

**EVALUATING THE ERGONOMICS OF HEALTHCARE PROVIDERS
USING KINEMATIC MOTION ANALYSIS,
ELECTROMYOGRAPHY, AND MUSCULOSKELETAL MODELING**

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EVALUATING THE ERGONOMICS OF HEALTHCARE PROVIDERS USING
KINEMATIC MOTION ANALYSIS, ELECTROMYOGRAPHY, AND
MUSCULOSKELETAL MODELING

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ABSTRACT

Work-related musculoskeletal disorders (MSDs) in healthcare providers have been heavily reported, and are a major cause of occupational discomfort, disability, and occupational absence. Current evaluation methodology of occupational posture in healthcare professionals includes qualitative methods such as survey-based instruments that report on the characteristics of existing pain, or observational instruments where still photographs or videos of occupational postures are evaluated by independent raters to assess risk or exposure to musculoskeletal disorders. This research program used marker-based kinematic motion capture, surface electromyography, and musculoskeletal modeling to evaluate occupational postures in eye care providers and dental operators. Reclining the patient during refraction and strabismus exams reduced the amount of procedural time that eye care providers' necks were in non-neutral postures. For eye care providers performing the slit lamp exam, it was observed that moving the patient forward and adjusting slit lamp biomicroscope height led to reduced non-neutral neck postures as indicated by

a reduction in sagittal plane neck flexion range of motion, upper trapezius muscle activity and the percentage of procedural time with non-neutral neck flexion. Additionally, the use of an elbow rest when holding up exam lenses at the slit lamp reduced the procedural time that the anterior deltoid muscle was active, indicating a lower likelihood of shoulder musculoskeletal disorders. For dental operators, this research investigated the effect of using two kinds of Galilean magnification loupes on neck postures in dental hygienists performing sub-gingival probing. It was observed that both loupes reduced the range of motion of sagittal plane neck flexion in dental hygienists when compared to no magnification. The use of two kinds of through-the-lens Galilean loupes used by ophthalmic surgeons was also evaluated using motion capture, electromyography, and musculoskeletal modeling. A musculoskeletal model of a 50th percentile adult male demonstrated that holding a human head balanced at the working neck flexion of a lighter loupe required a smaller angular torque than a heavier loupe. Since this lower torque was a function of both neck flexion and loupe weight, neck muscle activity was evaluated at three different neck flexions for both loupes. It was observed that using a lighter loupe with a larger angle of declination led to a decrease in upper trapezius muscle activity. Postural adjustment, patient positioning, equipment re-positioning and supportive equipment choice (such as elbow rests for slit lamp examinations, or magnification loupes for periodontal probing and ophthalmic surgery) may be easy to implement methods that can reduce the exposure of healthcare providers to work-related musculoskeletal disorders.

APPROVAL PAGE

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TABLE OF CONTENTS

ABSTRACT	iii
LIST OF ILLUSTRATIONS	x
LIST OF TABLES	xii
LIST OF ABBREVIATIONS	xiii
ACKNOWLEDGMENTS	xiv
 Chapter	
1 INTRODUCTION	1
1.1 Motivation	1
1.2 Dissertation Objectives	2
1.3 Dissertation Content	2
2 BACKGROUND	4
2.1 Musculoskeletal Disorders	4
2.2 Musculoskeletal Disorders in Healthcare Providers	6
2.3 Occupational Postural Ergonomics Evaluation Methods	8
2.4 Ergonomic Posture Evaluation using Motion Analysis	10
2.5 Ergonomic Posture Evaluation using Electromyography	11
2.6 Current Ergonomic Interventions Towards Reducing Musculoskeletal Disorders in Healthcare Providers	12

3	EVALUATING POSTURE IN EYE CARE PROVIDERS PERFORMING REFRACTION AND STRABISMUS EXAMS USING KINEMATIC MOTION CAPTURE AND ELECTROMYOGRAPHY	15
3.1	Introduction	15
3.2	Methods	18
3.2.1	Apparatus and Approach	18
3.2.2	Participants	19
3.2.3	Experimental Procedure	20
3.2.4	Data Analysis	24
3.3	Results	27
3.4	Discussion	31
4	POSTURAL EVALUATION OF EYE CARE PROVIDERS AT THE SLIT LAMP USING KINEMATIC MOTION CAPTURE AND ELECTROMYOGRAPHY	34
4.1	Introduction	34
4.2	Methods	36
4.2.1	Apparatus and Approach	36
4.2.2	Participants	38
4.2.3	Experimental Procedure	39
4.2.4	Data Capture and Analysis	41
4.3	Results	45
4.4	Discussion	48

5	USING MOTION CAPTURE TECHNOLOGY TO MEASURE THE EFFECTS OF MAGNIFICATION LOUPES ON DENTAL OPERATOR POSTURE: A PILOT STUDY	50
5.1	Abstract	50
5.2	Introduction	52
5.3	Review of the Literature	54
5.4	Methodology	58
5.4.1	Subjects	58
5.4.2	Equipment and Measurement Procedures	58
5.5	Data Collection and Analysis	62
5.6	Results	63
5.6.1	Forward Flexion (α)	63
5.6.2	Lateral Flexion (β)	64
5.7	Discussion	65
5.8	Conclusion	67
6	EFFECT OF MAGNIFICATION LOUPE WEIGHT AND ANGLE OF DECLINATION ON NECK MUSCLE EFFORT IN OPHTHALMIC SURGEONS	69
6.1	Introduction	69
6.2	Methods	71
6.3	Results	77
6.4	Discussion	80
7	CONCLUSION	81
7.1	Significance of Findings	81
7.2	Limitations	83

7.3 Future Directions	85
Appendices	86
A. Appendix A	87
B. Appendix B	94
REFERENCES	107
VITA	119

LIST OF ILLUSTRATIONS

Figure	Page
3.1 27 marker upper-body motion analysis configuration	22
3.2 Shoulder and head co-ordinate systems (L) used to calculate the rotational angles of the neck (R), adapted from mcqs.leedsmedics.org.uk	26
3.3 Effect of patient recline on eye care providers' sagittal plane neck flexion range of motion. Error bars = 1 standard error of the mean. .	28
3.4 Effect of patient recline on the percentage of time that eye care providers' neck was in non-neutral flexion. Error bars = 1 standard error of the mean.	29
3.5 Muscle activation area (mV) of the Right Erector Spinae (Iliocostalis fibers) during the Refraction exams when reaching over to examine the patient's left eye from the right side vs. examining the patient's left eye from the left side. Error bars = 1 standard error of the mean.	31
4.1 27 marker upper-body motion analysis configuration	40
4.2 Shoulder and head co-ordinate systems (L) used to calculate the rotational angles of the neck (R), adapted from mcqs.leedsmedics.org.uk	43
4.3 Sagittal plane neck flexion range of motion (A), percentage of procedural time that the neck was in non-neutral flexion (B), activation area of the right Upper Trapezius (C) and the percentage of procedural time right Anterior Deltoid was active (D). Error bars = 1 standard error of the mean.	46
5.1 Photo of acceptable, compromised and harmful posture	53

5.2	(a) Safety lenses with light attachment-no magnification. (Basic eye-wear BL), (b) Through the lens magnification loupes with light attachment. (TTL), (c) Flip Up magnification loupes-with light attachment. (FL)	55
5.3	Photo of Operator at Chairside wearing body suit	60
6.1	Conventional Galilean Loupe (A), Re-designed Galilean Loupe with Suh-Hermsen strap (B), Nasal bridge force calculations for Conventional Loupe (C), and Nasal Bridge force calculations for Re-designed Loupe (D)	72
6.2	Viewing angle determination of the conventional and redesigned loupes in an ophthalmic surgery setting, using a bubble inclinometer	73
6.3	Neck flexions for the conventional and re-designed loupes, demonstrating the motion capture and EMG sensors	76
6.4	Musculoskeletal model depicting the amount of counter torque needed to maintain the neck at the operating neck flexion angles of the conventional and re-designed loupes	78
6.5	Bilateral Upper Trapezius muscle loading for the conventional and re-designed loupes at 0°, 20° and 40° neck flexion	79
A.1	Recruitment letter, March 2017	87
A.2	Recruitment letter, October 2017	88
A.3	Questionnaire provided to each participant	92
A.4	EMG sensor order	93

LIST OF TABLES

Table	Page
3.1 Procedures performed by each study participant and the adjustments implemented for each procedure	23
3.2 Descriptive statistics and paired t-test results for the effect of patient recline on neck flexion angle range of motion (degrees)	28
3.3 Effect of patient recline on the percentage of procedural time eye care providers' necks were in non-neutral flexion (%)	29
3.4 Muscle activation area (mV) of the Right Erector Spinae (Iliocostalis fibers) during the Refraction exams when reaching over to examine the patient's left eye from the right side vs. examining the patient's left eye from the left side	30
4.1 Slit lamp examinations and relevant adjustments	41
4.2 Neck flexion angle range of motion (degrees), procedural time with non-neutral neck flexion (%), Upper Trapezius muscle activation area (mV) and procedural time with the Anterior Deltoid muscle active (%) for the conditions: No Adjustment (NA), Postural Adjustment (PA) and Postural Adjustment with Elbow Rest installed (PA+ER)	47
5.1 Dental Operator Demographics	58
5.2 Schedule for lenses/loupes use	60
5.3 Forward flexion range of motion (ROM), in degrees, for all lens types (BL, TTL, and FL) and all analysis periods (T_{40} , T_{9-12} , and T_{Reach}) .	64

5.4	Forward flexion standard deviation (SD), in degrees, for all lens types (BL, TTL, and FL) and all analysis periods (T_{40} , T_{9-12} , and T_{Reach})	64
5.5	Lateral Flexion Range of Motion (ROM), in degrees, for all lens types (BL, TTL, and FL) and all analysis periods (T_{40} , T_{9-12} , and T_{Reach})	65
5.6	Lateral Flexion standard deviation (SD), in degrees, for all lens types (BL, TTL, and FL) and all analysis periods (T_{40} , T_{9-12} , and T_{Reach})	65
6.1	Upper Trapezius loading (%MVC; Mean \pm 1 S.D.) of all neck flexion and loupe conditions	79
A.1	Randomized Subject ID and procedure repetition randomization, as assigned to specific time-slots	89

LIST OF ABBREVIATIONS

<i>MSD</i>	=	Musculoskeletal Disorder
<i>EMG</i>	=	Electromyography (usually attributed to electrical activity produced by skeletal muscles)
<i>MATLAB</i>	=	MATrix LABoratory, a multi-paradigm numerical computing environment and fourth-generation programming language developed by MathWorks, Inc.
<i>ROM</i>	=	Range of motion
<i>LCS</i>	=	Local Coordinate System
<i>MVC</i>	=	Maximal Voluntary Contraction (reference muscular contractions usually recorded in surface Electromyography)
<i>TTL</i>	=	Through-the-lens magnification loupe
<i>FL</i>	=	Flip-up-lens magnification loupe

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Musculoskeletal disorders (MSDs) stemming from prolonged, unergonomic posture represent a major cause of occupational absences and injury. For health care professionals such as ophthalmologists and dentists who often maintain static postures of the wrist, elbow and neck, MSDs can be a major occupational health problem. MSDs in health professionals have been extensively documented, with a large body of work related to MSDs in the dental [1–3] and ophthalmic fields, reporting high incidence of neck and lower back pain [4–8].

The current evaluation methods and instruments of occupational posture in both populations are highly qualitative. These include survey based instruments that report on the characteristics of existing pain, or observational instruments where still photographs or videos of occupational postures are evaluated by independent raters to assess risk or exposure to musculoskeletal disorders. To have an objective measure of the ergonomics of practicing eye care providers and dental operators, a motion-driven quantitative metric is required. Fields such as laparoscopy and microlaryngoscopy where physicians face very similar occupational MSDs, have utilized biomechanical motion capture [9] and electromyography [10, 11] in such a capacity .

1.2 Dissertation Objectives

The objectives of this dissertation are to:

1. Use biomechanical motion analysis and electromyography to examine the posture of eye care providers and dental operators.
2. Investigate the effect of patient and equipment re-positioning on the working neck posture in eye care providers during refraction (visual acuity) and strabismus (ocular misalignment) examinations.
3. Examine the effect of postural adjustment, patient position and elbow support on neck posture and neck and shoulder muscle activity during slit lamp examinations.
4. Measure the effects of magnification loupes on dental operator posture.
5. Evaluate the effect of ophthalmic surgical magnification loupe weight and angle of declination on neck muscle effort.

1.3 Dissertation Content

Chapter 2 provides a brief background on occupational musculoskeletal disorders (MSDs) and their cost, prevalence and evaluation methodology (including current instruments and the use of biomechanical motion analysis and electromyography in ergonomic research). Study methodology, experimental design and data analyses for evaluating eye care provider posture using biomechanical motion analysis data and electromyography data are presented in Chapter 3 for the strabismus and refraction exams and in Chapter 4 for slit lamp examinations. Chapter 5 presents a published pilot study that investigated the effect of using two different kinds

of magnification loupes on dental operator postures. Magnification loupe usage is also addressed in Chapter 6, which evaluated neck muscle effort for two kinds of through-the-lens ophthalmic magnification loupes using motion capture, EMG and musculoskeletal modeling. Chapter 7 serves as the conclusion, tying together the major findings from this dissertation, discussing their significance to occupational practice among healthcare providers, and presenting potential future directions for this research.

CHAPTER 2

BACKGROUND

2.1 Musculoskeletal Disorders

Musculoskeletal disorders are comprised of a family of more than a 100 diagnoses that affect the locomotor system, according to the World Health Organization's (WHO) International Classification of Diseases (ICD-10) [12]. These disorders can be characterized by persistent pain, which may subsequently lead to limitations in mobility and functional ability such as occupational dexterity. According to the WHO, the musculoskeletal diseases with the most common occurrence include osteoarthritis, neck and back pain, fractures caused by fragile bones, injuries and systemic inflammatory conditions.

In a 2016 study of the Global Burden of Disease (GBD), MSDs were the second leading contributor to disability globally, with lower back pain being the single leading cause [13]. While reporting of the incidence of MSDs varies among population classifications such as age group and occupation, as many as 33% of the global population currently live with a painful MSD [14]. A 2016 study from the Bone and Joint Initiative reports that approximately 50% of American adults live with a MSD, which is the same proportion of the adult US population suffering from chronic respiratory diseases and cardiovascular ailments combined [15].

While the susceptibility and prevalence of MSDs increases with age, a younger demographic have been consistently affected, often within the peak of their careers. MSDs are a significant cause of occupational absence in developed countries [16–

18], and are associated with a high economic cost [15]. The American Academy of Orthopedic Surgeons reported that, in 2012, 25.5 million people were affected by MSDs, 290.8 million workdays were lost to back or neck pain, and that the average person (across all professions) lost 11.4 workdays in the year to MSDs, bringing the monetary cost of treating MSDs in the US to \$213 billion [15].

The most common physical risk factors for developing MSDs include performing tasks with a high force demand, tasks with frequent repetition, tasks where awkward postures are sustained, and tasks of long duration [19, 20]. Awkward postures include elevated arms above the head, elevated elbows above the shoulders, twisting, reaching, kneeling or squatting, and bending of the wrist, back and neck. Non-physical risk factors, such as comorbid diseases, physiological and psychosocial factors, and other personal factors also play a role in the incidence of MSDs [21]. In the context of dental operators and eye care providers, the most relevant physical MSD risk factors include repetition, tasks of long duration and sustained awkward postures such as twisting, reaching and bending of the wrist, back and neck.

Neck flexion, neck rotation and elevated arm postures are said to subject neck and shoulder tissues to strain, which may provide an indication of why these postures are associated with neck pain [22] and shoulder pain [23]. Similarly, tissue loading in the spine [20] due to twisting and bending of the back is said to be indicative of the likelihood of experiencing lower back pain [24]. In determining the exposure-outcome association of occupational postures and MSDs, Coenen et. al. reported significant associations between neck flexion and rotation and neck pain, and arm elevation and neck and shoulder pain [25]. A systematic review of studies that examine causal relationship between awkward postures and low back pain concluded that it was unlikely that awkward occupational postures were independently causative of lower back pain [26].

According to a systematic review of neck pain and disability in workers conducted by Côté et. al., at least 5% of the working population are likely to develop recurring neck MSDs annually, and that as many as 10% of these workers may experience at least one bout of limitation in mobility or activity. Within the scope of this systematic review, it was stated that workers who sat for more than 95% of the time were twice as likely to develop neck MSDs compared to workers who were not as sedentary [27], workers who performed daily repetitive work were 30-40% more likely to report at least 3 days of neck pain per month [28], workers who maintained awkward occupational postures such as frequent bending or turning of the torso experienced a higher incidence of neck pain than workers who did not maintain such postures [29], workers who used armrests had a lower risk of developing neck and shoulder MSDs compared to those who did not use armrests [30], and that working with the neck in forward flexion $\geq 20^\circ$ increased the risk of developing neck pain [27,31].

2.2 Musculoskeletal Disorders in Healthcare Providers

MSDs in health professionals have been extensively documented, with the largest body of work related to MSDs in laparoscopic surgeons and dental operators. A survey-questionnaire based study by Stomberg et. al. looked at the occurrence of MSDs in 558 gynecologists and general surgeons who routinely performed laparoscopic surgery [32]. More than 70% of laparoscopists demonstrated one or more symptoms of MSDs, with pain, fatigue and stiffness frequently reported in the lower back, neck and shoulders. There was a significant correlation between MSD occurrence, workload, and aging. A 2013 study by Esposito et. al. also exhibited a strong association between MSD symptoms and the number of laparoscopic procedures performed [33].

Dentists and dental hygienists frequently encounter neck, back, and shoulder injuries as a result of spending long durations of time in non-neutral positions [1, 34–37]. Musculoskeletal pain will begin early in the careers of dentists and dental hygienists and will eventually worsen to result in reduction of work hours or early exit from clinical practice [36, 38]. Morse et. al. examined the occurrence of neck pain among dental hygiene students, dental assistants and experienced dental hygienists [1]. The study found an increased risk of neck and shoulder disorders within dental hygienists who have a background in dental assistant work, and that neck symptoms were considerably more prevalent than shoulder symptoms. Key risk factors for MSDs were found to be neck bending, supervisor support and sustained positioning of hygienists’ hands above shoulder height. A more recent survey based study by Rambabu et. al. found that dental surgeons (N=100) experience a higher prevalence of MSDs compared to physicians (N=100) and other surgeons (N=100) [2].

Over the last couple of decades, the frequency of work-related MSD in ophthalmologists has also been reported widely. The prevalence of MSD symptoms in these ophthalmology studies varies depending on the evaluation criteria, populations studied and survey instrumentation used. In 1994, Chatterjee et al. conducted a survey among 325 ophthalmologists in the UK, 174 (54%) of whom reported significant attacks of back pain, with the longest serving ophthalmic consultants having an increased incidence. Of these 174, 34% reported neck pain and 81% reported lower back pain [4]. Nearly a decade later, in 2005, Dhimitri et. al. conducted a survey study among 697 ophthalmologists in the Northeastern United States, 51.8% of whom reported experiencing neck, upper body, or lower back MSD symptoms in the prior month. 15% of the ophthalmologists participating in this study reported being slightly to moderately limited in their work as a result of these symptoms [6].

Sivak-Callcott et. al., in a 2011 survey study of occupational pain and injury consisting of 137 ophthalmic plastic surgeons, noted that 72.5% of respondents reported pain associated with operating and 9.2% reported stopping operating due to pain or spine injury [7]. In a recent survey study among consultant ophthalmologists in the UK, Hyer et. al. had 31.8% of participants reporting incidence of neck pain and 50.6% respondents reporting incidence of back pain [8]. When compared to their family medicine colleagues, it was observed that ophthalmologists reported a statistically significant increased prevalence of neck, hand/wrist, and lower back pain [39]. In light of the high incidences of work-related MSDs in ophthalmologists, there is a clear need for evaluating the ergonomics of practicing ophthalmologists in order to identify risk factors and develop ergonomic interventions to address them.

2.3 Occupational Postural Ergonomics Evaluation Methods

Occupational postures and their likelihood of leading to MSDs have traditionally been evaluated through different instruments that mathematically assess MSD risk based on postures maintained at work throughout the day, sometimes factoring in the prevalence of existing musculoskeletal discomfort. While a number of observational tools have been developed to assess biomechanical exposure to potentially harmful occupational postures and activities, instruments with wide usage include the NIOSH Lifting Equation [40], the Liberty Mutual Force (Snook) Tables [41], the Quick Exposure Checklist (QEC) [42], the Ovako Working Posture Analysis (OWAS) [43], the Rapid Upper Limb Assessment tool (RULA) [44] and the Rapid Entire Body Assessment tool (REBA) [45]. Takala et. al., in their detailed review of the usability and efficacy of these observational tools, recommend that while these tools have been systematically evaluated for repeatability, validity and practicality, specific occupational settings may require clear definitions of ergo-

onomic evaluation aims, needs, and the usage of an appropriate evaluation tool by sufficiently trained observers to control observer variability [46].

