of exertion (% of total time)	**<10**	**10-29**	**30-49**	**50-79**	**≥80**
multiplier	**0.50**	**1.00**	**1.50**	**2.00**	**3.00**
efforts per minute (minutes)	**<4**	**4-8**	**9-14**	**15-19**	**≥20**
multiplier	**0.50**	**1.00**	**1.50**	**2.00**	**3.00**
hand and wrist posture (°) (i.e. wrist extension)	**0-10** **very good**	**11-25** **good**	**26-40** **fair**	**41-55** **bad**	**≥60** **very bad**
multiplier	**1.00**	**1.00**	**1.50**	**2.00**	**3.00**
speed of work (observed pace/predicted pace; %)	**≤80** **very slow**	**81-90** **slow**	**91-100** **fair**	**101-115** **fast**	**>115** **very fast**
multiplier	**1.00**	**1.00**	**1.00**	**1.50**	**2.00**
duration of task per day (hours)	**≤1**	**1-2**	**2-4**	**4-8**	**≥8**
multiplier	**0.25**	**0.50**	**0.75**	**1.00**	**1.50**

Semi-quantitative participant performance during each task of the SI is ranked from one to five. Each rating category is associated with a multiplier. The higher the rating category, the higher the multiplier, and the greater the injury-risk. The product of the respective task multipliers provides a composite measure of injury-risk or what is known as the SI score (i.e. SI score=intensity of exertion multiplier* duration of exertion multiplier*efforts per minute multiplier*hand and wrist posture multiplier*speed of work multiplier*duration of task per day multiplier).

A.1. Summary and conclusions

Existing literature is sparse with inconsistent methods and participant groupings. The methodology used to collect biomechanical variables and study injury-risk in signers has ranged from dynamometry to measure ROM and endurance, to simple visual observation through video recordings, to more complex motor and sensory nerve conduction studies, and rigorous EMG, biaxial electrogoniometric and electromagnetic motion capture studies. Lack of standardization of the methodology makes it challenging to compare across studies, reach a consensus, and inform signers of best recommended practices.