Dental operator posture has been studied both in a qualitative manner and a semi-quantitative manner over the last two decades. Branson et. al. developed and evaluated the Branson Dental Operator Posture Assessment Instrument (PAI) [47]. An expert panel consisting of occupational therapists, physical therapists and dental hygiene practitioners and educators evaluated recommendations of ergonomic posture for dental operators from a clinical dental hygiene textbook [48]. After a 100% consensus regarding the ideal and neutral dental operator posture from the provided text, the expert panel was provided with slide sets of pre-recorded static images of dental postures, and each member examined each slide set for deviation from neutral posture. Based on input from the expert panel, the posture assessment instrument was developed, with the posture categories “acceptable”, “compromised” and “harmful”. The categories were quantified by defining anatomic positioning and ranges of anatomical angles, including the hips, trunk, head/neck, shoulders and wrist. Hip position was defined as acceptable if the hips are level on the stool, and compromised if the hips are not level on the stool. Trunk and head/neck angles (flexion/extension, abduction/adduction, internal rotation) were defined as acceptable if they were $\leq 20^\circ$, compromised if they were between 20° and 45° , and harmful if they were $\geq 45^\circ$. Shoulder position was defined as acceptable if shoulders were relaxed and both shoulders level with trunk, and as compromised if shoulders were slumped forward and one or both shoulders elevated above line of trunk. Wrist angle (flexion/extension) was defined as acceptable if it was $\leq 15^\circ$ and compromised if it was $> 15^\circ$. The reliability of the instrument was evaluated by a generalizability study where four dental hygiene educators, who had received a short tutorial on the use of the instrument, viewed pre-recorded overhead

video feed of students performing probing procedures on real patients. For each video, operator and operator stool were marked with bright tape in order to distinguish anatomic landmarks necessary for observing the components of posture utilized in the instrument. PAI scores were similar among three raters, with the fourth rater's score being slightly higher. Branson's PAI was deemed adaptable to both dynamic real-time postures and static imaged postures. However, body posture visibility may be compromised in static images, and while captured video counteracts this issue, there exists the possibility of rater bias based on the visibility and/or identity of the participant. Motion capture technology allows the measurement of deviations from a baseline or neutral posture to be more precise than those made with observations and self-reports. Thus, motion capture technology may be a potentially useful and more precise modality in evaluating the effectiveness of magnification loupes on dental operator posture.

Eyecare provider posture has only been formally evaluated by Olitsky et. al. [49], who evaluated the posture of strabismus surgeons using Branson's PAI. They concluded that posture analysis instruments such as Branson's PAI may be able to help identify operating postures that may put operators at a risk of developing MSDs, and suggest operating positions and techniques to reduce these risks for surgeons performing strabismus surgery.

2.4 Ergonomic Posture Evaluation using Motion Analysis

Motion analysis has been used to examine posture in older adults, sports, and ambulatory settings [50–54]. Puthenveetil et. al. described a method of simulating an assembly operation in a virtual environment to analyze the posture of assembly workers in the aerospace industry. The positions, orientations of the head, elbow and wrist of a human body were recorded using optical markers and the observa-

tional postural evaluation tool Rapid Upper Limb Assessment (RULA) was used to evaluate the risk of workplace related injury.

Ergonomic studies of healthcare providers using biomechanical motion analysis have been conducted in the past. Statham et. al. evaluated the ergonomics of laryngologists performing simulated microlaryngoscopy at three different operative positions: on a supported chair with articulated arm support, on a supported chair with a Mayo stand, and with no arm support at all [9]. It was observed that higher-risk postures were obtained with unfavorably adjusted eyepieces and lack of any arm support during microlaryngoscopy, both of which increased neck strain and shoulder torque. Kolwadkar et. al. compared the ergonomics of a group of 17 surgeons and medical students using two types of surgical handheld manipulators: one using a controlling wheel, and the other with a controlling joint. It was observed that the controlling joint manipulator was more difficult to handle, resulting in larger range of motion, higher velocities and accelerations in some joints [55].

Biomechanical motion analysis has previously been utilized by Saleh et. al. to evaluate surgical skill in oculoplastic surgery [56] [57], intraocular surgery [58] [59] (by both Saleh et. al. and Hubschman et. al.) and corneal suturing [60]. However, there have not been any application of biomechanical motion analysis towards evaluating the ergonomics of eye care providers.

2.5 Ergonomic Posture Evaluation using Electromyography

Aaras et. al in 1994 investigated and established a relationship between trapezius muscle loading and musculoskeletal illness in neck and shoulder regions of assembly line workers and video display technicians [10]. This finding was refined upon by Hanvold et. al. in 2013 who presented that sustained trapezius muscle activity is associated with neck and shoulder pain and that this association was

strongest analyzing cross-sectional and short-term effects [61].

Fethke et. al. in 2015 studied neck and shoulder muscle activity among ophthalmologists during routine clinical examinations [11]. EMG readings were collected from the upper trapezius and anterior deltoid muscles. They found that indirect ophthalmoscope, followed by slit lamp exam require greater muscular demands than computer use or other clinical activities.

Rempel et. al. in 2011 studied simulated pipetting in a laboratory setting and reported a reduction in anterior deltoid activity when an elbow rest or arm rest was used, compared to when the forearm and upper arm were unsupported, as seen in pipette users where mean anterior deltoid activity was reduced due to forearm support [62]. This finding was supported by Goncalves et. al. in 2017 who studied shoulder muscle activity in female university students, and reported a decrease in anterior deltoid activity due to forearm support across multiple shoulder flexion angles [63].

2.6 Current Ergonomic Interventions Towards Reducing Musculoskeletal Disorders in Healthcare Providers

Ergonomic interventions have been widely implemented in the healthcare industry, particularly in occupations that experience forceful exertions, lifting tasks, and sustained awkward and twisting occupational postures.

Owen et. al. studied the effect of ergonomic interventions on perceived stress ratings reported by nursing staff, who often encounter forceful exertions and lifting tasks in their occupational practice [64]. These interventions included the use of electromechanical lifts and walking belts with handles to transfer patients from bed to chair (or toilet), and the use of friction reducing sheets under the draw sheet to transfer patients from the bed to a stretcher and vice versa. In their 1.5 and 5 year

follow up, Owen et. al. observed that utilizing these ergonomic interventions led to a decrease in back and shoulder injury rates and lost workdays in nursing staff.

For surgeons, the physical discomfort that may arise from maintaining sustained awkward and twisting occupational postures is an operative stressor that may impact decision making in surgery [65]. To reduce time spent by surgeons in awkward postures, robotic surgery has been suggested as an ergonomic alternative [66], as documented in studies conducted on laparoscopists [67] and colorectal surgeons [68].

Numerous interventions have been suggested in the literature to reduce the risks of MSDs among dental operators. Kanteshwari studied operator awareness of dental posture to counteract the pain of MSDs [69]. Hayes reported on interventions such as magnification loupes, proper light utilization and task analyses to direct the operator to more neutral positions in order to minimize musculoskeletal disorders [70]. Valachi reports on the use of physical fitness, stretching and exercise to offset the static postures common in dentistry [71–73]. Other researchers have studied ergonomic operator stools and their role in alleviating the impact of musculoskeletal disorders [74, 75]. One of the most frequently studied interventions is the use of magnification loupes to improve operator posture and vision to thus reduce musculoskeletal disorders among dental operators [76–83].

Ergonomic interventions have also been widely recommended in eye care providers to counteract the growing trend of MSDs in ophthalmologists, optometrists and ophthalmic surgeons [84, 85]. Strategies suggested to avoid neck injuries included modifying slit lamp table to move it closer to the examiner, adjusting examination chair such that the examiner does not have to lean forward during slit lamp exams, using lightweight indirect ophthalmoscopes, maintaining neutral spine postures during indirect ophthalmoscopy by adjusting examination chair height and patient

position, using light-weight prismatic magnification loupes with no incorporated illumination system, and using tiltable (adjustable) eyepiece lenses in microscope-assisted surgery. To avoid back injuries, equipment adjustments were recommended, especially in ophthalmic surgery. These included adjusting the height of operator chair, table and equipment to maintain neutral spine postures, and ensuring that the relative orientation between the operator chair and table allow for the operator's knees to be bent at 90° , their thighs parallel to the floor, and their feet planted flat on the floor. Prevention strategies for arm and hand injuries included proper computer workstation configurations to maintain ergonomic posture, and the use of wrist and elbow rests to alleviate sustained arm raise and the development of contact stress due to resting forearms or elbows on unpadded surfaces. In addition to ergonomic interventions, workplace exercise was also recommended which included stretches for the neck, shoulder, upper arm, wrist, hip, knee and leg.

CHAPTER 3

EVALUATING POSTURE IN EYE CARE PROVIDERS PERFORMING REFRACTION AND STRABISMUS EXAMS USING KINEMATIC MOTION CAPTURE AND ELECTROMYOGRAPHY

3.1 Introduction

Musculoskeletal disorders (MSDs) of the locomotor system can be characterized by persistent pain, which may lead to limitations in mobility and functional ability such as occupational dexterity. While the susceptibility and prevalence of MSDs increase with age, a younger demographic have been consistently affected, often within the peak of their careers. MSDs are a significant cause of occupational absence in developed countries [16–18], and are associated with a high economic cost [15]. In 2012, the American Academy of Orthopedic Surgeons reported that 25.5 million people in the US were affected by MSDs, 290.8 million workdays were lost to back or neck pain, and that the average person (across all professions) lost 11.4 workdays in the year to MSDs, bringing the monetary cost of treating MSDs in the US to \$213 billion [15].

Particularly for eye care providers such as ophthalmologists and optometrists, who often maintain static postures of the wrist, elbow, shoulder and neck, MSDs can be a major occupational health problem. MSDs in health professionals have been extensively documented, with the largest body of work related to MSDs in the dental and laparoscopic surgery fields [1–3, 32, 33]. Common physical risk factors for developing MSDs include performing tasks with frequent repetition, tasks where

awkward postures are sustained, and tasks of long duration [19, 20]. Neck flexion, neck rotation and elevated arm postures subject neck and shoulder tissues to strain, which may provide an indication of why these postures are associated with neck pain [22] and shoulder pain [23]. In determining the exposure-outcome association of occupational postures and MSDs, Coenen et. al. reported significant associations between neck flexion and rotation and neck pain, and arm elevation and neck and shoulder pain [25]. According to a systematic review of neck pain and disability in workers conducted by Côté et. al. [22], workers who maintained awkward occupational postures such as frequent bending or turning of the torso experienced a higher incidence of neck pain than workers who did not maintain such postures [29], workers who used armrests had a lower risk of developing neck and shoulder MSDs compared to those who did not use armrests [30], and workers working with their neck in forward flexion $\geq 20^\circ$ had a higher risk of developing neck pain [27, 31].

Over the last couple of decades, the frequency of work-related MSD among eye care providers has been reported widely, with high incidence of neck and lower back pain [4–8]. While the prevalence of MSD symptoms in these studies varies depending on the evaluation criteria, populations studied, and survey instrumentation used, these studies report an incidence of 30% - 70% for neck pain and 40%-80% for back pain. Similar findings were also reported in a recent survey study among consultant ophthalmologists in the UK, with 31.8% of participants reporting incidence of neck pain and 50.6% respondents reporting incidence of back pain [8]. When compared to their family medicine colleagues, eye care providers reported a statistically significant increased prevalence of neck, hand/wrist, and lower back pain [39].

In light of the high incidences of work-related MSDs in eye care providers, there is a clear need for evaluating occupational postures in eye care providers in order

to identify sustained non-neutral postures exhibited in working practice, and develop working posture adjustments to address these. Current postural evaluations of eye care providers' working practice consists of qualitative self-reported discomfort surveys (such as the Visual Analog Scale (VAS) [86]) and questionnaires which are key instruments used in the major publications that have brought forth a call for ergonomic adjustments to occupational practice. Additionally, a 2015 study by Fethke et. al. investigated neck and shoulder muscle activity among ophthalmologists during routine clinical examinations [11], and found that indirect ophthalmoscope, followed by slit lamp exam required greater muscular demands, compared to computer use or other clinical activities.

To have an objective measure of the ergonomics of practicing ophthalmologists, a motion-driven quantitative metric is required. Fields such as laparoscopy and microlaryngoscopy, where physicians encounter similar occupational MSDs, have utilized biomechanical motion capture [9] and electromyography [10] in such a capacity. Combining motion analysis and electromyography data may provide a granular, quantitative perspective on the operational ergonomics of eye care providers, and on the effectiveness of the procedural adjustments implemented in this study towards improving the ergonomics of eye care providers.

This study utilized kinematic motion capture and electromyography (EMG) to evaluate the effect of patient re-positioning on the posture of eye care providers performing simulated refraction and strabismus exams.

3.2 Methods

3.2.1 Apparatus and Approach

All experiments were conducted at the Broadway clinic of Children’s Mercy Hospital in Kansas City, MO, USA. A marker-based motion analysis system consisting of fourteen Optitrack Flex 13 cameras (Natural Point Inc., Corvallis, OR, USA), along with a Dell Precision T 3610 workstation (Dell Inc., Round Rock, TX, USA) were used for this study, provided by the Center for Health Insights (UMKC School of Medicine, Kansas City, MO, USA). A Delsys Trigno 16-channel wireless electromyography system (Delsys Inc., Natick, MA, USA) was used for this study, provided by the Human Balance and Ambulation Research Laboratory of the School of Computing and Engineering (University of Missouri-Kansas City, Kansas City, MO, USA). A Haag-Streit Reliance FXM 920 ophthalmic examination chair, child CPR manikin, ophthalmologist chair, standard lens rack, lens bar, retinoscope, occluder, refraction prism and a prism bar were provided by the Children’s Mercy Hospital Broadway clinic.

The motion capture cameras were positioned in the data capture area in a way that all cameras collectively had an adequate field of view of the patient examination chair, eye care providers’ chair and any relevant ophthalmic equipment. The space was then calibrated using an Optitrack calibration wand to ensure accuracy of motion analysis data. The Optitrack motion analysis system was synchronized with the Delsys Trigno electromyography system through the Delsys Trigno Trigger Module. The manikin was positioned on the examination chair.

Two Snellen Eye Charts [87], at different heights, were positioned approximately 10 ft. from the examination chair, on a wall that was in the line of sight of the

manikin. The two different heights of the eye charts corresponded with the manikin’s direct line of sight to the charts for an “upright” and a “reclined” setting of the examination chair, respectively. The manikin’s line of sight to the eye chart was determined by a laser pointer placed orthogonally on the manikin’s glabella, following which the corresponding contact point of the laser pointer on the wall was marked to be the position of the center of each printed eye chart. To maintain the consistency of the orientation of manikin recline for each study participant, an angle finder was placed on the medial-lateral axis of the examination chair. The examination chair recline angles for the “upright” position and the “reclined” position were 4° and 13° respectively.

A unique, randomized 3 digit participant identification (Subject ID) number was generated and assigned to each of the 20 possible time slots within the five planned days of data collection. Study participants were then assigned the participant identification number corresponding to the time slot in which they elected to participate in the study (see Table A.1 in Appendix A).

This study was approved by the Children’s Mercy Hospitals & Clinic Pediatric Institutional Review Board (IRB), which can be contacted at (816) 701-4358 for verification purposes.

3.2.2 Participants

Ten practicing pediatric ophthalmologists and optometrists (five male and five female, aged 40 ± 9.52 years old) from Children’s Mercy Hospital Broadway clinic were recruited to take part in this study. Recruitment was conducted by Dr. Scott E Olitsky, who is an ophthalmologist in Children’s Mercy Hospital Broadway clinic, and Rebecca Dent who is the Ophthalmology Research Coordinator at Children’s Mercy Hospitals. Potential study participants were emailed a letter explaining the

details of the study and inviting them to participate. The letter provided directions for them to reply by email to the study staff to secure a time for their study appointment. Study participants were not contacted again in order to avoid coercion to participate if they chose not to join the study. They were further informed that participation was voluntary and no positive or negative consequences would result from study participation. The recruitment letter is available in Appendix A.

Eligible study participants included eye care providers (pediatric ophthalmologists and optometrists) currently on staff or rotation at Children’s Mercy Hospitals Broadway clinic who are of age 18 or older, and who routinely perform pediatric ophthalmic procedures as part of their regular clinical practice. Potential participants were excluded if unable to comply with any of the task requirements, similar to those normally used in regular clinical practice, while wearing a motion capture suit and electromyography sensors. Prior surgical intervention was not an exclusion criteria. Prior musculoskeletal symptoms such as neck or back pain was neither inclusion nor exclusion criteria.

3.2.3 Experimental Procedure

Prior to motion analysis, participants were provided with their randomized 3 digit participant identification number and a laptop to fill out a confidential REDCap (Vanderbilt University, Nashville, TN) [88] questionnaire on which they were asked to self-report age, height, gender, handedness, ophthalmic subspeciality, years of experience, frequency of patients attended to and incidence of MSD. A blank copy of this questionnaire is available in Appendix A.

Once each participant had filled out the REDCap questionnaire, their EMG sites were prepared by cleaning with rubbing alcohol, and they were fitted with surface EMG sensors using double-sided hypoallergenic tape on the upper and lower

trapezius, anterior and posterior deltoid, and lumbar erector spinae (iliocostalis and longissimus fibers). EMG sensors were placed according to the European Recommendations for Surface Electromyography (SENIAM) [89]. The placement order of these electrodes was kept consistent for each participant by utilizing the native numbering system on each wireless electrode in the Trigno system and assigning each numbered electrode to a certain muscle (available in Appendix A). Each participant was then asked to don an upper body motion capture suit and fitted with a 27-marker upper body Motive motion capture setup. This setup is illustrated in Figure 3.1. Once in the capture area, participants were asked to stand still in the "T-pose" posture shown in Figure 3.1 to collect static data used to define neutral/upright neck postures.

Each study participant performed a refraction exam and a strabismus exam on the manikin, followed by repetitions of these procedures with the patient (manikin) reclined and/or equipment adjusted. The details of the procedures and their repetitions are described in detail in Table 3.1. The order in which participants performed refraction and strabismus was randomized. Additionally, the order in which the participants performed the repetitions within each procedure was also randomized. These randomizations are detailed in Table A.1 in Appendix A, where the procedure numbers listed correspond to the second column of Table 3.1. Data from these repetitions were analyzed to investigate whether reclining the patient during refraction and strabismus reduced the exposure to non-neutral neck postures, and whether muscle activity of the right erector spinae during refraction exams reduced as a result of examining the patient's left eye while sitting on the patient's left side compared to reaching over to examine the patient's left eye while sitting on the patient's right side.

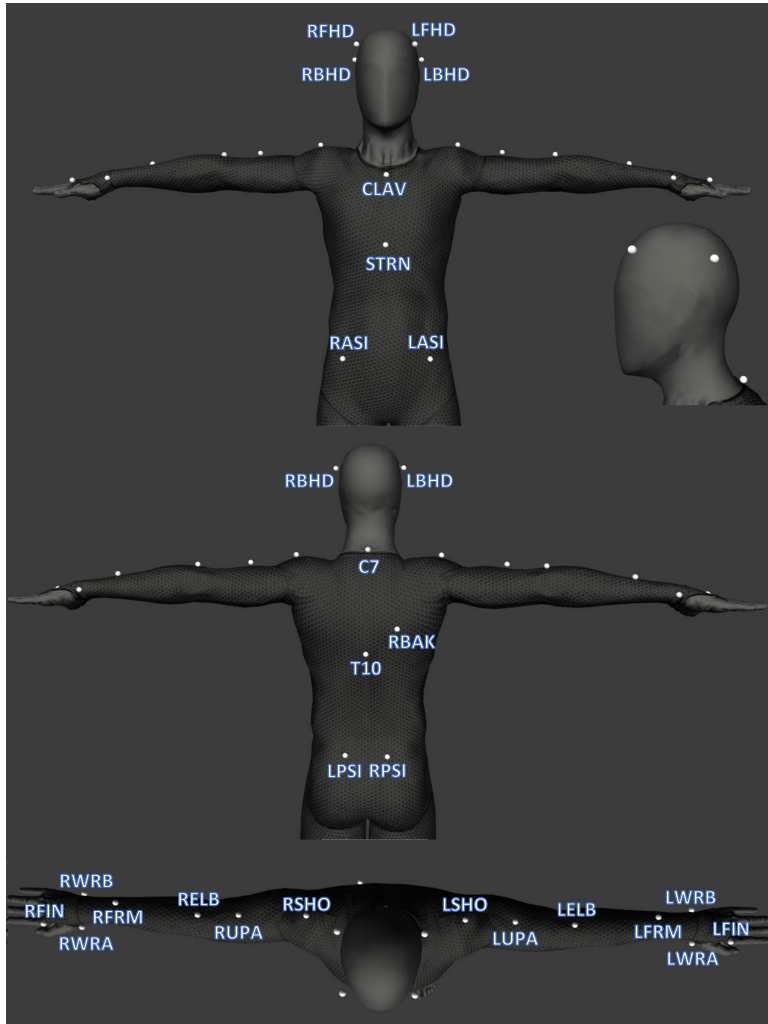


Figure 3.1: 27 marker upper-body motion analysis configuration

Table 3.1: Procedures performed by each study participant and the adjustments implemented for each procedure

Procedure	Experiment/ Repetition	Procedure Details	Setup Notes
Refraction	1	As the eye care provider usually performs the procedure (With a single Loose Lens)	For each refraction exam procedure and repetitions, participants examined first the right eye and then the left eye of the patient (manikin) while sitting to the right of the patient, after which they came back to a neutral sitting posture. Then the participants moved to the left of the patient (manikin) and only examined the left eye.
	1 + Int1	With a Lens Bar	
	1 + Int2	With Loose Lens, Patient (manikin) reclined to be able to view the higher Eye Chart, and participant seat height changed to their self-selected height	Right-hand dominant participants started off with the lens (or lens bar) in the left hand and the retinoscope on the right hand while they were on the right side of the patient (manikin). They were asked to switch hands for the lens (or lens bar) and retinoscope when they came around to the left side of the patient (manikin) to examine the left eye. In case the participants were left hand dominant, the procedure remained the same but the handedness of equipment handling was reversed.
	1 + Int3	With Lens Bar, Patient (manikin) reclined to be able to view the higher Eye Chart, and participant seat height changed to their self-selected height	
Strabismus	2	As the eye care provider usually performs the procedure (With Loose Prism)	For each strabismus exam procedure and repetitions, participants tested only the right eye of the patient (manikin). All participants held the prism (or prism bar) on their left hand while using the occluder with their right hand.
	2 + Int1	With a Prism Bar	
	2 + Int2	With Loose Prism, Patient (manikin) reclined to be able to view the higher Eye Chart, and participant seat height changed to their self-selected height	
	2 + Int3	With Prism Bar, Patient (manikin) reclined to be able to view the higher Eye Chart, and participant seat height changed to their self-selected height	

3.2.4 Data Analysis

Individual marker data was recorded by the Optitrack Motive software (Natural Point Inc, Corvallis, OR, USA). For each participant, relevant de-identified biometric data was collected from the REDCap questionnaire. The electromyography data for each participant was acquired through EMGWorks software (DELSYS, Natick, MA, USA). The principal measurements recorded were the 3D position data of the motion capture markers, and the electrical activity data of the EMG electrodes. Secondary measurements include the sampling rate of the Flex 13 cameras (120 Hz) and the surface EMG electrodes (1925.76 Hz). Motion data and EMG waveform data were exported as .csv files and analyzed using MATLAB R2016a (The Mathworks, Natick, MA, USA). IBM SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, NY, USA) was used for all statistical analyses.

Joint angles between any two body segments were calculated by first defining local coordinate systems (LCS) on each segment, and then relating the two segments via a Cardan rotation sequence [90]. The Cardan rotation sequence XYZ is often used in biomechanics to generate a 3-D rotation matrix, which is the orientation of one LCS with respect to another LCS, and is represented by three successive rotations about unique axes. This sequence is done in three steps: first, rotation about the laterally directed X axis (α), second, rotation about the anteriorly directed Y axis (β), and third, rotation about the vertical Z axis (γ). The Cardan rotation matrix between two LCS is equivalent to the element-wise dot product of the unit vector matrices of those two LCS (presented in Equation 3.1).

$$R = \begin{bmatrix} cac\beta & cas\beta s\gamma - sac\gamma & cas\beta s\gamma + sas\gamma \\ sac\beta & sas\beta s\gamma + cac\gamma & sas\beta s\gamma - cas\gamma \\ -s\beta & c\beta s\gamma & c\beta c\gamma \end{bmatrix} = \begin{bmatrix} i.I & j.I & k.I \\ i.J & j.J & k.J \\ i.K & j.K & k.K \end{bmatrix}$$

Equation 3.1 XYZ Cardan rotation matrix and its equivalent

where R = Cardan rotation matrix, s = sine, c = cosine, $[i, j, k]$ = Local coordinate system for Segment 1, $[I, J, K]$ = Local coordinate system for Segment 2.

Equating the two definitions of the rotation matrix allows the calculation of the three rotational angles, α , β , and γ . For anatomical segments, α is the flexion/extension, β is the abduction/adduction and γ is the pronation/supination (or axial rotation). Joint rotation angles calculated in this manner are Euler angles. While they are closely related to the anatomical rotation angles, they may not correlate exactly with physiological conventions.

Raw EMG waveforms were band-pass filtered using a 4th order butterworth filter between 35 Hz and 500 Hz, to reduce contamination from movement artifacts, electrocardiogram signals and high frequency noise [89, 91]. Upon inspecting power spectral density, it was noticed that EMG waveforms displayed spurious spikes at approximately 60 Hz. Assuming that these spikes were caused by electrical interference, the waveforms were notch-filtered between 59 Hz and 61 Hz using a 4th order butterworth filter. EMG waveforms were then full-wave rectified, demeaned and subjected to a low-pass 4th order Butterworth filter with a cutoff frequency of 50 Hz [92] to obtain the EMG envelope.

For this study, outcome measures include sagittal plane neck flexion angle range of motion, the percentage of procedural time that neck flexion remained in non-neutral posture (i.e. $> 20^\circ$ flexion and any extension [27, 31]), and the activation area of the upper trapezius, anterior deltoid, and erector spinae muscles.

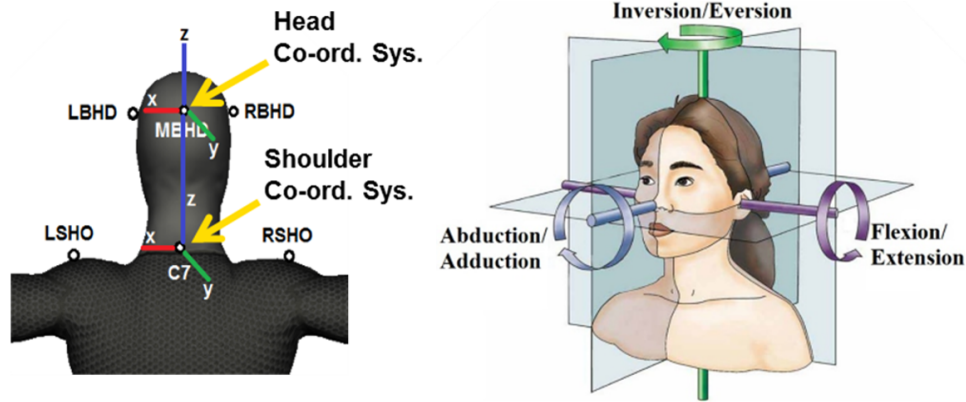


Figure 3.2: Shoulder and head co-ordinate systems (L) used to calculate the rotational angles of the neck (R), adapted from mcqs.leedsmedics.org.uk

Figure 3.2 illustrates the rotational euler angles of the neck as calculated by the shoulder and head local co-ordinate systems and a Cardan rotation sequence. Neck flexion angle range of motion was calculated by subtracting the minimum value of flexion in a times series from the maximum value of flexion. The percentage of procedural time with non-neutral neck flexion was calculated by finding the indices in the time series where neck flexion was greater than 20° or less than 0° (i.e. in extension) compared to the neutral/upright "T-pose" posture data collected at the beginning of each trial, and dividing that number by the total number of indices in the time series (multiplied by 100).

The activation area of a specific muscle is referred to as the area under the curve for filtered and rectified EMG waveform envelope of that muscle, found by trapezoidal integration. Since each procedure compared had slightly different times, the activation area of individual muscles was normalized by dividing their activation area by the time of each trial. It is to be noted that this method of calculating an activation area is not a standard outcome measure in EMG analysis, but was used in this study to provide a standardized basis for observing effects of procedu-

ral adjustments on muscle activity.

For analyses purposes, the time periods of the kinematic and EMG data were isolated only to the time period when the eye care provider was performing each examination (or a specific part of the examination). The kinematic and EMG outcome measures were compared pairwise (adjustment vs. no adjustment) using two-tailed paired t-tests if the differences between pairs of data points were normally distributed or by Wilcoxon signed-rank tests if the differences were not normally distributed. To test for the normality of the data, differences between the pairwise comparison datasets were calculated. These differences were visually inspected for outliers using a Q-Q plot and data normality was established if the Shapiro-Wilk test statistic was found to be non-significant (i.e. $p > 0.05$) for each comparison.

Since this study was a pilot study with a small sample size, considerations were implemented beyond simply finding two-tailed statistical significance (i.e. $p < 0.05$), where comparisons that generated p-values of 0.1 or lower were interpreted as "trends".

3.3 Results

Neck flexion angle range of motion decreased consistently as a result of reclining the patient, with the change being significant in the case of the loose prism Strabismus exam ($36.83^\circ \pm 7.42^\circ$ vs. $30.98^\circ \pm 7.44^\circ$, $t_9 = 3.45$, $p = 0.007$). Detailed results are available in Table 3.2, and illustrated in Figure 3.3.

The percentage of procedural time that sagittal plane neck flexion was in non-neutral postures decreased consistently as a result of reclining the patient, with the change being significant in the case of the loose prism Strabismus exam ($22.93\% \pm 15.15\%$ vs. $11.98\% \pm 8.17\%$, $t_9 = 2.94$, $p = 0.017$). Detailed results are available in Table 3.3, and illustrated in Figure 3.4.

Table 3.2: Descriptive statistics and paired t-test results for the effect of patient recline on neck flexion angle range of motion (degrees)

			Mean	Std. Dev.	t	Significance(p)
Refraction	Loose Lens	No Recline	40.00	9.28	1.203	0.260
		Recline	38.24	9.31		
	Lens Bar	No Recline	38.82	9.47	0.453	0.661
		Recline	37.32	12.22		
Strabismus	Loose Prism	No Recline	36.83	7.42	3.447	0.007
		Recline	30.98	7.44		
	Prism Bar	No Recline	34.09	9.91	0.794	0.447
		Recline	32.24	10.91		

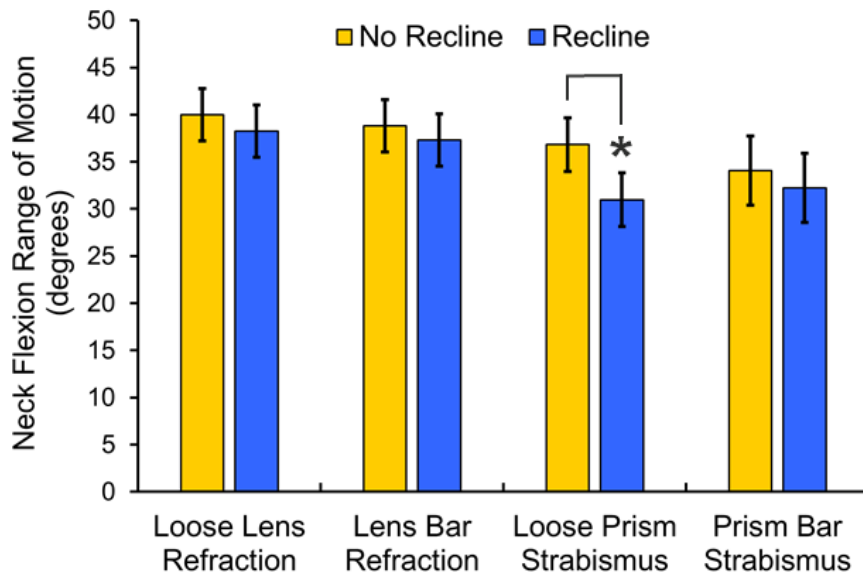


Figure 3.3: Effect of patient recline on eye care providers' sagittal plane neck flexion range of motion. Error bars = 1 standard error of the mean.

Table 3.3: Effect of patient recline on the percentage of procedural time eye care providers' necks were in non-neutral flexion (%)

			Mean	Std. Dev.	t	Significance(p)
Refraction	Loose Lens	No Recline	38.62	26.11	0.969	0.358
		Recline	32.52	11.69		
	Lens Bar	No Recline	39.77	25.72	1.348	0.211
		Recline	32.77	23.53		
Strabismus	Loose Prism	No Recline	22.93	15.15	2.937	0.017
		Recline	11.98	8.17		
	Prism Bar	No Recline	17.17	10.96	0.955	0.365
		Recline	13.56	6.87		

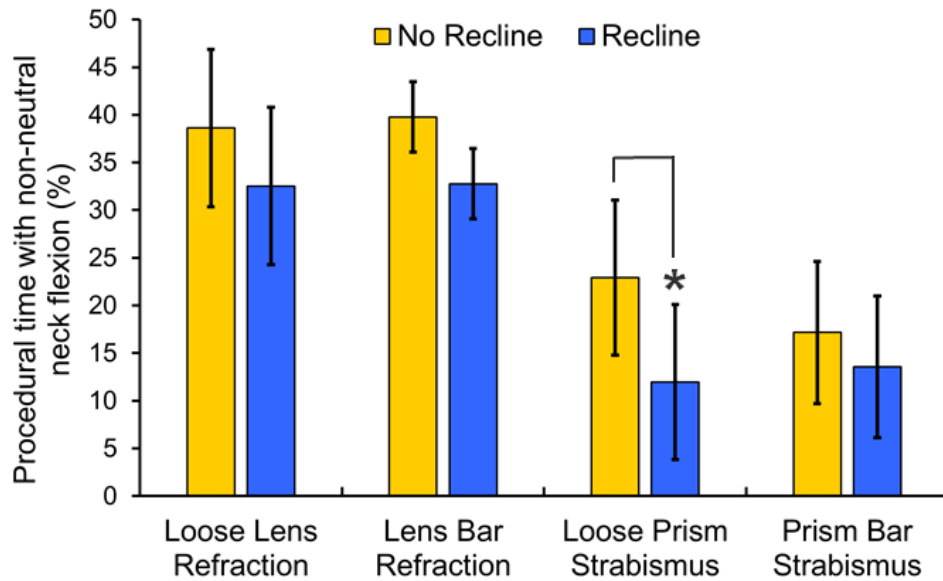


Figure 3.4: Effect of patient recline on the percentage of time that eye care providers' neck was in non-neutral flexion. Error bars = 1 standard error of the mean.

No consistent, discernible relationships were observed for the EMG data from the trapezius and deltoid muscles. Muscle activation area of the right erector spinae increased consistently in the refraction exams as a result of reaching over the patient from the right side to examine the left eye, compared to examining the patient's left eye from the left side. This change was statistically significant for loose lens refraction with no patient recline ($5.39 \text{ mV} \pm 2.58 \text{ mV}$ vs. $12.54 \text{ mV} \pm 8.67 \text{ mV}$, $t_9 = -2.519$, $p = 0.033$), and showed a trend towards significance (i.e. $p < 0.1$) for loose lens refraction with patient recline ($5.99 \text{ mV} \pm 4.19 \text{ mV}$ vs. $13.78 \text{ mV} \pm 10.53 \text{ mV}$, $t_9 = -2.104$, $p = 0.065$), and lens bar refraction with no recline ($5.32 \text{ mV} \pm 1.90 \text{ mV}$ vs. $13.30 \text{ mV} \pm 11.87 \text{ mV}$, $t_9 = -2.045$, $p = 0.071$). Detailed results are tabulated in Table 3.4 and visually depicted in Figure 3.5.

Table 3.4: Muscle activation area (mV) of the Right Erector Spinae (Iliocostalis fibers) during the Refraction exams when reaching over to examine the patient's left eye from the right side vs. examining the patient's left eye from the left side

		Mean	Std. Dev.	t	Significance(p)
Loose Lens - No Recline	No Reaching	5.39	2.58	-2.519	0.033
	Reaching	12.54	8.67		
Loose Lens - Recline	No Reaching	5.99	4.19	-2.104	0.065
	Reaching	13.78	10.53		
Lens Bar - No Recline	No Reaching	5.32	1.90	-2.045	0.071
	Reaching	13.30	11.87		
Lens Bar - Recline	No Reaching	6.77	4.22	-1.740	0.116
	Reaching	15.47	14.60		

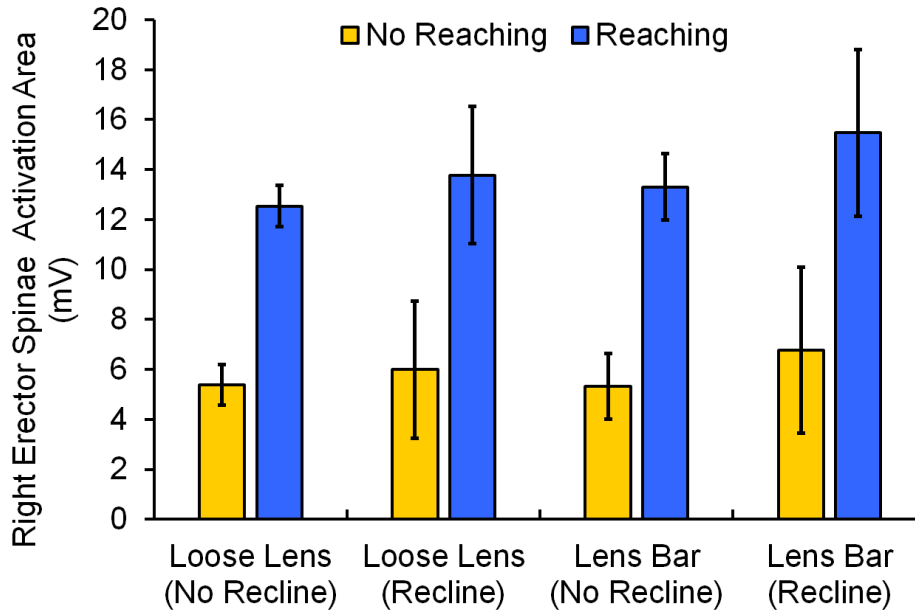


Figure 3.5: Muscle activation area (mV) of the Right Erector Spinae (Iliocostalis fibers) during the Refraction exams when reaching over to examine the patient’s left eye from the right side vs. examining the patient’s left eye from the left side. Error bars = 1 standard error of the mean.

3.4 Discussion

The National Institute of Occupational Safety and Health (NIOSH) recommends functional areas in the workplace to be designed in such a way that static loads and fixed postures are avoided, and that operators are not involved in activities that require them to lean to the front or side, hold limbs in bent or extended positions, or have the neck in flexion more than 15° for prolonged periods of time [19]. Prolonged, sustained static neck flexion (particularly if maintained at more than 15° or 20°) has been established in occupational health literature as a risk factor in diseases of the cervical spine and cervical disk [27, 93].

Reclining the patient for the refraction and strabismus examinations allowed eye care providers to move closer to the patient, and change their chair height to enable sitting upright when examining the patient. The observed reduction in sagittal plane neck flexion angle range of motion, and in the percentage of procedural time with non-neutral neck flexion as a result of patient recline in the refraction and strabismus examinations may indicate lower exposure for eye care providers to sustained non-neutral neck postures that may lead to the development of occupational MSDs. Additionally, the statistically significant reductions in neck flexion angle range of motion and the percentage of time with non-neutral neck flexion as a result of reclining the patient during loose prism strabismus may be due to the nature of the strabismus exam, where the patient focuses on a single point on the eye chart and the eye care provider has to ensure that they are not blocking the patient's line of sight.

Ophthalmic practice rooms are set up with right-hand dominant providers in mind, mainly because ophthalmic curriculum train eye care providers in a uniform, right-handed configuration. This may lead to consistent asymmetric loading of the trunk muscles, especially in the refraction exams where the eye care provider has to reach over the patient and maintain an awkward posture with abducted spine to examine the patient's left eye. Switching the eye care provider to the patient's left side to examine the patient's left eye (removing the need to reach over from the right side) exhibits a consistent decrease in erector spinae muscle activity in all the refraction exam trials. Designing ophthalmic examination rooms with ambidextrous access and refining training protocols to introduce bilateral training may help alleviate this asymmetric characteristic of trunk loading.

Overall, easily implemented postural adjustments may decrease the possibility of occupational MSDs by reducing time spent by eye care providers in un-ergonomic

postures.

This study did have some inherent limitations. The number of participants in this study was low, which made it challenging to observe statistically significant results. Furthermore, the use of a human surrogate (manikin), while necessary for standardization in this study, may not have adequately replicated daily activities faced by eye care providers in their clinics. Muscle activity characteristics, as a result of patient repositioning, may have been more consistent if the data was normalized using reference contractions (e.g. maximal voluntary or isometric contractions). Additionally, EMG sensor placement consistency may have affected data variability between subjects. However, since the EMG sensors were placed on individual subjects at the beginning of data collection and not removed until all trials were completed (and the study was set-up as a repeated measures study), within-subjects EMG data variability was likely minimal.

Despite its limitations, preliminary analyses from this and future studies may help establish a quantitative standard for ergonomic postures in ophthalmic practice, lead to a wide scale re-design of ophthalmic equipment, and facilitate the development of postural ergonomics-focused training curriculums for current and future ophthalmologists. However, a generalization of the procedural postural characteristics observed may not necessarily be accurate when applied to all practicing eye care providers, since this study focused specifically on pediatric eye care providers. Future studies should include a wider subset of eye care providers as participants, leading to a more generalizable study and a larger sample size.

CHAPTER 4

POSTURAL EVALUATION OF EYE CARE PROVIDERS AT THE SLIT LAMP USING KINEMATIC MOTION CAPTURE AND ELECTROMYOGRAPHY

4.1 Introduction

Eye care providers such as ophthalmologists and optometrists often maintain static postures of the neck, shoulder, elbow and wrist during their routine clinical examinations, which may lead to work-related musculoskeletal diseases (MSDs) and a decreased capacity for healthcare delivery. MSDs are a significant cause of occupational absence in developed countries [16–18], and are associated with a high economic cost [15]. In 2012, the American Academy of Orthopedic Surgeons reported that 25.5 million people in the US were affected by MSDs, 290.8 million workdays were lost to back or neck pain, and that the average person (across all professions) lost 11.4 workdays in the year to MSDs, bringing the monetary cost of treating MSDs in the US to \$213 billion [15].

MSDs in health professionals have been extensively documented, with the largest body of work related to MSDs in the dental and laparoscopic surgery fields [1–3, 32, 33]. Common physical risk factors for developing MSDs include performing tasks with frequent repetition, tasks where awkward postures are sustained, and tasks of long duration [19, 20]. Neck flexion, neck rotation and elevated arm postures subject neck and shoulder tissues to strain, which may provide an indication of why these postures are associated with neck pain [22] and shoulder pain [23]. In

determining the exposure-outcome association of occupational postures and MSDs, Coenen et. al. reported significant associations between neck flexion and rotation and neck pain, and arm elevation and neck and shoulder pain [25]. According to a systematic review of neck pain and disability in workers conducted by Côté et. al. [22], workers who maintained awkward occupational postures such as frequent bending or turning of the torso experienced a higher incidence of neck pain than workers who did not maintain such postures [29], workers who used armrests had a lower risk of developing neck and shoulder MSDs compared to those who did not use armrests [30], and that working with the neck in forward flexion $\geq 20^\circ$ increased the risk of developing neck pain [27, 31].

Over the last couple of decades, the frequency of work-related MSD among eye care providers has been reported widely, with high incidence of neck and lower back pain [4–8]. While the prevalence of MSD symptoms in these studies varies depending on the evaluation criteria, populations studied, and survey instrumentation used, these studies report an incidence of 30% - 70% for neck pain and 40%-80% for back pain. Similar findings were also reported in a recent survey study among consultant ophthalmologists in the UK, with 31.8% of participants reporting incidence of neck pain and 50.6% respondents reporting incidence of back pain [8]. When compared to their family medicine colleagues, eye care providers reported a statistically significant increased prevalence of neck, hand/wrist, and lower back pain [39].

In light of the high incidences of work-related MSDs in eye care providers, there is a clear need for evaluating occupational postures in eye care providers in order to identify sustained non-neutral postures exhibited in working practice, and develop working posture adjustments to address these. Current postural evaluations of eye care providers' working practice consists of qualitative self-reported discomfort

surveys (such as the Visual Analog Scale (VAS) [86]) and questionnaires which are key instruments used in the major publications that have brought forth a call for ergonomic adjustments to occupational practice. Additionally, a 2015 study by Fethke et. al. investigated neck and shoulder muscle activity among ophthalmologists during routine clinical examinations [11], and found that indirect ophthalmoscope, followed by slit lamp exam required greater muscular demands, compared to computer use or other clinical activities.