APPENDIX B

SUPPLEMENTAL STATISTICAL FIGURES

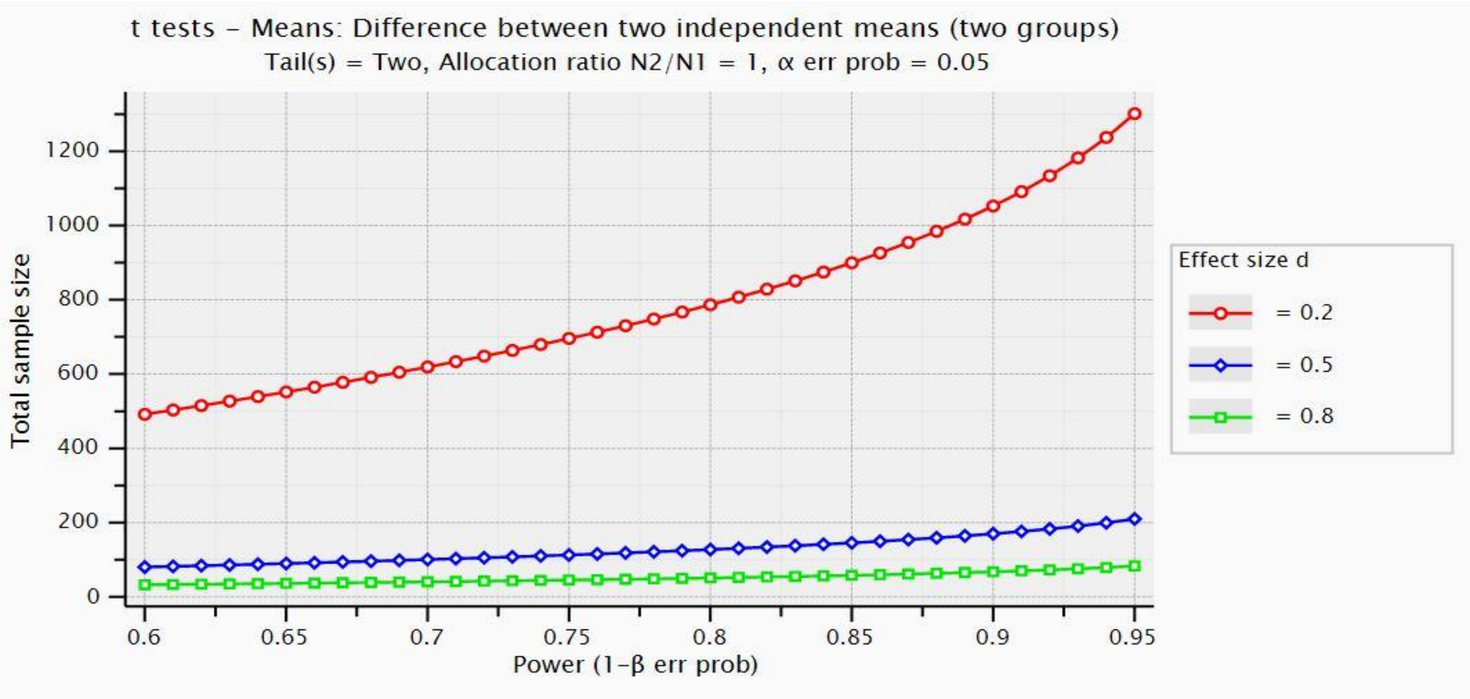

Figure B.1. Power analysis (power=0.80 and alpha=0.05) using GPower 3.1.9.2 software (Dusseldorf, Germany) from the preliminary work of Qin et al. (2008).