To have an objective measure of the ergonomics of practicing ophthalmologists, a motion-driven quantitative metric is required. Fields such as laparoscopy and microlaryngoscopy, where physicians encounter similar occupational MSDs, have utilized biomechanical motion capture [9] and electromyography [10] in such a capacity. Combining motion analysis and electromyography data may provide a granular, quantitative perspective on the operational ergonomics of eye care providers, and on the effectiveness of the procedural adjustments implemented in this study towards improving the ergonomics of eye care providers.

This study utilized kinematic motion capture and electromyography (EMG) to evaluate the effect of patient re-positioning, slit lamp height adjustment, and the use of an elbow rest on the posture of eye care providers performing simulated retina examinations at the slit lamp.

4.2 Methods

4.2.1 Apparatus and Approach

All experiments were conducted at the Broadway clinic of Children’s Mercy Hospital in Kansas City, MO, USA. A marker-based motion analysis system consisting of fourteen Optitrack Flex 13 cameras (Natural Point Inc., Corvallis, OR,

USA), along with a Dell Precision T 3610 workstation (Dell Inc., Round Rock, TX, USA) were used for this study, provided by the Center for Health Insights (UMKC School of Medicine, Kansas City, MO, USA). A Delsys Trigno 16-channel wireless electromyography system (Delsys Inc., Natick, MA, USA) was used for this study, provided by the Human Balance and Ambulation Research Laboratory of the School of Computing and Engineering (University of Missouri-Kansas City, Kansas City, MO, USA). A Haag-Streit Reliance FXM 920 ophthalmic examination chair, child CPR manikin, ophthalmologist chair, a Haag-Streit BM 900 slit lamp microscope and a Volk 90D double aspheric non-contact slit lamp lens were provided by Children’s Mercy Hospital Broadway clinic. Additional items used for this study included an angle finder, 4 C-clamps and a custom manufactured slit lamp platform elbow rest, all of which which were provided by (or manufactured at) the Human Balance and Ambulation Research Laboratory of the School of Computing and Engineering (University of Missouri-Kansas City, Kansas City, MO, USA).

The motion capture cameras were positioned in the data capture area in a way that all cameras collectively had an adequate field of view of the patient examination chair, ophthalmologists’ chair and any relevant ophthalmic equipment. The space was then calibrated using an Optitrack calibration wand to ensure accuracy of motion analysis data. The Optitrack motion analysis system was synchronized with the Delsys Trigno electromyography system through the Delsys Trigno Trigger Module. The manikin was positioned on the examination chair.

A unique, randomized 3 digit participant identification (Subject ID) number was generated and assigned to each of the 20 possible time slots within the five planned days of data collection. Study participants were then assigned the participant identification number corresponding to the time slot in which they elected to participate in the study (see Table A.1 in Appendix A).

This study was approved by the Children’s Mercy Hospitals & Clinic Pediatric Institutional Review Board (IRB), which can be contacted at (816) 701-4358 for verification purposes.

4.2.2 Participants

Ten practicing pediatric ophthalmologists and optometrists (five male and five female) aged 40 ± 9.52 years from Children’s Mercy Hospital Broadway clinic were recruited to take part in this study. Recruitment was conducted by Dr. Scott E Olitsky, who is an ophthalmologist in Children’s Mercy Hospital Broadway clinic, and Rebecca Dent who is the Ophthalmology Research Coordinator at Children’s Mercy Hospitals. Potential study participants were emailed a letter explaining the details of the study and inviting them to participate. The letter provided directions for them to reply by email to the study staff to secure a time for their study appointment. Study participants were not contacted again in order to avoid coercion to participate if they chose not to join the study. They were further informed that participation was voluntary and no positive or negative consequences would result from study participation. The recruitment letter is available in Appendix A.

Eligible study participants included eye care providers (pediatric ophthalmologists and optometrists) currently on staff or rotation at Children’s Mercy Hospitals Broadway clinic who are of age 18 or older, and who routinely perform pediatric ophthalmic procedures as part of their regular clinical practice. Potential participants were excluded if unable to comply with any of the task requirements, similar to those normally used in regular clinical practice, while wearing a motion capture suit and electromyography sensors. Prior surgical intervention was not an exclusion criteria. Prior musculoskeletal symptoms such as neck or back pain was neither inclusion nor exclusion criteria.

4.2.3 Experimental Procedure

Prior to motion analysis, participants were provided with their randomized 3 digit participant identification number and a laptop to fill out a confidential REDCap (Vanderbilt University, Nashville, TN) [88] questionnaire on which they were asked to self-report demographic information including age, height, gender, handedness, ophthalmic subspeciality, years of experience, frequency of patients attended to and incidence of MSD. A blank copy of this questionnaire is available in Appendix A.

Once each participant had filled out the REDCap questionnaire, their EMG sites were prepared by cleaning with rubbing alcohol, and they were fitted with surface EMG sensors using double-sided hypoallergenic tape on the upper and lower trapezius, and anterior and posterior deltoid. EMG sensors were placed according to the European Recommendations for Surface Electromyography (SENIAM) [89]. The placement order of these electrodes was kept consistent for each participant by utilizing the native numbering system on each wireless electrode in the Trigno system and assigning each numbered electrode to a certain muscle (available in Appendix A). Each participant was then asked to don an upper body motion capture suit with a 27-marker upper body Motive motion capture setup. This setup is illustrated in Figure 4.1. Once in the capture area, participants were asked to stand still in the "T-pose" posture shown in Figure 4.1 to collect static data used to define neutral/upright neck postures.

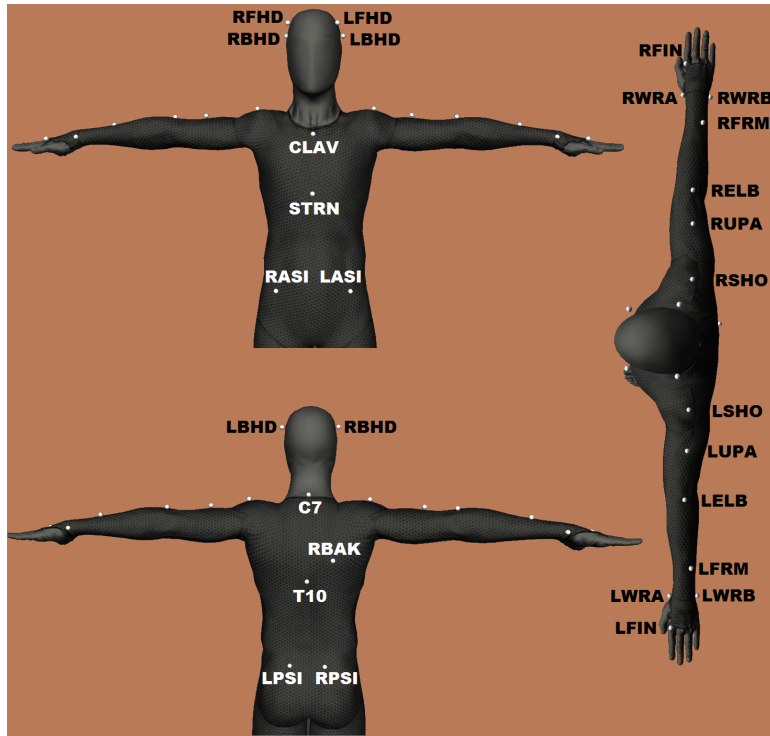


Figure 4.1: 27 marker upper-body motion analysis configuration

Slit lamp examinations were performed under 3 conditions: no postural adjustments (with the slit lamp at its lowest position and the patient sitting back in the chair), postural adjustment by altering slit lamp platform height and patient position (such that the eye care provider was sitting upright and not leaning forward), and postural adjustment with an elbow rest under arm holding the 90D lens (such that the upper arm was supported). The details of the different conditions are described in detail in Table 4.1.

Table 4.1: Slit lamp examinations and relevant adjustments

Procedure	Experiment/ Repetition	Procedure Details	Setup Notes
Slit Lamp Examination	3	Participant chair at lowest height, no elbow rest installed	All participants performed only a specific portion of the slit lamp examination, namely performing a general funduscopy examination of each eye of the patient (manikin) with a 90D double aspheric non-contact slit lamp lens. The examination order followed included spending equal times on first examining the right eye of the patient (manikin) and then the left eye.
	3 + Int1	Slit lamp platform and examination chair raised to give participant a more ergonomic sitting posture (back upright, no forward lean)	
	3 + Int2	Slit lamp platform and examination chair raised to give participant a more ergonomic sitting posture (back upright, no forward lean) and an elbow rest installed	The elbow rest was custom manufactured and had 4 different height levels which were adjusted for each participant based on the size of their forearms. Some participants had sufficiently long forearms and did not need an elbow rest, so only the top layer of the elbow rest was provided which was essentially a layer of padding for the elbow with minimal elbow height or support effect.

4.2.4 Data Capture and Analysis

Individual marker data was recorded by the Optitrack Motive software (Natural Point Inc, Corvallis, OR, USA). For each participant, relevant de-identified biometric data was collected from the REDCap questionnaire. The electromyography data for each participant was acquired through EMGWorks software (DELSYS, Natick, MA, USA). The principal measurements recorded were the 3D position data of the motion capture markers, and the electrical activity data of the EMG electrodes. Secondary measurements include the sampling rate of the Flex 13 cameras (120 Hz) and the surface EMG electrodes (1925.76 Hz). Motion data and EMG waveform data were exported as .csv files and analyzed using MATLAB R2016a (The Mathworks, Natick, MA, USA). IBM SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, NY, USA) was used for all statistical analyses.

Joint angles between neighboring body segments were calculated by first defining local coordinate systems (LCS) on each segment, and then relating the two segments via a Cardan rotation sequence [90]. The Cardan rotation sequence XYZ is often used in biomechanics to generate a 3-D rotation matrix, which is the orientation of one LCS with respect to another LCS, and is represented by three successive rotations about unique axes. This sequence is done in three steps: first, rotation about the laterally directed X axis (α), second, rotation about the anteriorly directed Y axis (β), and third, rotation about the vertical Z axis (γ). The Cardan rotation matrix between two LCS is equivalent to the element-wise dot product of the unit vector matrices of those two LCS (presented in Equation 4.1).

$$R = \begin{bmatrix} cac\beta & cas\beta s\gamma - sac\gamma & cas\beta s\gamma + sas\gamma \\ sac\beta & sas\beta s\gamma + cac\gamma & sas\beta s\gamma - cas\gamma \\ -s\beta & c\beta s\gamma & c\beta c\gamma \end{bmatrix} = \begin{bmatrix} i.I & j.I & k.I \\ i.J & j.J & k.J \\ i.K & j.K & k.K \end{bmatrix}$$

Equation 4.1 XYZ Cardan rotation matrix and its equivalent

where R = Cardan rotation matrix, s = sine, c = cosine, $[i, j, k]$ = Local coordinate system for Segment 1, $[I, J, K]$ = Local coordinate system for Segment 2.

Equating the two definitions of the rotation matrix allows the calculation of the three rotational angles, α , β , and γ . For anatomical segments, α is the flexion/extension, β is the abduction/adduction and γ is the pronation/supination (or axial rotation). Joint rotation angles calculated in this manner are Euler angles. While they are closely related to the anatomical rotation angles, they may not correlate exactly with physiological conventions.

Raw EMG waveforms were band-pass filtered using a 4th order butterworth filter between 35 Hz and 500 Hz, to reduce contamination from movement artifacts, electrocardiogram signals and high frequency noise [89,91]. Upon inspecting power spectral density, EMG waveforms exhibited spurious spikes at approximately 60 Hz.

Assuming that these spikes were caused by electrical interference, the waveforms were notch-filtered between 59 Hz and 61 Hz using a 4th order butterworth filter. EMG waveforms were then full-wave rectified, demeaned and subjected to a low-pass 4th order Butterworth filter with a cutoff frequency of 50 Hz [92] to obtain the EMG envelope.

For this study, outcome measures include sagittal plane neck flexion angle range of motion, the percentage of procedural time that neck flexion remained in non-neutral posture (i.e. $> 20^\circ$ flexion and any extension [27, 31]), activation area of the upper trapezius and anterior deltoid, and the percentage of procedural time that the upper trapezius and anterior deltoid muscles were active.

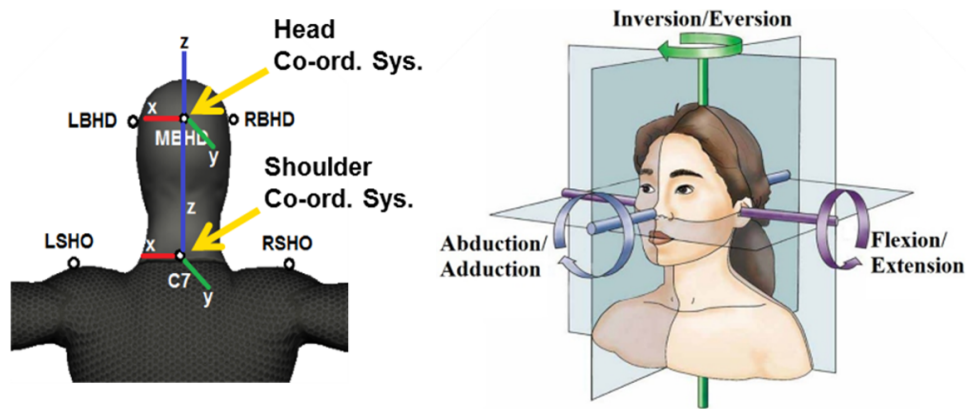


Figure 4.2: Shoulder and head co-ordinate systems (L) used to calculate the rotational angles of the neck (R), adapted from mcqs.leedsmedics.org.uk

Figure 4.2 illustrates the rotational euler angles of the neck as calculated by the shoulder and head local co-ordinate systems and a Cardan rotation sequence. Neck flexion angle range of motion was calculated by subtracting the minimum value of flexion in a time series from the maximum value of flexion. The percentage of procedural time with non-neutral neck flexion was calculated by finding the indices in the time series where neck flexion was greater than 20° or less than 0° (i.e. in ex-

tension) compared to the neutral/upright "T-pose" posture data collected at the beginning of each trial, and dividing that number by the total number of indices in the time series multiplied by 100.

Numerous methods have been developed and tested to determine EMG onset which requires detecting the first time a muscle starts showing electrical activity separate from ambient noise in the EMG signal. Notable methods of EMG onset determination include finding the first point where the EMG envelope crosses a threshold defined by deviation from baseline resting EMG levels [92], generalized likelihood methods [94,95], and the usage of Teager-Kaiser energy (TKE) operators [96]. EMG onset for this study was estimated to be the first time the filtered and rectified EMG envelope values exceeded a threshold value of the baseline (resting) EMG mean values added to three standard deviations from baseline. From the onset point, a muscle was said to be active when a sliding window of fifty samples in the EMG data had thirty-five or more samples that crossed the threshold [92]. The percentage of procedural time that a muscle was active was calculated by finding the indices of the time series where the muscle was active according to the definition above, and dividing that number by the total number of indices in the procedural time series, multiplied by 100.

The activation area of a specific muscle is referred to as the area under the curve for filtered and rectified EMG waveform envelope of that muscle, found by trapezoidal integration. Since each procedure compared had slightly different times, the activation area of individual muscles was normalized by dividing their activation area by the time of each trial. It is to be noted that this method of calculating an activation area is not a standard outcome measure in EMG analysis, but was used in this study to provide a standardized basis for observing effects of procedural adjustments on muscle activity.

For analyses purposes, the time periods of the kinematic and EMG data were isolated only to the time period when the eye care provider was performing each examination (or a specific part of the examination). The kinematic and EMG outcome measures were compared pairwise (adjustment vs. no adjustment) using two-tailed paired t-tests if the differences between pairs of data points were normally distributed or by Wilcoxon signed-rank tests if the differences were not normally distributed. To test for the normality of the data, differences between the pairwise comparison datasets were calculated. These differences were visually inspected for outliers using a Q-Q plot and data normality was established if the Shapiro-Wilk test statistic was found to be non-significant ($p > 0.05$) for each comparison.

Since this study was a pilot study with a small sample size, considerations were implemented beyond simply finding two-tailed statistical significance ($p < 0.05$), where comparisons that generated p-values of 0.1 or lower were interpreted as "trends".

4.3 Results

Due to postural adjustment, eye care providers' neck flexion angle range of motion decreased significantly ($44.44^\circ \pm 9.14^\circ$ vs. $36.94^\circ \pm 8.78^\circ$, $t_9 = 4.77$, $p = 0.001$), the percentage of procedural time that their sagittal plane neck flexion was in non-neutral postures decreased significantly ($34.65\% \pm 21.58\%$ vs. $16.55\% \pm 14.55\%$, $t_9 = 2.28$, $p = 0.049$), and their upper trapezius muscle activation area decreased ($54.98 \text{ mV} \pm 51.39 \text{ mV}$ vs. $42.25 \text{ mV} \pm 35.92 \text{ mV}$, $t_9 = 1.528$, $p = 0.161$). Using an elbow rest significantly decreased the percentage of procedural time that eye care providers' Anterior Deltoid muscle was active ($50.71\% \pm 15.66\%$ vs. $40.77\% \pm 13.64\%$, $t_9 = 2.84$, $p = 0.019$). Detailed results are available in Table 4.2, and illustrated in Figure 4.3.

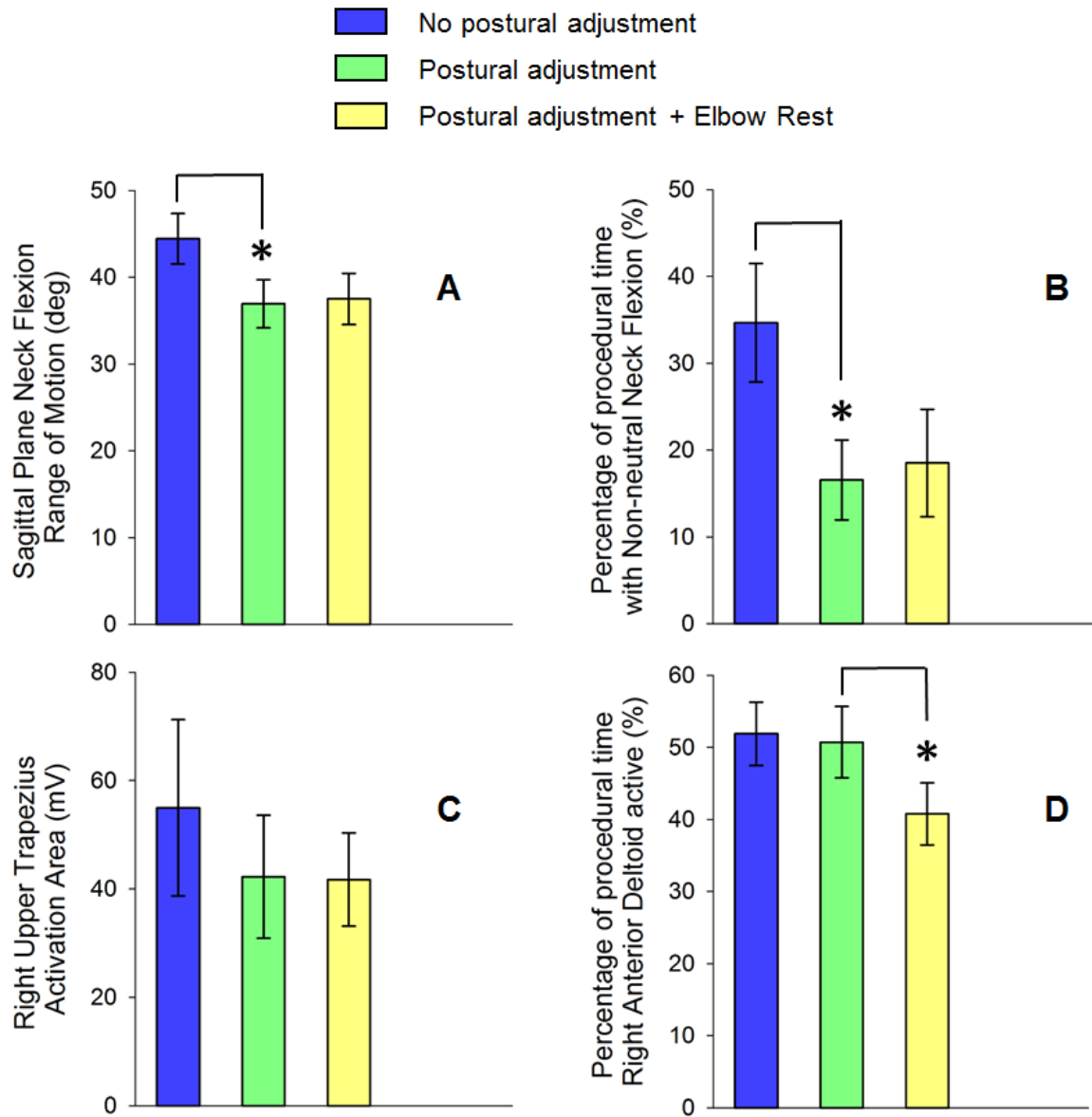


Figure 4.3: Sagittal plane neck flexion range of motion (A), percentage of procedural time that the neck was in non-neutral flexion (B), activation area of the right Upper Trapezius (C) and the percentage of procedural time right Anterior Deltoid was active (D). Error bars = 1 standard error of the mean.

Table 4.2: Neck flexion angle range of motion (degrees), procedural time with non-neutral neck flexion (%), Upper Trapezius muscle activation area (mV) and procedural time with the Anterior Deltoid muscle active (%) for the conditions: No Adjustment (NA), Postural Adjustment (PA) and Postural Adjustment with Elbow Rest installed (PA+ER)

		Mean	Std. Dev.	t	Significance (p)
Neck flexion	NA	44.44	9.14	4.774	0.001
	PA	36.94	8.78		
ROM (deg)	PA	36.94	8.78	-0.244	0.813
	PA + ER	37.51	9.33		
Procedural time with non-neutral neck flexion (%)	NA	34.65	21.58	2.276	0.049
	PA	16.55	14.55		
	PA	16.55	14.55	-0.777	0.457
	PA + ER	18.50	19.60		
Upper trapezius muscle Activation Area (mV)	NA	54.98	51.39	1.528	0.161
	PA	42.25	35.92		
	PA	42.25	35.92	0.109	0.916
	PA + ER	41.73	27.19		
Procedural time with anterior deltoid Active (%)	NA	51.89	13.88	0.179	0.862
	PA	50.71	15.66		
	PA	50.71	15.66	2.838	0.019
	PA + ER	40.77	13.64		

4.4 Discussion

Prolonged, sustained static neck flexion has been established in occupational health literature as a risk factor in diseases of the cervical spine and cervical disk. Occupations where neck flexion greater than 15° to 20° are prevalent have been shown to be highly associated with persistent pain, stiffness and muscle tenderness in the neck [27, 93]. This type of pain is characteristic of tension myalgia which occurs as a result of sustained static contraction of neck muscles [97].

Postural adjustment by moving the patient forward and raising the slit lamp platform height to where eye care providers were sitting upright (instead of hunching down and leaning forward) allowed eye care providers to examine the patient with more neutral postures. This was supported by the significant reductions in the sagittal plane neck flexion angle range of motion, the percentage of procedural time that the neck was in non-neutral neck flexion (i.e. greater than 20° flexion and any extension), and the upper trapezius muscle activation area when compared between no postural adjustment and postural adjustment.

Additionally, using an elbow rest allowed eye care providers to perform slit lamp biomicroscopy with a reduced amount of unsupported arm raise of the shoulder and upper arm, which may alleviate fatigue effects in a long workday. This was supported by the significant decrease in the percentage of time the anterior deltoid muscle was active when compared between no elbow rest use and elbow rest use. Our findings are in line with previous studies that have shown a reduction in anterior deltoid activity when an elbow rest or arm rest is used, compared to when the forearm and upper arm are unsupported, as seen in pipette users where mean anterior deltoid activity was reduced due to forearm support [62], and in female university students where anterior deltoid activity was seen to decrease due to forearm support

across multiple shoulder flexion angles [63].

Overall, easily implemented postural adjustments, patient repositioning and supportive equipment usage may decrease eye care providers' likelihood of occupational musculoskeletal disorders by reducing the time they spend in un-ergonomic postures.

This study did have some limitations. The number of participants in this study was low, which made it challenging to observe statistically significant results. Furthermore, the use of a human surrogate (manikin), while necessary for standardization in this study, may not have adequately replicated daily activities faced by eye care providers in their clinics. Muscle activity characteristics, as a result of patient repositioning, may have been more consistent if EMG data were normalized using reference contractions (e.g. maximal voluntary or isometric contractions). Additionally, EMG sensor placement consistency may have affected data variability between subjects. However, since the EMG sensors were placed on individual subjects at the beginning of data collection and not removed until all trials were completed (and the study was set-up as a repeated measures study), within-subjects EMG data variability due to sensor placement is likely to be low.

Despite of the limitations, preliminary analyses from this and future studies may help establish a quantitative standard for ergonomic postures in ophthalmic practice, lead to a wide scale re-design of ophthalmic equipment, and facilitate the development of postural ergonomics-focused training curriculum for current and future ophthalmologists. However, a generalization of the procedural postural characteristics observed may not necessarily be accurate when applied to all practicing eye care providers, since this study focused specifically on pediatric eye care providers. Future studies will include a wider subset of eye care providers as participants, leading to a more generalizable study and a larger sample size.

CHAPTER 5

USING MOTION CAPTURE TECHNOLOGY TO MEASURE THE EFFECTS OF MAGNIFICATION LOUPES ON DENTAL OPERATOR POSTURE: A PILOT STUDY

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5.1 Abstract

Background

Motion analysis has great potential for quantitatively evaluating dental operator posture and the impact of interventions such as magnification loupes on posture and subsequent development of musculoskeletal disorders.

Objective

This study sought to determine the feasibility of motion capture technology for measurement of dental operator posture and examine the impact that different sty-

les of magnification loupes had on dental operator posture.

Methods

Forward and lateral head flexion were measured for two different operators while completing a periodontal probing procedure. Each was measured while wearing magnification loupes (flip up-FL and through the lens-TTL) and basic safety lenses.

Results

Operators both exhibited reduced forward flexion range of motion (ROM) when using loupes (TTL or FL) compared to a baseline lens (BL). In contrast to forward flexion, no consistent trends were observed for lateral flexion between subjects.

Conclusions

The researchers can report that it is possible to measure dental operator posture using motion capture technology. More study is needed to determine which type of magnification loupes (FL or TTL) are superior in improving dental operator posture. Some evidence was found supporting that the quality of operator posture may more likely be related to the use of magnification loupes, rather than the specific type of lenses worn.

Keywords

Ergonomics, Musculoskeletal Disorders, Kinematics, Range of Motion, Biomechanics

5.2 Introduction

The literature is replete with evidence that dentists and dental hygienists frequently encounter neck, back, and shoulder injuries as a result of spending long durations of time in non-neutral positions. [1, 34–37] Musculoskeletal pain will begin early in the careers of dentists and dental hygienists and will eventually worsen to result in reduction of work hours or early exit from clinical practice. [36, 38] The impairment caused by musculoskeletal disorders (MSDs) on dental operators' clinical activities has a significant impact on the healthcare delivery system and can become a factor in the rising costs of healthcare. [37]

Numerous interventions have been suggested in the literature to reduce the risks of MSDs among dental operators. Kanteshwari studied operator awareness of dental posture to counteract the pain of MSDs. [69] Hayes reported on interventions such as magnification loupes, proper light utilization and task analyses to direct the operator to more neutral positions in order to minimized musculoskeletal disorders. [70] Valachi reports on the use of physical fitness, stretching and exercise to offset the static postures common in dentistry. [71–73] Others have investigated the impact of ergonomic operator stools to offset the impact of musculoskeletal disorders. [74, 75] One of the most frequently studied interventions is the use of magnification loupes to improve operator posture and vision to thus reduce musculoskeletal disorders among dental operators. [76–83]

Many researchers have reported overall improvement in dental operator posture while wearing magnification loupes. [74, 76, 81, 98, 99] However, posture in these studies was characterized using subjective measurements from self-reports and observer impressions during real-time or video-tape evaluations. [69, 100–102] Other studies have addressed these limitations by using more quantitative dental ergonomic mea-

asures such as electromyography to evaluate muscle use and forces. [103–106] Motion analysis has been used to examine posture in older adults, sports, and ambulatory settings. [50–54] This type of measurement has great potential for quantitatively evaluating dental operator posture and the impact of interventions such as magnification loupes on posture and development of MSDs.

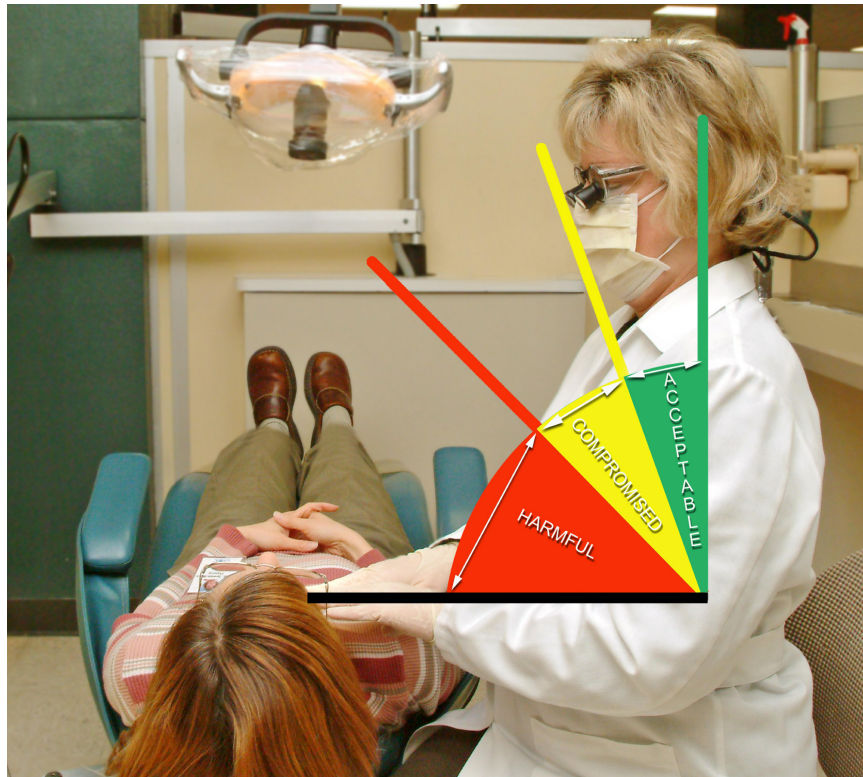


Figure 5.1: Photo of acceptable, compromised and harmful posture

Traditionally, dental operator posture is evaluated as it deviates from the desirable neutral posture. Neutral posture assumes that the operator stays in an upright baseline position along the frontal and mid-sagittal plane with little deviation forward (forward flexion) or sideways (lateral deviation). (Figure 5.1). Branson reports that movement deviating from these planes may put a dental operator in a compromised or at risk position for MSDs, depending upon the length of time that the non-neutral posture is held. [47] The use of motion capture technology al-

lows the measurement of deviations from a baseline or neutral posture to be more precise than those made with observations and self-reports. Thus, motion capture technology may be a potentially useful and more precise modality in evaluating the effectiveness of magnification loupes on dental operator posture.

5.3 Review of the Literature

A review of the literature shows a notable increase in the number of dental professionals using loupes to improve visual acuity and improved posture. Mansueto reported that in 2003 55% of dental professionals were using magnification loupes in the delivery of dental care. [107] A Clinical Research Report, August, 2016, stated that in a recent survey of 1600 dental clinicians, 90% used magnification loupes. [108] The dental loupes industry features many types and qualities of loupes designs. These features include a wide variance in the configuration of the optics. Two notable types are diopter and Galilean optics. Diopter lenses are similar to a magnifying glass and the rounded shape of the lens leads to chromatic and spherical aberrations. Diopter lenses are also heavier than the Galilean systems. Galilean lens systems have a series of compound lenses which allow for the bending of light and greater sharpness of the image. Also, prices of the loupes vary based on the quality of the lenses with diopter configurations often costing less than \$150.00 and Galilean lenses usually costing between \$500.00 and \$1000.00. [108]

Dental operators must also consider the depth and width of the field to be visualized. This is related to the power of the lenses. The greater the power, i.e. 6x magnification, the less the size of the depth and width of field. Also, the working distance from the operator's eyes to the target tooth/teeth must be considered. This distance is usually 16 to 20 inches. The weight of the loupes presents as a further consideration when making a purchase decision. Typically the lighter

the loupes, the less head and neck tension one will experience. Some loupes weigh as little as 2.3 ounces. Another area of concern when choosing loupes is the angle of declination of the head. In other words, the angle of forward flexion of the head along the midsagittal plane that the loupes fixes the head for visualizing the mouth. [107]



Figure 5.2: (a) Safety lenses with light attachment-no magnification. (Basic eye-wear BL), (b) Through the lens magnification loupes with light attachment. (TTL), (c) Flip Up magnification loupes-with light attachment. (FL)

Minimal literature exists to give dental operators guidance in purchasing loupes that will be effective at meeting individual needs. Often decisions are influen-

ced by salespersons from the optical companies; in addition to price promotions, sales techniques and peer recommendations. In addition to sales techniques, purchase decisions are based on width and depth of vision desired, weight, comfort and style. Evidence is non-existent to support the purchase of one form of loupes over another. Most dental operators choose to wear Galilean loupes. There are two configurations of Galilean lenses- “Through-the Lens” (TTL) style loupes or “Flip-Up” (FL) style loupes. [108, 109] See Figure 5.2. TTL style loupes have the magnification loupes fixed onto the lenses of the safety glasses and adjustment of head forward flexion, or declination angle, is not possible, because the angle is fixed in one position. FL style loupes are hinged onto the body of the safety lenses. The moveable hinge allows for an adjustment of the forward flexion of the head.

The choice of purchasing TTLs or FL is an important consideration in that the operator’s angle of declination (forward flexion of the head) could be influenced by the style of loupes. Only anecdotal preferences are reported. [110] Bethany Valachi, physical therapist and author of many publications dealing with dental ergonomics, states that TTL loupes tend to force the dental operator’s head forward greater than the optimal 20 degrees due to an un-adjustable declination angle. She reports that FL loupes are a more desirable style due to the adjustable declination angle. [110] No studies were found to substantiate the degree of forward head flexion that exists with each type of loupes.

To the best of our knowledge, motion analysis studies, specifically ones involving marker-based motion analysis, have not been conducted to evaluate the ergonomics and working postures of dental operators. Ergonomic postural analysis studies using motion analysis have been conducted in the past among laryngologists [9], laparoscopists [55] and assembly line operators. [111] A 2009 study by Statham et. al. evaluated the working posture of laryngologists performing simulated

microlaryngoscopy at three different operative positions. [9] It was observed that higher-risk postures were obtained with unfavorably adjusted eyepieces and lack of any arm support during microlaryngoscopy, both of which increased neck strain and shoulder torque. Kolwadkar et. al. compared the postural characteristics of a group of 17 surgeons and medical students using two types of surgical handheld manipulators: one using a controlling wheel, and the other with a controlling joint. It was observed that the controlling joint manipulator was more difficult to handle, resulting in larger range of motion, higher velocities and accelerations in some upper extremity joints [55]. Puthenveetil et. al. in 2015 described a method of simulating an assembly operation in a virtual environment to analyze the posture of assembly workers in the aerospace industry. The positions, orientations of the head, elbow and wrist of a human body were recorded using optical markers to evaluate the risk of workplace related injury. [111]

The researchers in this study sought to pilot test the use of motion capture as a means to analyze the effects that TTL loupes and FL loupes had on working postures of dental operators in comparison to non-magnified baseline lenses (BL). The purpose of the study was to determine the feasibility of motion capture technology to measure dental operator posture and examine the impact that different styles of magnification loupes had on the posture of dental operators.

5.4 Methodology

5.4.1 Subjects

Two dental operators served as subjects for this study which was reviewed by the University of Missouri-Kansas City Institutional Review Board. Operators were chosen based on a variety of opposing demographics. One operator being male, the other female. One operator was a recent graduate from a periodontal residency program and the other a dental hygienist with twenty-eight years of clinical experience. Both were of similar height. Descriptions of Operators 1 and 2 can be found in Table 5.1.

Table 5.1: Dental Operator Demographics

Characteristics	Operator 1	Operator 2
Gender	Male	Female
Age	29	52
Years in Clinical Practice	2 years	28 years
Height	5'7"	5'2"
Profession	Newly Graduated Periodontist	Dental Hygienist

5.4.2 Equipment and Measurement Procedures

Each operator received a complimentary set of TTL loupes, FL loupes and basic safety glasses (BL) from the Orascoptic[®]Company. Each subject was fitted for TTL and FL loupes by the same Orascoptic[®]sales representative. The female operator was fitted with an Orascoptic[®]RDH frame, with a magnification power of 2.5 x for both sets of loupes. The male operator was fitted with the Orascoptic[®]Rydon frame, with a magnification power of 2.5 X for both sets of loupes. Additionally

the dental hygienist operator had her optical prescription put into all the lenses (TTL, DL and BL). This consisted of basic safety lenses worn by the periodontist and prescription lenses worn by the dental hygienist. Additionally each operator used an Orascoptic® Endeavor LED headlight attached to the loupes. When using basic eyewear, the overhead dental operatory light was used.

The dental operatory was outfitted with a standard patient chair with over the patient delivery. An overhead dental light was secured to the dental chair for use with the basic eye wear. The operator sat upon a standard operator stool equipped with back and wheels for mobility. This setting was selected because the researchers wanted to test feasibility of using motion capture in an authentic dental office setting.

Movement of the operators was captured while performing a simple periodontal probe depth measurement sequence on all quadrants of a live patient. This procedure was selected because both dentists and dental hygienists commonly complete the periodontal probing procedure and both operators were well-practiced in using the periodontal probe. The same live patient was used for all procedures to control for variability associated with patient differences.

In the time period prior to the motion capture session the operator would wear the designated lenses or loupes for a period of two weeks to become adjusted to the type of lenses/loupes to be measured in the upcoming motion capture session. The type of lenses/loupes that each operator wore for the session varied by operator. The schedule for measurement of lenses/loupes is displayed in Table 5.2.

Table 5.2: Schedule for lenses/loupes use

Operator 1	Operator 2
BL Adjustment Period (Two weeks)	FL Adjustment Period (Two weeks)
Data Capture Session 1	Data Capture Session 1
TTL Adjustment Period (Two weeks)	BL Adjustment Period (Two weeks)
Data Capture Session 2	Data Capture Session 2
FL Adjustment Period (Two weeks)	TTL Adjustment Period (Two weeks)
Data Capture Session 3	Data Capture Session 3



Figure 5.3: Photo of Operator at Chairside wearing body suit

Each operator was fitted with a motion capture suit to wear during testing sessions to make movement observation easier and adherence of the motion capture sensors more secure. At the beginning of each motion capture session the operator donned the motion capture suit. Retroreflective markers were attached on the suit over major bony landmarks. A photograph of the suit is displayed in Figure 5.3.

A standard dental operatory was equipped with a 10-camera OptiTrack motion capture system (NaturalPoint, Inc., Corvallis, OR, USA). This system measured and recorded 3D positions of operators' reflective markers during each procedure. Data were collected using Motive software (NaturalPoint) and analyzed using MATLAB (The MathWorks Inc., Natick, MA, USA). Data were sampled at a rate of 120 Hz, resulting in a time series matrix containing the X, Y, and Z coordinates of each marker for each procedure performed. All camera equipment was set up strategically around the room so that each camera had a clear view of the target volume, defined as the area in which the operator moves around the patient. Prior to each motion capture session, the cameras and software were calibrated and tested by researchers in the UMKC Department of Civil and Mechanical Engineering. Prior to the beginning of the motion capture session, the operator was instructed to sit on the operator stool and make any adjustments to the stool that were necessary. The operator was also told to adjust the height of the patient chair to facilitate visualization of the patient's mouth. The operator was instructed to move freely around the head of patient that was most comfortable to them. When analyzing the data we found that operators were mostly between the 8:00 and 12:00 positions when treating the patient. The operator was also told that asking the patient to move their head in any direction to facilitate instrumentation was permissible. All conditions were set so that the procedure should proceed just as it would in an actual clinical setting.

During the motion capture session, the operator would begin by assuming a neutral posture and the research assistant would take a measurement to determine the baseline or neutral posture. Then the operator would proceed to collect the periodontal depths of the patient using a standard probe. There was no time limit in which this procedure had to be completed.

5.5 Data Collection and Analysis

Shoulder and head marker positions were used to define unit vector matrices forming the axes of local coordinate systems (LCS) for the torso and head, respectively. The element-wise dot product of the LCS unit vector matrices was calculated. This result is equivalent to the 3D Cardan rotation matrix representing the relative orientation between the torso and head LCS.

$$R = \begin{bmatrix} i_T \cdot i_H & j_T \cdot i_H & k_T \cdot i_H \\ i_T \cdot j_H & j_T \cdot j_H & k_T \cdot j_H \\ i_T \cdot k_H & j_T \cdot k_H & k_T \cdot k_H \end{bmatrix} = \begin{bmatrix} \cos\alpha\cos\beta & \cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma & \cos\alpha\sin\beta\sin\gamma + \sin\alpha\sin\gamma \\ \sin\alpha\cos\beta & \sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma & \sin\alpha\sin\beta\sin\gamma - \cos\alpha\sin\gamma \\ -\sin\beta & \cos\beta\sin\gamma & \cos\beta\cos\gamma \end{bmatrix}$$

Angle time series representing sagittal-plane (α) and frontal-plane (β) head flexion were extracted from this matrix by equating elements of the dot product matrix to corresponding Cardan rotation matrix terms:

$$\beta = -\sin^{-1}R_{3,1}$$

$$\alpha = \sin^{-1}\frac{R_{2,1}}{\cos\beta}$$

These angles were selected as they are equivalent to the head forward and lateral flexion angles away from the body midline used in the Branson's Posture Assessment Instrument. [47] Although the equations above enable head axial rotation (γ), this angle was not analyzed further in the context of this pilot study.

Angular ranges of motion (ROM) and standard deviations (SD) were extracted from the α and β time series. This was done in 3 ways. First, ROM and SD were

extracted from a fixed 40-second duration of time (T_{40}), which was the longest period of continuous task performance observed in both participants. Since the operators took different amounts of time to complete the procedure, we also extracted ROM and SD from two additional periods of data defined by position rather than by time. The first of these (T_{9-12}) was defined as the longest amount of time the operator was working within the 9-12 o'clock position when viewed from above. The second (T_{Reach}) was defined as the duration from which the operator selected the probe and then continued with the probe before reaching for the tray to set the probe aside.

ROM and SD metrics were calculated for each subject (O1 and O2) within the three durations (T_{40} , T_{9-12} , and T_{Reach}) for each lenses studied (BL, TTL, FL). Results from TTL and FL lenses were compared to the results while using basic lenses (BL) with no magnification. Since this was a pilot study, a full statistical analysis was not possible; only qualitative comparisons were made in outcome metrics among lens conditions.