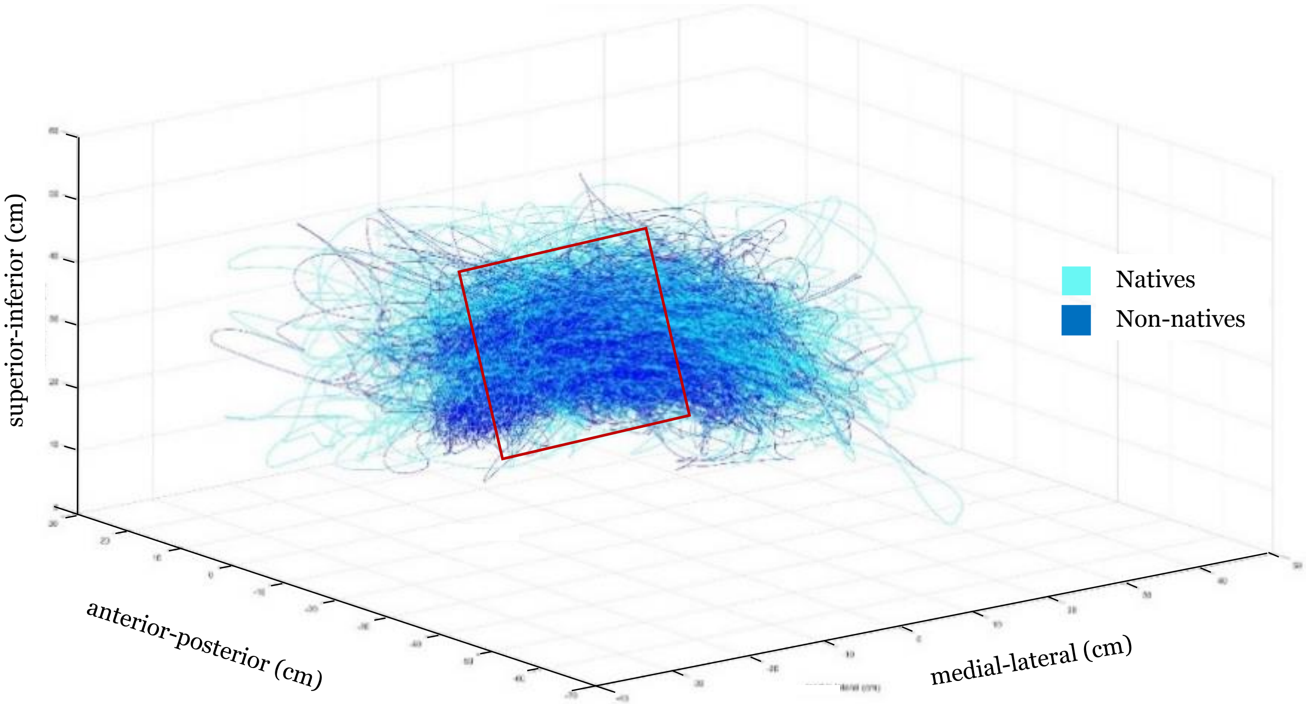

Figure B.2. Three-dimensional plot of the dominant second metacarpophalangeal joint surface marker location relative to the ipsilateral acromion surface marker location for natives (cyan) and non-natives (blue) with recommended 25cm x 25cm work envelope norm (red).

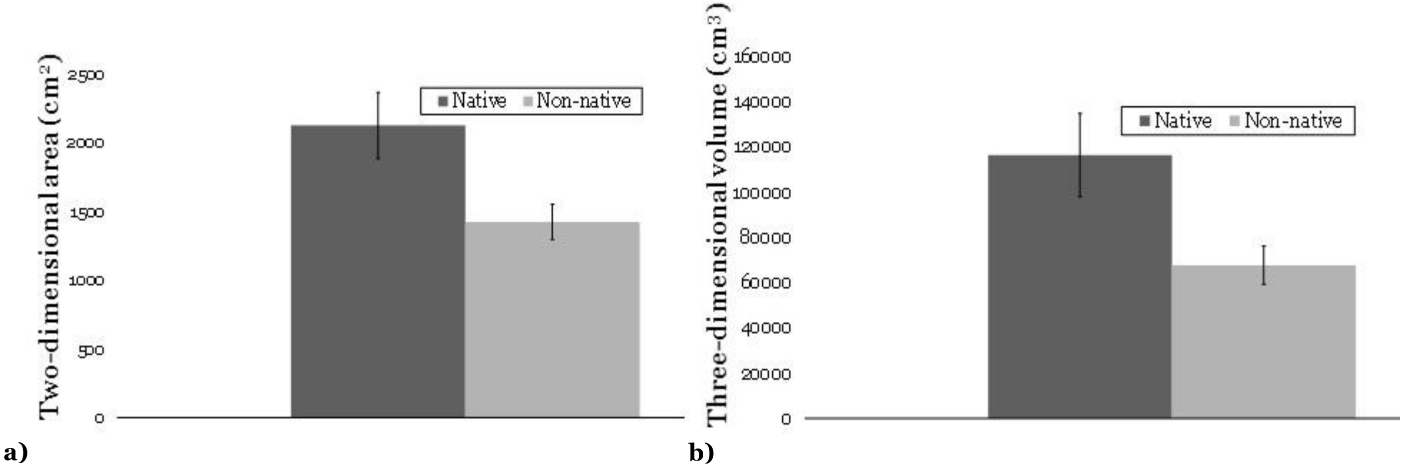

Figure B.3. a) Mean (±SE) relative two-dimensional area and b) three-dimensional volume for native and non-native signers.

APPENDIX C

INSTITUTE REVIEW BOARD APPROVAL FROM ARIZONA STATE UNIVERSITY

ASU Knowledge Enterprise Development

APPROVAL: EXPEDITED REVIEW

Meghan Vidt
SNHP: Exercise Science and Health Promotion
mvidt@asu.edu

Dear Meghan Vidt:

On 2/3/2016 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Upper extremity biomechanics in American Sign Language: native versus second language users
Investigator:	Meghan Vidt
IRB ID:	STUDY00003832
Category of review:	(6) Voice, video, digital, or image recordings, (4) Noninvasive procedures, (7)(a) Behavioral research
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• PROTOCOLTemplate_GR_Modifications.docx, Category: IRB Protocol; • ASLDataCollectionForm-Strength, Category: Technical materials/diagrams; • ASL-ScreeningQuestionnaire, Category: Screening forms; • ASLDataCollectionForm-MovementAssessment, Category: Technical materials/diagrams; • ASL_NPRS, Category: Technical materials/diagrams; • CONSENT BIOSCIENCE_Revision2.pdf, Category: Consent Form; • Flyer_ASLBiomechanics_for_upload.pdf, Category: Recruitment Materials;

The IRB approved the protocol from 2/3/2016 to 2/2/2017 inclusive. Three weeks before 2/2/2017 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 2/2/2017 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the “Documents” tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,
IRB Administrator

cc:
Gretchen Roman

ASU Knowledge Enterprise Development

APPROVAL: CONTINUATION

Meghan Vidt
SNHP: Exercise Science and Health Promotion
mvidt@asu.edu

Dear Meghan Vidt:

On 1/5/2017 the ASU IRB reviewed the following protocol:

Type of Review:	Continuing Review
Title:	Upper extremity biomechanics in American Sign Language: native versus second language users
Investigator:	Meghan Vidt
IRB ID:	STUDY00003832
Category of review:	(6) Voice, video, digital, or image recordings, (4) Noninvasive procedures, (7)(a) Behavioral research
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• CONSENT BIOSCIENCE_GR_MODIFIED2.pdf, Category: Consent Form;

The IRB approved the protocol from 1/5/2017 to 2/1/2018 inclusive. Three weeks before 2/1/2018 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 2/1/2018 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the “Documents” tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,
IRB Administrator

cc:

Shannon Kenny, Kristina Huffman, Gretchen Roman, Jeffrey Landram, Naoaki Ito, Aaron Tran, Hikaru Fujita

ASU Knowledge Enterprise Development

APPROVAL:CONTINUATION

Pamela Swan
SNHP: Exercise Science and Health Promotion
602/827-2281
PSwan@asu.edu

Dear Pamela Swan:
On 1/18/2018 the ASU IRB reviewed the following protocol:

Type of Review:	Continuing Review
Title:	Upper extremity biomechanics in American Sign Language: native versus non-native signers
Investigator:	Pamela Swan
IRB ID:	STUDY00003832
Category of review:	(6) Voice, video, digital, or image recordings, (4) Noninvasive procedures, (7)(b) Social science methods, (7)(a) Behavioral research
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	

The IRB approved the protocol from 1/18/2018 to 1/31/2019 inclusive. Three weeks before 1/31/2019 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.
If continuing review approval is not granted before the expiration date of 1/31/2019 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.
In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,
IRB Administrator

cc:
Thurmon Lockhart, Daniel Peterson, Gretchen Roman

C.1. Consent Form: Bioscience

Title of research study: Upper extremity biomechanics in American Sign Language: native versus non-native signers

Investigator: Meghan Vidt, PhD

Why am I being invited to take part in a research study?

We invite you to take part in a research study because you are an ostensibly healthy adult (e.g. no neuromuscular disorders, such as Parkinson's disease and no pacemakers), older than 18 years, with fluency in American Sign Language (ASL). A history of upper extremity pathology secondary to sign language use (e.g. carpal tunnel or cubital tunnel syndrome, cervical muscular strain, subacromial impingement) is allowable. Your participation is completely voluntary. Please take your time to make your decision and ask the study investigators or staff to explain or interpret any information that you do not understand.

Pregnant individuals will be excluded because increased abdominal size, particularly from later stages of pregnancy, may artificially alter arm kinematics during signing.

Why is this research being done?

The purpose of this research is to confirm or deny the presence of 5 biomechanical measures unique to signers. Biomechanics refers to how we move our bodies in space. Using motion capture and electromyography (EMG) data, this research will compare the observed biomechanics of native and non-native signers. We also plan to investigate if there an association between biomechanics and musculoskeletal pain from communicating in sign language. Lastly, we will also investigate if there is an association between strength and musculoskeletal pain from communicating in sign language.