5.6 Results

5.6.1 Forward Flexion (α)

The two operators both exhibited reduced forward flexion range of motion (ROM) when using loupes (TTL or FL) compared to a baseline lens (BL). On average, Operator 1 achieved marginally better results when using the TTL lens (a 50.1% decrease in flexion ROM from BL, as compared with 48.9% decrease when using the FL lens). On average, Operator 2 achieved consistently better results when using the FL lens (a 73.9% decrease in flexion ROM from BL, as compared with 26.6% decrease in forward flexion when using the TTL lens). (Table 5.3) The mag-

nification conditions (TTL and FL) were associated with consistently smaller standard deviations (SD) of forward flexion for Operator 1, with the TTL producing larger decreases from BL (40.1%) compared to FL (20.6%). Magnification conditions appeared to have minimal effects on SD of forward flexion for Operator 2. (Table 5.4)

Table 5.3: Forward flexion range of motion (ROM), in degrees, for all lens types (BL, TTL, and FL) and all analysis periods (T_{40} , T_{9-12} , and T_{Reach})

	Operator 1			Operator 2		
	T_{40}	T_{9-12}	T_{Reach}	T_{40}	T_{9-12}	T_{Reach}
BL	22.3	19.6	20.2	16.8	18.2	21.7
TTL	12.3	8.5	10.3	12.7	14.3	14.3
FL	10.0	10.8	10.8	0.4	8.7	6.1

Table 5.4: Forward flexion standard deviation (SD), in degrees, for all lens types (BL, TTL, and FL) and all analysis periods (T_{40} , T_{9-12} , and T_{Reach})

	Operator 1			Operator 2		
	T_{40}	T_{9-12}	T_{Reach}	T_{40}	T_{9-12}	T_{Reach}
BL	0.8561	4.042	3.925	0.9551	2.6874	2.6881
TTL	0.4281	1.7334	3.4036	1.8872	2.3216	2.3216
FL	0.4757	3.6363	3.6363	1.5785	2.9859	3.2992

5.6.2 Lateral Flexion (β)

In contrast to forward flexion, no consistent trends were observed for lateral flexion between subjects. In Operator 1, the magnification conditions produced inconsistent trends in comparison to BL lenses across the 3 analysis periods, with an average increase in lateral flexion when using magnification. Similar inconsistencies

were observed in Operator 2, but with an average decrease in lateral flexion for the magnification conditions in comparison to BL. (Table 5.5) The magnification conditions (TTL and FL) were associated with consistently larger standard deviations (SD) of lateral flexion for Subject 1, with the FL producing larger decreases from BL (25.4%) compared to TTL (18.4%). Magnification conditions appeared to have minimal effects on SD of lateral flexion for Subject 2. (Table 5.6)

Table 5.5: Lateral Flexion Range of Motion (ROM), in degrees, for all lens types (BL, TTL, and FL) and all analysis periods (T_{40} , T_{9-12} , and T_{Reach})

	Operator 1			Operator 2		
	T_{40}	T_{9-12}	T_{Reach}	T_{40}	T_{9-12}	T_{Reach}
BL	12.4	12.9	9.9	24.0	14.8	16.2
TTL	8.9	20.8	9.9	2.0	13.7	13.7
FL	8.1	22.6	22.6	17.2	12.2	16.6

Table 5.6: Lateral Flexion standard deviation (SD), in degrees, for all lens types (BL, TTL, and FL) and all analysis periods (T_{40} , T_{9-12} , and T_{Reach})

	Operator 1			Operator 2		
	T_{40}	T_{9-12}	T_{Reach}	T_{40}	T_{9-12}	T_{Reach}
BL	2.047	9.6272	11.7327	2.5985	9.5663	17.6374
TTL	1.6268	7.3664	10.4047	2.1261	13.7730	13.7727
FL	1.2255	8.6682	8.6682	2.7999	9.4125	17.4889

5.7 Discussion

This pilot study was designed to assess the feasibility of using motion capture technology to measure changes in dental operator posture. Furthermore, the researchers developed the methods to observe differences in posture while wearing

TTL, FL or basic eye wear. The operators were evaluated in real time in an authentic dental clinic setting, It was determined that the motion capture equipment and software used were capable of measuring dental operator posture, specifically forward and lateral flexion of the head.

This study analyzed postural changes from neutral in regard to specific movements (lateral flexion and forward flexion) and not in an overall fashion as was the method in other studies. [81, 99] However, in all studies there was an improvement in posture when magnification loupes were worn. There was no recognizable difference in the improvement as based upon the type of lenses-TTL or FL. The type of magnification loupes that improved posture was dependent on the specific operator.

Drawbacks in using motion capture in an authentic setting during real time were realized. Set up was time consuming, requiring an average of two hours prior to testing. Space was also an issue to be dealt with in that the equipment consumed most of the open space in the dental operator. Operators were slightly hampered by the use of body suits and the attachment of the sensors to the body. These drawbacks could be diminished by using wireless sensors and capturing data in a dental operator designed specifically for measurement of posture using motion capture technology. Such an operator would allow for the equipment to remain in a ready mode and would therefore avoid lengthy setup times while still being authentic.

Recommendations for future research call for the operators to access only a specific area of the mouth, rather than the entire mouth. This study presented difficulty in isolating movements of the operators when in similar areas of the mouth in order to capture posture-related data.

In this study the actual forward and lateral flexions of the head were measu-

red. Future research may examine the percentage of time the operator's posture is outside of an acceptable position. This may provide a wider range for review of operator postures. Furthermore, the operator's comfortable neutral posture should be more thoroughly examined prior to beginning the data capture of posture while treating the patient. It could be that years of dental chairside care has altered the neutral posture of an operator.

This particular study observed some changes in operator posture while wearing FL, TTL or BL eyewear. However, the differences were small, somewhat inconsistent, and should not be generalized. It was clear that forward flexion of the head was decreased while wearing some form of magnification loupes. This could be expected. However, results indicating which type of lenses had a greater impact on the forward flexion were inconsistent. Preliminary results indicate the decrease in forward flexion of the head may be more of an operator-specific matter, rather than the actual type of lenses worn. This would be in contrast to popular anecdotal evidence that FL lenses would provide a more optimal forward flexion of the head.

This study selected only two posture positions, forward and lateral flexion of the head. It is recommended that future studies also include the levelness of the shoulders and the position of the wrist. And, of course, future research should include a greater variety of operators with various skill levels and body sizes.

5.8 Conclusion

In conclusion, the researchers can report with confidence that it is possible to measure dental operator posture using motion capture technology. More study will be needed to determine which type of magnification loupes FL or TTL, if any, are superior in improving dental operator posture. Some evidence was found which supports that the quality of operator posture may more likely be related to the fact

that the operator uses magnification loupes, rather than the specific type of lenses worn.

CHAPTER 6

EFFECT OF MAGNIFICATION LOUPE WEIGHT AND ANGLE OF DECLINATION ON NECK MUSCLE EFFORT IN OPHTHALMIC SURGEONS

6.1 Introduction

Magnification loupes consist of magnifying lenses mounted on eye glasses and are often used by clinicians in investigative and surgical procedures. The magnification provided by these loupes bring the advantage of enhanced vision to clinical procedures that require precise movements, often in small areas where discernment between minute biological structures and tissue are crucial [112]. Surgical advantages of using magnification loupes have been well documented, particularly with regards to improved visualization and reduction in the usage of complex instrumentation [113, 114]. This documentation is well supported in the literature by loupe usage statistics, where survey studies indicate loupe usage of 100% among maxillofacial, cardiothoracic and plastic surgeons, 83.3% among ophthalmologists, 75% among pediatric surgeons [115] and approximately 80% among oculoplastic surgeons [116, 117].

While surgical magnification loupes are shown to improve surgical precision [118, 119], visual acuity [120] and operator posture [74, 76, 81, 98, 99], the occupational health literature is replete with evidence that magnification loupes may limit depth of vision [121] and increase strain in the neck and back [79, 122]. Recent studies have shown increasing prevalence of neck pain among surgeons who operate

using magnification loupes, with 53% of ear nose throat (ENT) surgeons reporting neck and back pain as a result of performing surgery [123], and 72.5% ophthalmic plastic surgeons reporting pain due to surgery, 58% of whom reported neck pain as the significant complaint.

In general usage, there are two families of magnification loupes, namely Keplerian and Galilean telescopic loupes. Keplerian telescopic loupes have a weak positive diopter objective lens and a strong positive diopter eyepiece lens, which produces an inverted image and hence needs a correcting lens. Galilean telescopic loupes have a weak negative diopter objective lens and a strong positive diopter eyepiece lens, which produce an upright image and for allow for the bending of light and greater sharpness of the image. While Keplerian loupes allow for greater magnification, the correcting lens adds weight and scope length to the loupe. Additionally, Keplerian loupes have a narrower field of view compared to Galilean lenses [124]. Hence, Galilean loupe usage is more common in clinicians. There are two configurations of Galilean lenses- “Through-the Lens” (TTL) style loupes or “Flip-Up” (FL) style loupes [108]. TTL style loupes have the magnification loupes fixed onto the lenses of the safety glasses and adjustment of head forward flexion, or declination angle, is not possible, because the angle is fixed in one position. FL style loupes are hinged onto the body of the safety lenses. The moveable hinge allows for an adjustment of the forward flexion of the head. However, FL style loupes are heavier than TTL loupes, and proper design considerations can produce a TTL loupe that is lightweight and has a high declination angle to reduce the amount of neck flexion needed to achieve desired viewing angles.

This pilot study utilized kinematic motion capture, electromyography and musculoskeletal modeling to examine the effect of using a new design of lightweight TTL loupe on neck muscle effort and activity, compared to a conventional TTL loupe.

6.2 Methods

Dr. Donny Suh and colleagues at the University of Nebraska Medical Center designed a TTL loupe that was lighter than conventional designs, had a large angle of declination, and was fitted with a proprietary Suh-Hermsen head strap that reduced loupe slippage and offloaded weight from the nasal bridge to be evenly distributed to the top of the head. The angle of declination of the redesigned loupe was reported to be 42° , as opposed to a 25° angle of declination in the conventional loupe. Additionally, the force imparted on the nasal bridge was calculated as 0.136 N for the re-designed loupe, and 0.324 N for the conventional loupe. Dr. Suh's group quantified their findings using material and inertial properties of each segment of the new design of loupe, as well as a conventional TTL loupe. Photographs of the conventional loupe and the new design of loupe, and a visual depiction of the calculations done are presented in Figure 6.1.

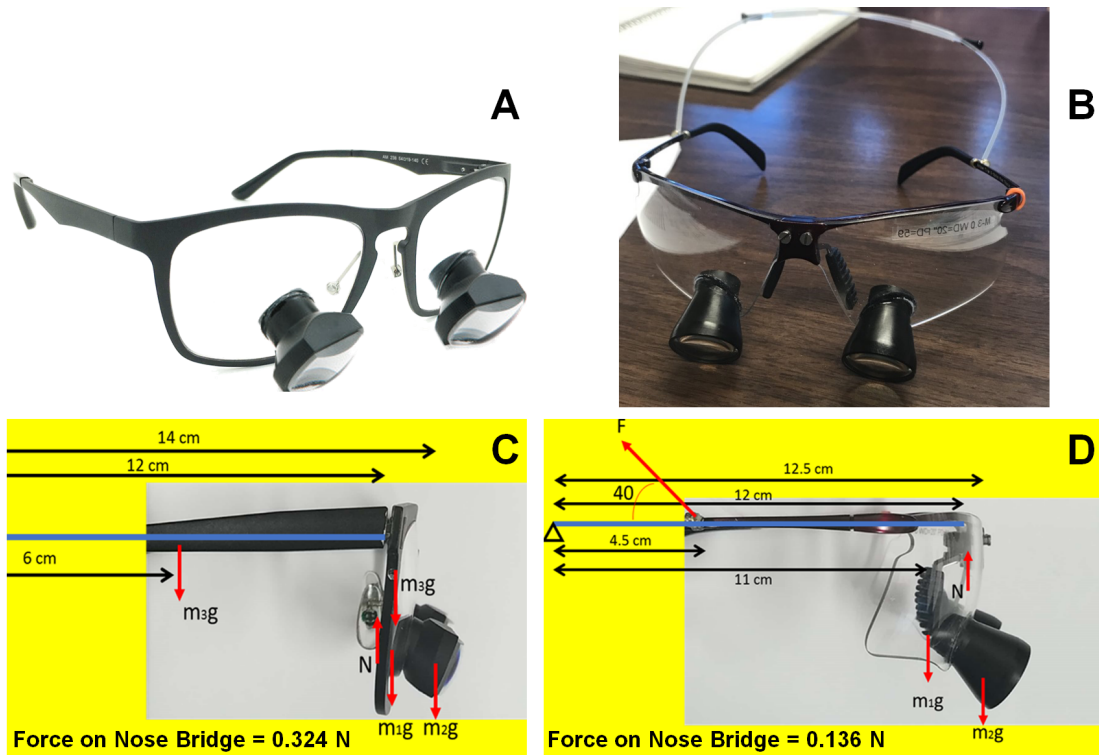


Figure 6.1: Conventional Galilean Loupe (A), Re-designed Galilean Loupe with Suh-Hermesen strap (B), Nasal bridge force calculations for Conventional Loupe (C), and Nasal Bridge force calculations for Re-designed Loupe (D)

An estimation of the operating (viewing) angle of both loupes was also conducted by Dr. Suh's group in a surgical setting using a bubble inclinometer, where the viewing angle of the redesigned loupe was found to result in 15° of sagittal plane neck flexion, as opposed to 40° neck flexion in the conventional loupe. Photographs of this data capture procedure is shown in Figure 6.2.



Figure 6.2: Viewing angle determination of the conventional and redesigned loupes in an ophthalmic surgery setting, using a bubble inclinometer

Dr. Suh's team provided this new design of loupe, along with the conventional loupe to the Human Balance and Ambulation Research Laboratory at the University of Missouri-Kansas City. In collaboration with the Musculoskeletal Biomechanics Research Laboratory at the University of Missouri-Kansas City, we employed a musculoskeletal modeling approach to estimate neck loading between the two loupes.

A 50th percentile adult male upper body model was exported from OpenSim [125], and imported into MSC Adams (MSC Software, Newport Beach, CA), a multibody dynamics modeling software. Material properties, including bone density and inertial properties of body segments, were imported from the OpenSim mo-

del. The model was fixed at the base of the rib cage with a fixed joint. All joints that generate significant motion in this model were defined as revolute joints. All muscle forces, scapular joints, vertebral joints, as well as the abduction/adduction and internal rotation joint components of the neck were suppressed so that only neck flexion/extension movement was allowed as a 2-D revolute joint. This was implemented to simplify the effect of the loupe weight on neck load, and because literature indicates that strenuous postures in ophthalmic professionals are limited to the flexion/extension plane [126].

In this state, the model had no external forces acting on it, and only had a revolute joint at the neck. Therefore, simulations run in this configuration resulted in the head just falling forward in the sagittal plane, ensuring that model movement was indeed restricted to the sagittal plane. An outcome measure to estimate neck muscle effort was determined to be the magnitude of counter torque applied to the neck to keep the head and neck balanced at specific neck flexion configurations.

Since the values of the force imparted by the two loupes on the nasal bridge, as well as the sagittal plane neck flexion angles needed to achieve the desired viewing angles of both loupes were known, the musculoskeletal model was set up in three configurations: no loupe and upright posture, redesigned loupe with 0.136 N orthogonal force on the nasal bridge at 15° neck flexion, and conventional loupe with 0.324 N orthogonal force on the nasal bridge at 40° neck flexion. The simulations were run on Adams, and counter torque values applied to the neck were manually altered until the neck was observed to be balanced at each configuration (at least within the bounds of a 10 second simulation).

Counter torque values obtained through this method are equivalent to neck muscle effort in the sagittal plane. However, since the neck muscle effort values observed are a function of both the loupe weight and the operating neck posture, we

designed a study to investigate muscle activity in the neck for both loupes at three sustained flexion angles, using kinematic motion capture and EMG.

One healthy male subject voluntarily participated in this data collection. They were outfitted with a standard upper body retro-reflective marker set that was tracked at 120 Hz by a system of 7 Vicon MX-T40 cameras. Delsys wireless EMG electrodes were fitted bilaterally to the Sternocleidomastoid and the Upper Trapezius muscles. Maximal voluntary contractions from both sets of muscles were recorded. Upper Trapezius MVC was collected by having the subject sit on a stool, and perform symmetric shoulder elevation against the protruding base of the stool, with as much force as possible for at least 5 seconds. Sternocleidomastoid MVC was collected by the subject clenching with as much force as possible at a position of maximal intercuspation. This procedure was repeated three times with 120 second breaks in between MVCs for both sets of muscles. Among these measurements, the highest measured mean force value (after filtering and rectification) was considered to be the MVC of the respective muscles.

The subject maintained upright, approximately 20° neck flexion and approximately 40° neck flexion while wearing both loupes. The trial order for each was randomized, and each condition was repeated three times. A visual depiction of all possible loupe and flexion conditions is presented in Figure 6.3.

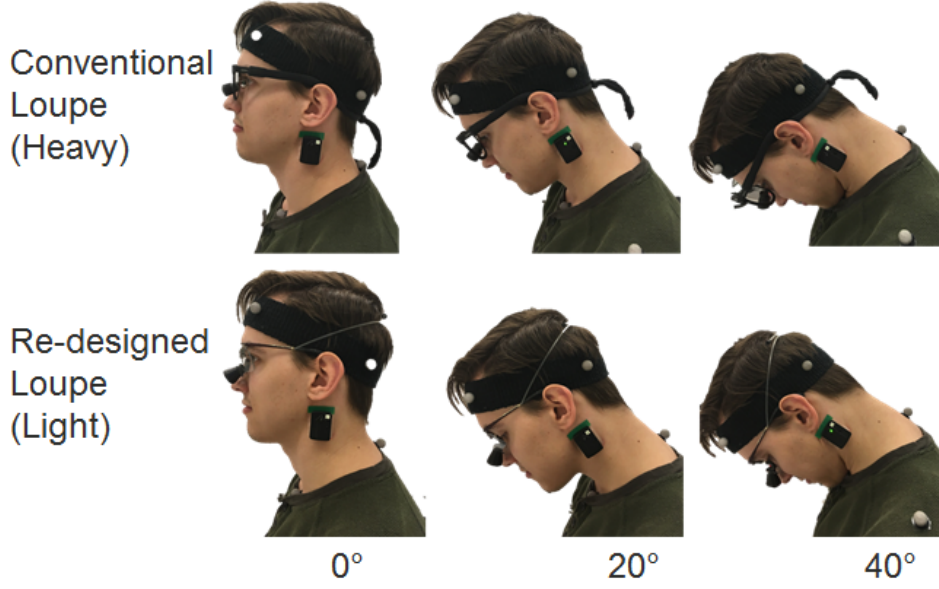


Figure 6.3: Neck flexions for the conventional and re-designed loupes, demonstrating the motion capture and EMG sensors

Shoulder and head marker positions from the kinematic data were used to define unit vector matrices forming the axes of local coordinate systems (LCS) for the torso and head, respectively. The element-wise dot product of the LCS unit vector matrices was calculated. This result is equivalent to the 3D Cardan rotation matrix representing the relative orientation between the torso and head LCS.

$$R = \begin{bmatrix} i_T \cdot i_H & j_T \cdot i_H & k_T \cdot i_H \\ i_T \cdot j_H & j_T \cdot j_H & k_T \cdot j_H \\ i_T \cdot k_H & j_T \cdot k_H & k_T \cdot k_H \end{bmatrix} = \begin{bmatrix} \cos\alpha\cos\beta & \cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma & \cos\alpha\sin\beta\sin\gamma + \sin\alpha\sin\gamma \\ \sin\alpha\cos\beta & \sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma & \sin\alpha\sin\beta\sin\gamma - \cos\alpha\sin\gamma \\ -\sin\beta & \cos\beta\sin\gamma & \cos\beta\cos\gamma \end{bmatrix}$$

Angle time series representing sagittal-plane (α) neck flexion was extracted from this matrix by equating elements of the dot product matrix to corresponding Cardan rotation matrix terms:

$$\alpha = \sin^{-1} \frac{R_{2,1}}{\cos\beta}$$

Raw EMG waveforms were band-pass filtered using a 4th order butterworth filter between 35 Hz and 500 Hz, to reduce contamination from movement artifacts, electrocardiogram signals and high frequency noise [89, 91]. EMG waveforms were then full-wave rectified, demeaned and subjected to a low-pass 4th order Butterworth filter with a cutoff frequency of 50 Hz [92] to obtain the EMG envelope. Outcome measure for EMG data for each condition depicted in Figure 6.3 was the mean value (across three trials for each individual condition) of the EMG waveform of each muscle, divided by the previously determined MVC values for each muscle.

6.3 Results

From the musculoskeletal model, it was observed that the counter torque needed to keep the head upright was 290 Nmm, to keep the head balanced at the operating posture for the conventional loupe was 1500 Nmm, and to keep the head balanced at the operating posture for the re-designed loupe was 920 Nmm. An illustration of the musculoskeletal model and the mentioned results are provided in Figure 6.4.

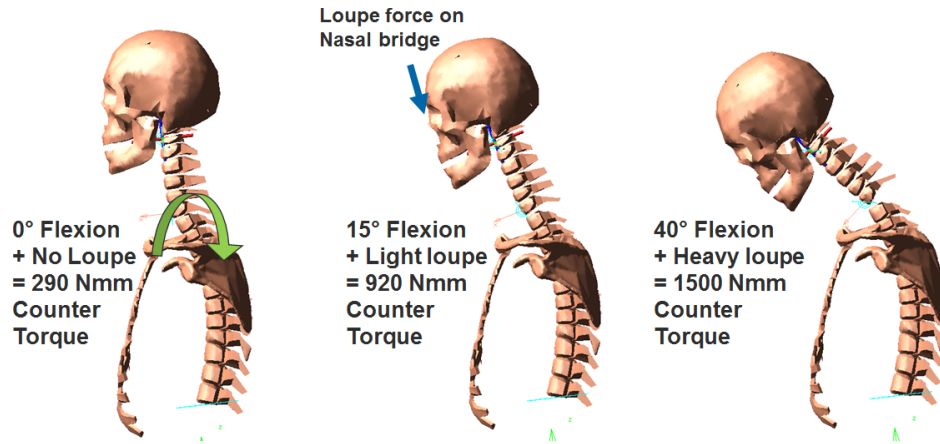


Figure 6.4: Musculoskeletal model depicting the amount of counter torque needed to maintain the neck at the operating neck flexion angles of the conventional and re-designed loupes

Sagittal plane neck flexion angles obtained were normalized by the mean neck flexion value found in the upright neck trials, such that these trials would essentially depict 0° neck flexion, and assist in the numeric visualization of the 20° and 40° neck flexion values, across both loupes. After the normalization, the mean neck values found for the approximately 20° neck flexion were $20.32^\circ \pm 0.46^\circ$, and for the approximately 40° neck flexion were $39.80^\circ \pm 0.09^\circ$.

EMG activity is expressed as % MVC in Table 6.1, and visually depicted in Figure 6.5.

Table 6.1: Upper Trapezius loading (%MVC; Mean \pm 1 S.D.) of all neck flexion and loupe conditions

		Neck Flexions		
		0°	20°	40°
Right Upper Trapezius Activity (%MVC)	Conventional Loupe	0.182 \pm 0.012	0.299 \pm 0.070	0.331 \pm 0.018
	Redesigned Loupe	0.230 \pm 0.035	0.180 \pm 0.009	0.304 \pm 0.077
Left Upper Trapezius Activity (%MVC)	Conventional Loupe	0.091 \pm 0.006	0.258 \pm 0.091	0.521 \pm 0.047
	Redesigned Loupe	0.141 \pm 0.032	0.150 \pm 0.037	0.499 \pm 0.084

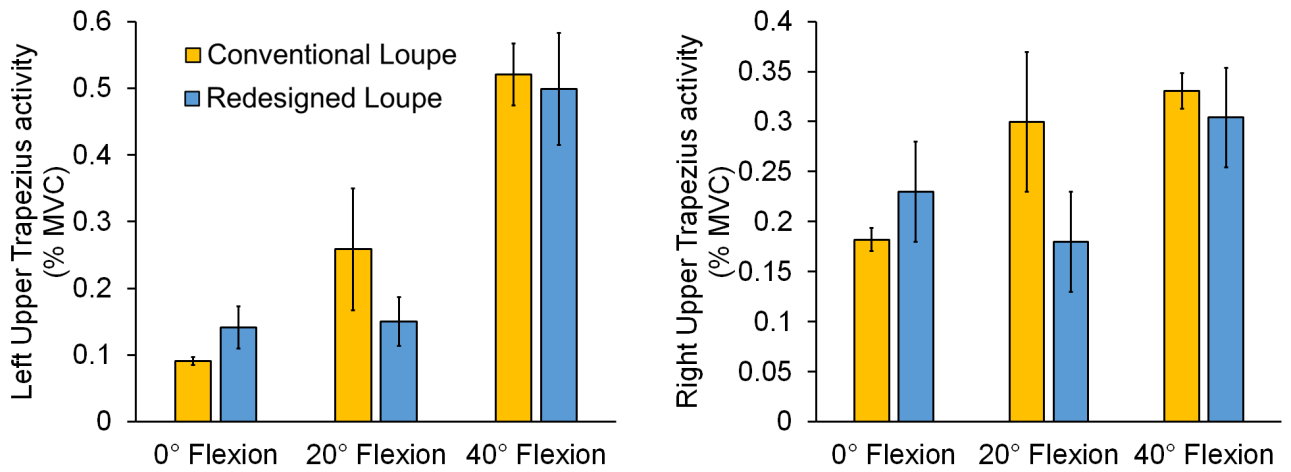


Figure 6.5: Bilateral Upper Trapezius muscle loading for the conventional and re-designed loupes at 0°, 20° and 40° neck flexion

6.4 Discussion

A high angle of declination in a surgical magnification loupe is potentially beneficial to surgeons because it may allow them to view the operating site with a lower sustained neck flexion, reducing time spent in non-neutral neck postures. The results from this study indicated that using a lighter Galilean loupe, with a high angle of declination (adjusted to individual working distances) has the potential to reduce neck muscle effort, and that the effect of a reduced weight loupe alone could reduce muscle activity in the neck at non-neutral flexions, indicating a lower exposure to potential musculoskeletal disorders of the neck stemming from prolonged muscle loading at non-neutral neck postures.

Counter torque parameters obtained in MSC Adams to signify neck muscle effort were obtained manually. More accurate estimates of the required counter torques could be achieved by optimization using MATLAB and Simulink. The musculoskeletal model used in this study was simplistic and generalized for the effect of magnification loupe weight and angle of declination on a 50th percentile male upper body model. While this model demonstrates differences in neck muscle effort between the two kinds of loupes, more reliable results may be obtained by using subject-specific multibody models with an optimized approach to estimate muscle effort from individual muscles imported from the OpenSim model. EMG data was acquired only from a single subject. For the findings to be translatable, future studies should include a larger sample size.

CHAPTER 7

CONCLUSION

7.1 Significance of Findings

Work-related musculoskeletal disorders (MSDs) in healthcare providers have been heavily reported, and are a major cause of occupational discomfort, disability and occupational absence. Current evaluation methodology of occupational posture in healthcare providers include qualitative methods such as survey based instruments that report on the characteristics of existing pain, or observational instruments where still photographs or videos of occupational postures are evaluated by independent raters to assess risk or exposure to musculoskeletal disorders. This study used marker-based kinematic motion capture, surface electromyography and musculoskeletal modeling to evaluate occupational postures in eye care providers and dental operators.

Reclining the patient during refraction and strabismus exams reduced the amount of procedural time that eye care providers' necks were in non-neutral postures, which indicates lower time spent in neck postures that may lead to neck MSDs. Additionally, switching the eye care provider's position to the patient's left side to examine the patient's left eye (removing the need to reach over to examine the eye) exhibited a consistent decrease in erector spinae muscle activity in all refraction exam conditions, indicating a lower exposure to asymmetric trunk muscle activity. For eye care providers performing the slit lamp exam it was observed that moving the patient forward and adjusting slit lamp biomicroscope height led to reduced

non-neutral neck postures as indicated by a reduction in sagittal plane neck flexion range of motion, upper trapezius muscle activity and the percentage of procedural time with non-neutral neck flexion. Additionally, the use of an elbow rest when holding up exam lenses at the slit lamp reduced the procedural time that the anterior deltoid muscle was active, which may reduce the likelihood of future shoulder musculoskeletal disorders.

For dental operators, this study investigated the effect of using two kinds of Galilean magnification loupes on neck postures in dental hygienists performing subgingival probing. It was observed that both loupes reduced the range of motion of sagittal plane neck flexion in dental hygienists, when compared to no magnification. Due to the nature of periodontal probing, where the tendency of the provider is to hunch down to get a closer view of their work, the range of motion calculated is likely to be representative of neck flexion only, and no extension. This would indicate that dental providers had a higher likelihood of spending time in neutral neck postures while using magnification loupes, when compared to not using a loupe.

Neck muscle effort exhibited by wearing two kinds of through-the-lens Galilean loupes used by ophthalmic surgeons was also evaluated using motion capture, electromyography and musculoskeletal modeling. A musculoskeletal model of a 50th percentile adult male demonstrated that holding a human head balanced at the working neck flexion of a lighter loupe required a smaller angular torque than a heavier loupe. Since this lower torque was a function of both neck flexion and loupe weight, neck muscle activity was evaluated at three different neck flexions for both loupes. It was observed that using a lighter loupe with a larger angle of declination led to a decrease in upper trapezius muscle activity, indicating lower neck muscle effort when using the lighter loupe, regardless of the loupes' operating neck flexion.

Postural adjustment, patient positioning, equipment re-positioning and suppor-

tive equipment choice (such as elbow rests for slit lamp examinations, or magnification loupes for periodontal probing and ophthalmic surgery) are easily-implemented methods that may reduce the exposure of dental operators and eye care providers to non-neutral postures which lead to occupational musculoskeletal disorders. Preliminary analyses from this and future studies can help establish a quantitative standard for ergonomic postures in ophthalmic and dental practice, lead to a wide scale re-design of ophthalmic and dental equipment, and facilitate the development of postural ergonomics-focused training curriculums for current and future dental operators and eye care providers. Equipment re-design could include variable height eye charts, designing ophthalmic examination rooms with ambidextrous access, shortening the slit-lamp platform to reduce forward leaning, adjustable eyepieces for the slit lamp biomicroscope, and improvements on currently developed lightweight magnification loupes. Future ophthalmic training protocol could be refined to introduce ambidextrous training, so as to reduce asymmetric muscle activity during ophthalmic procedures.

Generalization of the procedural postural characteristics observed may not necessarily be accurate when applied to all practicing dental operators and eye care providers, since these studies focused specifically on dental hygienists and pediatric eye care providers. Future studies will include a wider subset of eye care providers and dental operators as participants, leading to a more generalizable study and a larger sample size.

7.2 Limitations

For the eye care provider studies outlined in Chapters 3 and 4, the number of participants was low, which made it challenging to observe statistically significant results. These participants were all pediatric eye care providers. Future studies can

include a larger sample size with a wider subset of eye care providers. Additionally, the use of a human surrogate (manikin), while necessary for standardization in this study, may not have adequately replicated daily activities faced by eye care providers in their clinics. Muscle activity characteristics, as a result of patient repositioning, may have been more consistent provided that the data was normalized using reference contractions (e.g. maximal voluntary or isometric contractions). Furthermore, EMG sensor placement consistency may have affected between-subjects EMG data variability. However, since the EMG sensor were placed on individual subjects at the beginning of data collection and not removed until all trials were completed, within-subjects EMG data variability was likely low. Future studies can be conducted in a non-simulated clinical setting with a marker-less motion analysis system to record real-time kinematics, and EMG sensors to record muscle activity where reference EMG contractions taken multiple times during a workday may help normalize muscle activity data by factoring in fatigue effects.

For the dental operator study outlined in Chapter 5, statistical analyses were not conducted since there were only two participants. Drawbacks of using motion capture in an authentic dental clinical setting were realized, including discomfort experienced by dental operators as a result of wearing form-fitting marker suits, and a restricted capture volume that led to marker occlusions. These drawbacks could be diminished by using a system of wireless sensors with a fast setup time and an unobtrusive physical footprint. Since operators accessed the entire mouth during probing, isolating operator movements in similar areas of the mouth was difficult. Future research could reduce this variability by having operators access only a specific area of the mouth at a time. This study extracted only the forward and lateral flexion of the head from the kinematic data. While comparing range of motion of the head's rotational angles demonstrate the effect of magnification

loupe usage on neck postures, future research would benefit from examining metrics similar to the eye care provider study where the percentage of procedural time in non-neutral neck postures were quantified. Additionally, a more comprehensive understanding of dental operator posture can be obtained in future studies by quantifying kinematic outcomes from shoulder and wrist postures, and by designing studies that include operators of different sub-specialties with various skill levels and body sizes.

For the ophthalmic magnification loupe study outlined in Chapter 6, counter torque parameters obtained in MSC Adams to signify neck muscle effort were obtained manually. More accurate estimates of the required counter torques could be achieved by optimization using MATLAB and Simulink. The musculoskeletal model used in this study was simplistic and generalized for the effect of magnification loupe weight and angle of declination on a 50th percentile male upper body model. While this model demonstrates differences in neck muscle effort between the two kinds of loupes, more reliable results maybe obtained by using subject-specific multibody models with an optimized approach to estimate muscle effort from individual muscles imported from the OpenSim model. EMG data was acquired only from a single subject. For the findings to be translatable, future studies should include a larger sample size.

7.3 Future Directions

Observational methods that currently assess occupational postures may be adequate for dental operators and eye care providers for quick assessments of occupational exposure to MSD risk. However, biomechanical motion capture and electromyography data provide a more detailed insight into the physiological response of occupational postural adjustments. To improve the quality of the insight provi-

ded by these methods (and hence improve the predictive validity of modified observational methods), longitudinal studies need to be conducted using motion capture and electromyography where detailed definitions of MSD risk and exposure are quantified, such as the effect of force/load, recurrence, intensity and duration of occupational postures on the likelihood of developing a MSD. Additionally, incorporating musculoskeletal modeling into future experiments may allow the creation of subjects specific models to investigate parameters such as prolonged fatigue effects that may not otherwise be feasibly undertaken with human subjects.

While marker-based kinematic motion capture yields high-quality data, it cannot currently be applied to evaluate most clinical procedures outside of simulation settings, partly due to concerns about sterility, marker interference with procedure tasks, and the unfamiliarity and occupational mobility restrictions imposed by the marker suit to clinicians. Marker-less motion analysis technologies are becoming available and would resolve many of these concerns if they can be demonstrated to offer comparable resolution and accuracy. Although not specifically applied in evaluating clinical procedures in simulation or practice, marker-less motion analysis technologies are increasingly used as a means to track natural (i.e. unrestricted) human motion. For example, marker-less systems have been used to assess gait [127, 128] and postural control [129, 130]. Marker-less systems such as the Microsoft Kinect, in conjunction with wireless EMG systems and wearable sensors (e.g. strain-gauges, inertial measurement units, accelerometers and gyroscopes) may provide adequate indications of clinician ergonomics in the context of cervical spinal loading and postures maintained during real-time procedures in a clinical setting.

APPENDICES

Appendix A



IRB # 16070501

Dear Provider:

I am writing to tell you about a research study currently being conducted at Children's Mercy Hospitals and Clinics. You are receiving this letter because you are an Eye Care Provider. The purpose of this study is to identify postural risk factors for musculoskeletal disorders (MSDs) among eye care providers during routine examinations, and evaluate the effectiveness of ergonomic interventions in reducing exposure to these risk factors. The study will focus on two procedures- the strabismus exam and slit lamp exam- performed regularly by ophthalmologists and optometrists which put them at risk for MSDs including neck, back, and shoulder pain. This study will utilize biomechanical motion analysis and electromyography (EMG) as tools to quantify postural and muscle activity characteristics among ophthalmologists. Motion analysis and EMG data will be collected from practitioners performing each procedure in a control condition, as they normally would, and with an ergonomic intervention designed to minimize musculoskeletal stress. Muscle activity and kinematic (motion analysis) data will be compared pairwise pre- and post-intervention to determine the effectiveness of each intervention in minimizing risk factors including non-neutral body postures, repetitive motion patterns, and mechanical pressure concentrations.

You are being invited to participate in this research project because you routinely perform eye examinations at Children's Mercy. It is anticipated that the survey will take about 2 minutes to complete and the exam and EMG will take approximately 90 minutes during administrative time to complete

As a participant in this research study, there is no direct benefit for you; however, information from this study may benefit other people now or in the future.

By taking part in this study, you may experience the following risks:

- Social risks (e.g., possible loss of confidentiality, possible effect to employment status)

This survey will be completely anonymous. All information collected about you during the course of this study will be kept without any identifiers. No identifying information will be collected, and your answers cannot be linked back to you.

Being in this study is completely voluntary. You are free to not answer any questions or withdraw at any time. Your decision will not change any present or future relationships with Children's Mercy Hospitals and Clinics or its affiliates.

There is no extra cost for being in the study. You will not be paid for taking part in this study.

Please contact the principal investigator, Scott Olitsky, MD at 816-960-8000 if you have any questions about this study. You may also call the Children's Mercy Hospitals & Clinics Pediatric Institutional

Review Board (IRB) at (816) 701-4358 with questions or complaints about this study. The IRB is a committee of physicians, statisticians, researchers, community advocates, and others that ensures that a research study is ethical and that the rights of study participants are protected.

If you do not want to participate in this study, please do not reply to this email.

If you are willing to participate in this study, please reply to this email within the next 24 hours and you will be scheduled for an exam with EMG.

Thank you in advance for considering this request.

Sincerely,

Scott Olitsky, MD
Principal Investigator

Figure A.1: Recruitment letter, March 2017



IRB # 16070501

October 25, 2017

Dear Provider:

You are receiving this letter because you are an Eye Care Provider who was invited to participate in the Ergonomics research study in March, 2017 at Children's Mercy Hospitals and Clinics. In the study analysis phase, it was determined that specific physical measurements were needed in addition to the data collected. The measurements include:

- Shoulder Offset (mm)
- Elbow Width (mm)
- Wrist Width (mm)
- Hand Thickness (mm)
- Hand Length (mm)
- Forearm Length (mm)
- Upper Arm Length (mm)

It is anticipated that the additional survey measurements will take about 2 minutes to complete.

As a participant in this research study, there is no direct benefit for you; however, information from this study may benefit other people now or in the future.

By taking part in this additional part of the study, you may experience the following risks:

- Social risks (e.g., possible loss of confidentiality)

This survey will be completely anonymous. All information collected about you during the course of this study will be kept without any identifiers. No identifying information will be collected, and your answers cannot be linked back to you.

Being in this study is completely voluntary. You are free to not answer any questions or withdraw at any time. Your decision will not change any present or future relationships with Children's Mercy Hospitals and Clinics or its affiliates.

There is no extra cost for being in the study. You will not be paid for taking part in this study.

Please contact the principal investigator, Scott Olitsky, MD at 816-960-8000 if you have any questions about this study. You may also call the Children's Mercy Hospitals & Clinics Pediatric Institutional Review Board (IRB) at (816) 701-4358 with questions or complaints about this study. The IRB is a committee of physicians, statisticians, researchers, community advocates, and others that ensures that a research study is ethical and that the rights of study participants are protected.

If you do not want to participate in this study, please do not reply to this email.

If you are willing to participate in this part of the study, please reply to this email within the next 24 hours and you will be scheduled for an appointment with a study team member.

Thank you in advance for considering this request.

Sincerely,

Scott Olitsky, MD
Principal Investigator

Figure A.2: Recruitment letter, October 2017

Table A.1: Randomized Subject ID and procedure repetition randomization, as assigned to specific time-slots

CMH-Ophthalmology-MoCap/EMG-Project

Subject ID + Procedure Order

Date	Time Slot	Randomized Subject ID	Proc A	Proc B	Proc C	Proc D	Proc E	Proc F	Proc G	Proc H	Proc I	Proc J	Proc K
March 27 (Monday)	8AM – 10AM	036	1	1+Int1	1+Int2	1+Int3	2	2+Int1	2+Int2	2+Int3	3	3+Int1	3+Int2
	10AM – 12PM	850	1	1+Int1	1+Int3	1+Int2	3	3+Int2	3+Int1	2	2+Int1	2+Int3	2+Int2
	1PM – 3PM	934	2	2+Int1	2+Int2	2+Int3	1	1+Int1	1+Int2	1+Int3	3	3+Int1	3+Int2
	3PM – 5PM	679	2	2+Int1	2+Int3	2+Int2	3	3+Int2	3+Int1	1	1+Int1	1+Int3	1+Int2
March 28 (Tuesday)	8AM – 10AM	758	3	3+Int1	3+Int2	1	1+Int1	1+Int2	1+Int3	2	2+Int1	2+Int2	2+Int3
	10AM – 12PM	744	3	3+Int2	3+Int1	2	2+Int1	2+Int3	2+Int2	1	1+Int1	1+Int3	1+Int2
	1PM – 3PM	393	3	3+Int1	3+Int2	1	1+Int1	1+Int2	1+Int3	2	2+Int1	2+Int2	2+Int3
	3PM – 5PM	656	2	2+Int1	2+Int3	2+Int2	3	3+Int2	3+Int1	1	1+Int1	1+Int3	1+Int2
March 29 (Wednesday)	8AM – 10AM	172	2	2+Int1	2+Int2	2+Int3	1	1+Int1	1+Int2	1+Int3	3	3+Int1	3+Int2
	10AM – 12PM	707	1	1+Int1	1+Int3	1+Int2	3	3+Int2	3+Int1	2	2+Int1	2+Int3	2+Int2
	1PM – 3PM	032	1	1+Int1	1+Int2	1+Int3	2	2+Int1	2+Int2	2+Int3	3	3+Int1	3+Int2
	3PM – 5PM	277	1	1+Int1	1+Int3	1+Int2	3	3+Int2	3+Int1	2	2+Int1	2+Int3	2+Int2
March 30 (Thursday)	8AM – 10AM	047	2	2+Int1	2+Int2	2+Int3	1	1+Int1	1+Int2	1+Int3	3	3+Int1	3+Int2
	10AM – 12PM	098	2	2+Int1	2+Int3	2+Int2	3	3+Int2	3+Int1	1	1+Int1	1+Int3	1+Int2
	1PM – 3PM	824	3	3+Int1	3+Int2	1	1+Int1	1+Int2	1+Int3	2	2+Int1	2+Int2	2+Int3
	3PM – 5PM	695	3	3+Int2	3+Int1	2	2+Int1	2+Int3	2+Int2	1	1+Int1	1+Int3	1+Int2
March 31 (Friday)	8AM – 10AM	318	3	3+Int1	3+Int2	1	1+Int1	1+Int2	1+Int3	2	2+Int1	2+Int2	2+Int3
	10AM – 12PM	951	2	2+Int1	2+Int3	2+Int2	3	3+Int2	3+Int1	1	1+Int1	1+Int3	1+Int2
	1PM – 3PM	035	2	2+Int1	2+Int2	2+Int3	1	1+Int1	1+Int2	1+Int3	3	3+Int1	3+Int2
	3PM – 5PM	439	1	1+Int1	1+Int3	1+Int2	3	3+Int2	3+Int1	2	2+Int1	2+Int3	2+Int2

Ophthalmology Study Questionnaire: Mars # 16070501

Record ID _____

Please type the number that the research assistant has given you. If the research assistant has not yet assigned you a number, please ask him or her for your randomized number. This is to ensure your confidentiality as a study participant.

Please select among the following options:

- I agree that video in which my participation has been rendered as an animation may be utilized in presentations and publications.
- I agree that still images resulting from motion capture animations may be utilized in presentations and publications.
- OR choose this option: I do not want any visuals resulting from my participation to be included in presentations or publications.

Height (in total inches)
Tip: 4 ft = 48 inches, 5 ft = 60 inches, 6 ft = 72 inches

Weight (in pounds) _____

Handedness
 Right
 Left
 Ambidextrous

Age _____

Gender
 Male
 Female
 Other
 Prefer not to answer

Shoulder Offset (mm) _____

Elbow Width (mm) _____

Wrist Width (mm) _____

Hand Thickness (mm) _____

Hand Length (mm) _____

Forearm Length (mm) _____

Upper Arm Length (mm) _____

How many years have you been performing strabismus and slit lamp exams? _____

How many times per week do you typically perform the strabismus exam? _____

How many times per week do you typically perform the slit lamp exam? _____

Please identify your status

- Ophthalmologist
- Optometrist
- Other

If you selected "other" as your status, please specify.

How frequently have you performed aerobic exercise in the last four weeks?