If you choose to participate in this research study, there may not be any direct benefit to you. We believe that the benefits of participation include confirmation that biomechanics are unique to signers, and being able to differentiate between native versus non-native signers and those with and without pain. Studying the biomechanics of signers without pain will help to educate future generations of signers and lessen the incidence of painful conditions associated with sign language.

How long will the research last?

We expect that individuals will spend approximately five hours in a single study visit participating in the proposed activities.

How many people will be studied?

We expect about 50 people will participate in this research study.

What happens if I say yes, I want to be in this research?

It is up to you to decide whether or not to participate. If you take part in this study, you will have the following tests and procedures:

You will be asked to come to the Arizona Biomedical Complex – 1 (ABC-1) building on Arizona State University's Downtown Phoenix campus. During one visit, lasting approximately five hours, all tests and procedures associated with the study will be performed. For this visit, you will be asked to remove your shirt (male study participants) or wear a sports bra (female study participants) for the testing to ensure proper placement of markers and electrodes. Alternatively, you may wear a close-fitting tank top.

Measurements of height, weight, and body segment length and circumference will be taken. Body height and weight will be measured with a scale and measuring stick. Lengths and circumferences of your upper arms, forearms, and whole arms will be measured. Measurements will be taken in the Movement Analysis Laboratory in ABC-1.

You will also be asked to communicate a variety of sign language utterances. Before the analysis begins, reflective markers will be attached to anatomical landmarks (e.g. inner/outer elbow, inner/outer wrist, side of the shoulder and chest bone) on your body using tape, pre-wrap and/or ace bandages. Cameras will be used to record the movement of these markers so we can determine how you move during the tasks. These cameras only record the markers and no image of your face or body is taken. The motion capture assessment will take place in the Movement Analysis Laboratory in ABC-1.

Also, during these tasks, we will measure the activations of muscles on your arms and torso using EMG. To measure muscle activity, we will use tape to place electrodes on the skin over top of your muscles. Specifically, muscles on the forearms, upper arms, shoulder blades, ribcage, and neck will be monitored. Your skin will be prepared before electrode placement to ensure we get a good measurement; as necessary, your skin may be prepared by shaving, light abrasion, and cleansed with alcohol. The electrodes will measure when your muscles are activated and they do not send any signal to you. You will not feel anything from the electrodes. We do not want you to become fatigued or experience any discomfort or pain at any time during the testing session. Please inform the study staff if you feel fatigued or experience any discomfort or pain. You can discontinue participation in the study at any time. EMG assessment will take place in the Movement Analysis Laboratory in ABC-1.

Study staff want you to feel comfortable. We will need to place the markers and electrodes on you to ensure proper placement. If you are a female participant and prefer a female study staff or a male participant and prefer a male study staff assist you with the marker/electrode placement, just let us know. Body hair can impede transmittal of EMG signal, and you may be asked to shave the region where the electrodes will be placed. You will be free to shave prior to your arrival; while on site a disposable razor will be used to shave the area where electrodes will be placed. Alternatively, you may shave the location on your torso/arms under the guidance of the study staff prior to electrode placement. If you are not interested in having markers/electrodes placed on your body, you should not participate in this study.

We will ask you a few questions about pain. Pain will be measured with a self-report measure called the numeric pain rating scale. You will be asked to indicate on a scale between 0 and 10 the number that best describes your pain at the time. Zero means ‘no pain’ and 10 means the ‘most severe pain.’

A dynamometer is a device that allows us to measure your strength. Sitting with your arms relaxed at your side and your elbow bent, grip strength will be measured using a hand-held dynamometer. Sitting with straps across your chest to prevent torso movement and braces to prevent other arm joint movement, strength testing of your shoulders and wrists will be measured using an isokinetic dynamometer. All strength assessments will take place the Exercise Physiology Laboratory on the 1st floor of ABC-1. For all aspects of the testing for this study, you will interact with members of the research team. Upon completion of these tests during your visit, your participation in the study is complete. There is no follow-up associated with this study. The research team may ask if you would be willing to include your name on an internal (for the laboratory’s use only) list of individuals who are willing to be contacted about possible research study participation in the future. Such inclusion is completely voluntary.

What happens if I say yes, but I change my mind later?

Taking part in this research study is voluntary. You can leave the research at any time and it will not be held against you. This is not an intervention study or a clinical trial, and no adverse consequences related to the study are anticipated if you decide to leave the research. If you decide to leave the research, contact the investigator so that the investigator can answer any questions or concerns you have about the study and document your termination.

If you stop being in the research, already collected data will not be removed from the study database. If your withdrawal from the study is related to concerns about the risks associated with a testing procedure(s), you may be asked whether you would like to participate in remaining testing procedure(s) associated with the study.

Is there any way being in this study could be bad for me?

Being in this study involves some minimal risk to you. You should discuss the risks of being in this study with the study staff. The risks related to the tests involved with this study include:

- Physical risks:
  Motion Capture Testing, Dynamometry and Electromyography
  There is a small risk of injury during the motion capture testing, dynamometry, and electromyography, such as a muscle strain or pull, or a joint injury. If you are sensitive or allergic to adhesives or the gel on electrodes, it is possible you could experience a skin irritation or rash where tape or electrodes come into contact with your skin. These reactions typically go away in a short period of time. All tests will be supervised by study staff who will instruct you in proper technique. The staff will supervise a practice session, which will allow you to become accustomed to the movements during the test and also help to decrease the potential for discomfort or the occurrence of muscle soreness or injury.

- Privacy risks:
  Taking part in this research study may involve providing information that you consider confidential or private. Efforts will be made to keep your information safe, including de-identifying research records, keeping research records secure, and only allowing authorized people to access research records.

Will being in this study help me any way?
We cannot promise any benefits to you or others from your taking part in this research. However, possible benefits include providing valuable information about which biomechanical factors are associated with musculoskeletal pain from sign language use and will serve as a platform upon which to build future research. It is also anticipated that the information gained from this research will inform interventions for pain reduction specific to signers, such as strategies for adopting neutral upper extremity biomechanics or upper extremity strengthening.

What happens to the information collected for the research?
Efforts will be made to limit the use and disclosure of your personal information, including research study and medical records, to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB and other representatives of this organization. Data collected from this research study will be securely maintained for 7 years, or as long as required by law, before hard and electronic copies of identifying information is securely destroyed. No reference will be made to individual participants in any reports, presentations, or publications that result from this research study.

What else do I need to know?
Each participant who completes the study will receive $100 (cash) to compensate them for their time and effort toward the research study. If needed, participant parking costs while participating in the study will be covered. Should you agree to participate in the study, consent does not waive any of your legal rights. However, no funds have been set aside to compensate you in the event of injury.

The primary purpose of this research is to use motion capture and EMG to scientifically investigate biomechanical components unique to signers. However, following completion of the study, it is possible that some results may be shared with the community through academic manuscripts. Any data will be anonymized and reported in aggregate form. You can contact Dr. Gretchen Roman to request a copy of any article(s) produced which describe the results from this study.

Who can I communicate with?
If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team at:
Meghan Vidt, PhD
Principal Investigator
Exercise Science and Health Promotion
ABC-1, Room 224
425 North Fifth Street
Phoenix, AZ 85004

602-827-2280
mvidt@asu.edu

This research has been reviewed and approved by the Bioscience IRB ("IRB"). You may talk to them at (480) 965-6788 or research.integrity@asu.edu if:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research participant.
- You want to get information or provide input about this research.

Signature Block for Capable Adult
Your signature documents your permission to take part in this research.

Signature of participant	Date
Printed name of participant	
Signature of person obtaining consent	Date
Printed name of person obtaining consent	

Are you interested in being contacted for *possible research study participation in the future?*
_____Yes _____No

If yes, please provide your contact information:
Mailing address: ____________________________________
____

Email address: ____________________________________

Phone number: ____________________________________