- Not at all
- 1-4 times
- 5-10 times
- 11-19 times
- 20 or more times

How much time did you spend on this activity?

- Less than 12 minutes
- 13-29 minutes
- 30-44 minutes
- 45 or more minutes

How frequently in the last four weeks have you performed weightlifting or other anaerobic exercise?

- Not at all
- 1-4 times
- 5-9 times
- 10-19 times
- 20 or more times

How much time did you spend on this activity?

- Less than 12 minutes
- 13-29 minutes
- 30-44 minutes
- 45 or more minutes

Have you previously experienced any musculoskeletal problems?

- Yes
- No

How frequently do you experience each of the following caused by your work?

	Daily	Weekly	Monthly	Less than monthly	Never
Neck Pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lower Back Pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Upper Back Pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Arm or Shoulder Pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How frequently do each of the following limit your mobility?

	Never	Daily	Weekly	Monthly	Less than monthly	Never
Neck pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lower back pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Upper back pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Arm and shoulder pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Have you undergone surgery for musculoskeletal pain in your neck or back?

- Yes
- No

Which of the following conditions have you experienced?

- cervical herniated disk
- fusion for cervical herniated disk
- discectomy for cervical herniated disk
- other treatment for cervical herniated disk
- none

If you selected "other treatment for cervical herniated disk," please describe.

Which of the following have you experienced?

- lumbar herniated disk
- fusion for lumbar herniated disk
- discectomy for lumbar herniated disk
- other treatment for lumbar herniated disk
- none

If you selected "other treatment for lumbar herniated disk," please describe.

Figure A.3: Questionnaire provided to each participant

CMH-Ophthalmology-MoCap/EMG-Project

EMG Sensor placement order

EMG Sensor No.	Placement Location (Refer to SENIAM photos for details)
1	RIGHT Upper Trapezius
2	LEFT Upper Trapezius
3	RIGHT Lower Trapezius
4	LEFT Lower Trapezius
5	RIGHT Anterior Deltoid
6	LEFT Anterior Deltoid
7	RIGHT Posterior Deltoid
8	LEFT Posterior Deltoid
9	RIGHT Erector Spinae Iliocostalis
10	LEFT Erector Spinae Iliocostalis
11	RIGHT Erector Spinae Longissimus
12	LEFT Erector Spinae Longissimus
13	RIGHT Flexor Carpi Ulnaris
14	LEFT Flexor Carpi Ulnaris
15	RIGHT Extensor Carpi Radialis
16	LEFT Extensor Carpi Radialis

Figure A.4: EMG sensor order

Appendix B

MATLAB Code

```
clear
clc
close all

SubList = [036 047 172 277 318 744 824 850 934 951]; %List of Subject IDs

kin_SC = ones(110,6);
kin_ROM = ones(110,5);
kin_NonNeut = ones(110,5);
e_Cocon = ones(110,19);
e_MusAct = ones(110,18);
e_MusActR = ones(110,18);
e_MusActL = ones(110,18);
e_Activation = ones(110,12);
e_ActivationR = ones(110,11);
e_ActivationL = ones(110,11);
e_RMS = ones(110,10);
e_RMS1 = ones(110,11);
e_RMS2 = ones(110,11);
e_AsymR = ones(110,12);
e_AsymL = ones(110,12);

for i = 1:10

ebase = strcat('Sub',subfinder(i),'_Baseline','_EMG.csv'); % Filename string for baseline file
ebasedata = csvread(ebase,1,0); % EMG baseline data
etimebase = ebasedata(:,1);
ebasedata = EMGabsfilt(ebasedata,etimebase);
ebaseavg = mean(ebasedata); % Mean of baseline
ebaseRMS = rms(ebasedata); % RMS of EMG Baseline

    for j = 1:11

        %% MOCAP
        mtrialname = strcat('Sub',subfinder(i),'_',trialfinder(j),'_csv'); % MoCap trial file name

        fs_m = 120; % Sampling rate for Motion Capture

        mdata = csvread(mtrialname,2,0); % MoCap data

        % Data import
        mtime = mdata(:,1); % Time for MoCap data
        LASI = mdata(:,2:4); % Left Anterior Superior Iliac Spine
        RASI = mdata(:,5:7); % Right Posterior Superior Iliac Spine
        LPSI = mdata(:,8:10); % Left Posterior Superior Iliac Spine
        RPSI = mdata(:,11:13); % Right Posterior Superior Iliac Spine
        CLAV = mdata(:,14:16); % Clavicle
        T10 = mdata(:,17:19); % T10
        STRN = mdata(:,20:22); % Sternum
        RBAK = mdata(:,23:25); % Offset on right side on posterior torso, off of T10
        C7 = mdata(:,26:28); % C7
        LFHD = mdata(:,29:31); % Left Forehead
        RFHD = mdata(:,32:34); % Right Forehead
        LBHD = mdata(:,35:37); % Left Backhead
        RBHD = mdata(:,38:40); % Right Backhead
        LSHO = mdata(:,41:43); % Left Shoulder
        LELB = mdata(:,44:46); % Left Elbow
        LUPA = mdata(:,47:49); % Left Upper Arm
        LFRM = mdata(:,50:52); % Left Forearm
        LFIN = mdata(:,53:55); % Left Finger (marker on knuckle on index finger)
        LWRB = mdata(:,56:58); % Left Wrist marker, Ulnar side
        LWRA = mdata(:,59:61); % Left Wrist marker, Radial side
        RSHO = mdata(:,62:64); % Right Shoulder
        RELB = mdata(:,65:67); % Right Elbow

    end

end
```

```

RUPA = mdata(:,68:70); % Right Upper Arm
RFRM = mdata(:,71:73); % Right Forearm
RFIN = mdata(:,74:76); % Right Finger
RWRB = mdata(:,77:79); % Right Wrist marker, Ulnar side
RWRA = mdata(:,80:82); % Right Wrist marker, Radial side

% Data analysis

[P1beg,P1end,P2beg,P2end] = findoveralProcframes(i,j);
[T1,T2] = findTposeange(i,j);
[P1,P2] = StartProc2StartTframes(i,j);

neck_angle = neckangle(LSHO,RSHO,LFHD,RFHD,LBHD,RBHD,C7,CLAV,i,j);
neck_angle = filter_data(neck_angle,6,120); %6Hz lpf
nflex_ROM = rom(neck_angle(:,1),1); %Neck flexion/extension ROM
nabad_ROM = rom(neck_angle(:,2),1); %Neck abduction/adduction ROM
ninvev_ROM = rom(neck_angle(:,3),1);%Neck inversion/eversion ROM

% Percentage time neck flexion is in non-neutral position

NonNeutral_Neck = nonneutral(T1,T2,P1,P2,mtime,neck_angle);
NeckFlex = NonNeutral_Neck(1);
NeckAbAd = NonNeutral_Neck(2);
NeckInvev = NonNeutral_Neck(3);

% Special case variables
if j <= 8
    nflex_sus_LR = mean(neck_angle(P1beg:P1end,1)); %Sustained Neck flexion/extension LR
    nflex_sus_RR = mean(neck_angle(P2beg:P2end,1)); %Sustained Neck flexion/extension RR

    nabad_sus_LR = mean(neck_angle(P1beg:P1end,2)); %Sustained Neck abduction/adduction ROM
    nabad_sus_RR = mean(neck_angle(P2beg:P2end,2)); %Sustained Neck abduction/adduction ROM
else
    nflex_sus_LR = mean(neck_angle([P1beg:P1end,P2beg:P2end],1)); %Neck flexion/extension
ROM
    nabad_sus_LR = mean(neck_angle([P1beg:P1end,P2beg:P2end],2)); %Neck abduction/adduction
ROM
end

kin_SC(j+11*(i-1),1) = [i];
kin_SC(j+11*(i-1),2) = [j];
kin_SC(j+11*(i-1),3) = [nflex_sus_LR];
kin_SC(j+11*(i-1),4) = [nflex_sus_RR];
kin_SC(j+11*(i-1),5) = [nabad_sus_LR];
kin_SC(j+11*(i-1),6) = [nabad_sus_RR];

%
kin_ROM(j+11*(i-1),1) = [i];
kin_ROM(j+11*(i-1),2) = [j];
kin_ROM(j+11*(i-1),3) = [nflex_ROM];
kin_ROM(j+11*(i-1),4) = [nabad_ROM];
kin_ROM(j+11*(i-1),5) = [ninvev_ROM];

%
kin_NonNeut(j+11*(i-1),1) = [i];
kin_NonNeut(j+11*(i-1),2) = [j];
kin_NonNeut(j+11*(i-1),3) = [NeckFlex];
kin_NonNeut(j+11*(i-1),4) = [NeckAbAd];
kin_NonNeut(j+11*(i-1),5) = [NeckInvev];

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%% EMG
% Data import
etrialname = strcat('Sub',subfinder(i),'_',trialfinder(j),'_EMG.csv'); % EMG trial file name

fs_e = 1925.926; % Sampling rate for EMG

edata = csvread(etrialname,1,0); % EMG data
etime = edata(:,1); % Time for EMG data
edata = EMGabsfilt(edata,etime);

P1temp = size(find(etime<=P1/120)); % Converts MoCap frames to EMG frames
P1EMG = P1temp(1);

P1begtemp = size(find(etime<=P1beg/120)); % Converts MoCap frames to EMG frames
P1begEMG = P1begtemp(1);
P1endtemp = size(find(etime<=P1end/120)); % Converts MoCap frames to EMG frames
P1endEMG = P1endtemp(1);

P2temp = size(find(etime<=P2/120)); % Converts MoCap frames to EMG frames
P2EMG = P2temp(1);

P2begtemp = size(find(etime<=P2beg/120)); % Converts MoCap frames to EMG frames
P2begEMG = P2begtemp(1);
P2endtemp = size(find(etime<=P2end/120)); % Converts MoCap frames to EMG frames
P2endEMG = P2endtemp(1);
% Analysis

UpTrap_R = edata(:,2);% - ebaseavg(:,2); % Right Upper Trapezius
UpTrap_L = edata(:,3);% - ebaseavg(:,3); % Left Upper Trapezius
LowTrap_R = edata(:,4);% - ebaseavg(:,4); % Right Lower Trapezius
LowTrap_L = edata(:,5);% - ebaseavg(:,5); % Left Lower Trapezius
AntDelt_R = edata(:,6);% - ebaseavg(:,6); % Right Anterior Deltoid
AntDelt_L = edata(:,7);% - ebaseavg(:,7); % Left Anterior Deltoid
PostDelt_R = edata(:,8);% - ebaseavg(:,8); % Right Posterior Deltoid
PostDelt_L = edata(:,9);% - ebaseavg(:,9); % Left Posterior Deltoid
ErecSpinIlio_R = edata(:,10);% - ebaseavg(:,10); % Right Erector Spinae Iliocostalis
ErecSpinIlio_L = edata(:,11);% - ebaseavg(:,11); % Left Erector Spinae Iliocostalis
ErecSpinLong_R = edata(:,12);% - ebaseavg(:,12); % Right Erector Spinae Longissimus
ErecSpinLong_L = edata(:,13);% - ebaseavg(:,13); % Left Erector Spinae Longissimus
FlexCU_R = edata(:,14);% - ebaseavg(:,14); % Right Flexor Carpi Ulnaris
FlexCU_L = edata(:,15);% - ebaseavg(:,15); % Left Flexor Carpi Ulnaris
ExtCR_R = edata(:,16);% - ebaseavg(:,16); % Right Extensor Carpi Radialis
ExtCR_L = edata(:,17);% - ebaseavg(:,17); % Left Extensor Carpi Radialis

%% EMG Data Analysis

% LTA_rms = rms(LTA); LSO_rms = rms(LSO); RTA_rms = rms(RTA); RSO_rms = rms(RSO);

%% Cocontraction to look at measure of symmetry, also the Correlation

[Area_UpTrap_R,Area_UpTrap_L,COCON_UpTrap,Rho_UpTrap] =
cocontraction(UpTrap_R(P1EMG:P2EMG),UpTrap_L(P1EMG:P2EMG)); % Cocontraction R/L Upper
Trapezius
[Area_LowTrap_R,Area_LowTrap_L,COCON_LowTrap,Rho_LowTrap] =
cocontraction(LowTrap_R(P1EMG:P2EMG),LowTrap_L(P1EMG:P2EMG)); % Cocontraction R/L Lower
Trapezius
[Area_AntDelt_R,Area_AntDelt_L,COCON_AntDelt,Rho_AntDelt] =
cocontraction(AntDelt_R(P1EMG:P2EMG),AntDelt_L(P1EMG:P2EMG)); % Cocontraction R/L Anterior
Deltoid
[Area_PostDelt_R,Area_PostDelt_L,COCON_PostDelt,Rho_PostDelt] =
cocontraction(PostDelt_R(P1EMG:P2EMG),PostDelt_L(P1EMG:P2EMG)); % Cocontraction R/L
Posterior Deltoid

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[Area_ErecSpinIlio_R,Area_ErecSpinIlio_L,COCON_ErecSpinIlio,Rho_ErecSpinIlio] =
cocontraction(ErecSpinIlio_R(P1EMG:P2EMG),ErecSpinIlio_L(P1EMG:P2EMG)); % Cocontraction R/L
Erector Spinae Iliocostalis
[Area_ErecSpinLong_R,Area_ErecSpinLong_L,COCON_ErecSpinLong,Rho_ErecSpinLong] =
cocontraction(ErecSpinLong_R(P1EMG:P2EMG),ErecSpinLong_L(P1EMG:P2EMG)); % Cocontraction R/L
Erector Spinae Longissimus
[Area_FlexCU_R,Area_FlexCU_L,COCON_FlexCU,Rho_FlexCU] =
cocontraction(FlexCU_R(P1EMG:P2EMG),FlexCU_L(P1EMG:P2EMG)); % Cocontraction R/L Flexor Carpi
Ulnaris
[Area_ExtCR_R,Area_ExtCR_L,COCON_ExtCR,Rho_ExtCR] =
cocontraction(ExtCR_R(P1EMG:P2EMG),ExtCR_L(P1EMG:P2EMG)); % Cocontraction R/L Extensor Carpi
Radialis

[Area_UpTrap_RR,Area_UpTrap_LR,COCON_UpTrapR,Rho_UpTrapR] =
cocontraction(UpTrap_R(P1begEMG:P1endEMG),UpTrap_L(P1begEMG:P1endEMG)); % Cocontraction R/L
Upper Trapezius
[Area_UpTrap_RL,Area_UpTrap_LL,COCON_UpTrapL,Rho_UpTrapL] =
cocontraction(UpTrap_R(P2begEMG:P2endEMG),UpTrap_L(P2begEMG:P2endEMG)); % Cocontraction R/L
Upper Trapezius

[Area_LowTrap_RR,Area_LowTrap_LR,COCON_LowTrapR,Rho_LowTrapR] =
cocontraction(LowTrap_R(P1begEMG:P1endEMG),LowTrap_L(P1begEMG:P1endEMG)); % Cocontraction
R/L Lower Trapezius
[Area_LowTrap_RL,Area_LowTrap_LL,COCON_LowTrapL,Rho_LowTrapL] =
cocontraction(LowTrap_R(P2begEMG:P2endEMG),LowTrap_L(P2begEMG:P2endEMG)); % Cocontraction
R/L Lower Trapezius

[Area_AntDelt_RR,Area_AntDelt_LR,COCON_AntDeltR,Rho_AntDeltR] =
cocontraction(AntDelt_R(P1begEMG:P1endEMG),AntDelt_L(P1begEMG:P1endEMG)); % Cocontraction
R/L Anterior Deltoid
[Area_AntDelt_RL,Area_AntDelt_LL,COCON_AntDeltL,Rho_AntDeltL] =
cocontraction(AntDelt_R(P2begEMG:P2endEMG),AntDelt_L(P2begEMG:P2endEMG)); % Cocontraction
R/L Anterior Deltoid

[Area_PostDelt_RR,Area_PostDelt_LR,COCON_PostDeltR,Rho_PostDeltR] =
cocontraction(PostDelt_R(P1begEMG:P1endEMG),PostDelt_L(P1begEMG:P1endEMG)); % Cocontraction
R/L Posterior Deltoid
[Area_PostDelt_RL,Area_PostDelt_LL,COCON_PostDeltL,Rho_PostDeltL] =
cocontraction(PostDelt_R(P2begEMG:P2endEMG),PostDelt_L(P2begEMG:P2endEMG)); % Cocontraction
R/L Posterior Deltoid

[Area_ErecSpinIlio_RR,Area_ErecSpinIlio_LR,COCON_ErecSpinIlioR,Rho_ErecSpinIlioR] =
cocontraction(ErecSpinIlio_R(P1begEMG:P1endEMG),ErecSpinIlio_L(P1begEMG:P1endEMG)); %
Cocontraction R/L Posterior Deltoid
[Area_ErecSpinIlio_RL,Area_ErecSpinIlio_LL,COCON_ErecSpinIlioL,Rho_ErecSpinIlioL] =
cocontraction(ErecSpinIlio_R(P2begEMG:P2endEMG),ErecSpinIlio_L(P2begEMG:P2endEMG)); %
Cocontraction R/L Posterior Deltoid

[Area_ErecSpinLong_RR,Area_ErecSpinLong_LR,COCON_ErecSpinLongR,Rho_ErecSpinLongR] =
cocontraction(ErecSpinLong_R(P1begEMG:P1endEMG),ErecSpinLong_L(P1begEMG:P1endEMG)); %
Cocontraction R/L Posterior Deltoid
[Area_ErecSpinLong_RL,Area_ErecSpinLong_LL,COCON_ErecSpinLongL,Rho_ErecSpinLongL] =
cocontraction(ErecSpinLong_R(P2begEMG:P2endEMG),ErecSpinLong_L(P2begEMG:P2endEMG)); %
Cocontraction R/L Posterior Deltoid

%% Percentage of time muscles active (3 SD from mean of baseline)

allmusac = muscleaseactive(i,j,P1,P2,etime,[UpTrap_R,UpTrap_L,LowTrap_R,...
LowTrap_L,AntDelt_R,AntDelt_L,PostDelt_R,PostDelt_L,ErecSpinIlio_R,...
ErecSpinIlio_L,ErecSpinLong_R,ErecSpinLong_L,FlexCU_R,FlexCU_L,ExtCR_R,...
ExtCR_L],ebasedata,3); % 3 is the SD

allmusacL = muscleaseactive(i,j,P1beg,P1end,etime,[UpTrap_R,UpTrap_L,LowTrap_R,...
LowTrap_L,AntDelt_R,AntDelt_L,PostDelt_R,PostDelt_L,ErecSpinIlio_R,...

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ErecSpinIlio_L,ErecSpinLong_R,ErecSpinLong_L,FlexCU_R,FlexCU_L,ExtCR_R,...
ExtCR_L],ebasedata,3); % 3 is the SD

allmusacR = muscactive(i,j,P2beg,P2end,etime,[UpTrap_R,UpTrap_L,LowTrap_R,...
LowTrap_L,AntDelt_R,AntDelt_L,PostDelt_R,PostDelt_L,ErecSpinIlio_R,...
ErecSpinIlio_L,ErecSpinLong_R,ErecSpinLong_L,FlexCU_R,FlexCU_L,ExtCR_R,...
ExtCR_L],ebasedata,3); % 3 is the SD

e_Cocon(j+11*(i-1),1) = [i];
e_Cocon(j+11*(i-1),2) = [j];
e_Cocon(j+11*(i-1),3) = [length(etime)/max(etime)];
e_Cocon(j+11*(i-1),4) = [COCON_UpTrap];
e_Cocon(j+11*(i-1),5) = [COCON_UpTrapR];
e_Cocon(j+11*(i-1),6) = [COCON_UpTrapL];
e_Cocon(j+11*(i-1),7) = [COCON_LowTrap];
e_Cocon(j+11*(i-1),8) = [COCON_LowTrapR];
e_Cocon(j+11*(i-1),9) = [COCON_LowTrapL];
e_Cocon(j+11*(i-1),10) = [COCON_AntDelt];
e_Cocon(j+11*(i-1),11) = [COCON_AntDeltR];
e_Cocon(j+11*(i-1),12) = [COCON_AntDeltL];
e_Cocon(j+11*(i-1),13) = [COCON_PostDelt];
e_Cocon(j+11*(i-1),14) = [COCON_PostDeltR];
e_Cocon(j+11*(i-1),15) = [COCON_PostDeltL];
e_Cocon(j+11*(i-1),16) = [COCON_ErecSpinIlioR];
e_Cocon(j+11*(i-1),17) = [COCON_ErecSpinIlioL];
e_Cocon(j+11*(i-1),18) = [COCON_ErecSpinLongR];
e_Cocon(j+11*(i-1),19) = [COCON_ErecSpinLongL];

e_MusAct(j+11*(i-1),1) = [i];
e_MusAct(j+11*(i-1),2) = [j];
e_MusAct(j+11*(i-1),3) = allmusac(1); % UpTrap_R
e_MusAct(j+11*(i-1),4) = allmusac(2); % UpTrap_L
e_MusAct(j+11*(i-1),5) = allmusac(3); % LowTrap_R
e_MusAct(j+11*(i-1),6) = allmusac(4); % LowTrap_L
e_MusAct(j+11*(i-1),7) = allmusac(5); % AntDelt_R
e_MusAct(j+11*(i-1),8) = allmusac(6); % AntDelt_L
e_MusAct(j+11*(i-1),9) = allmusac(7); % PostDelt_R
e_MusAct(j+11*(i-1),10) = allmusac(8); % PostDelt_L
e_MusAct(j+11*(i-1),11) = allmusac(9); % ErecSpinIlio_R
e_MusAct(j+11*(i-1),12) = allmusac(10); % ErecSpinIlio_L
e_MusAct(j+11*(i-1),13) = allmusac(11); % ErecSpinLong_R
e_MusAct(j+11*(i-1),14) = allmusac(12); % ErecSpinLong_L
e_MusAct(j+11*(i-1),15) = allmusac(13); % FlexCU_R
e_MusAct(j+11*(i-1),16) = allmusac(14); % FlexCU_L
e_MusAct(j+11*(i-1),17) = allmusac(15); % ExtCR_R
e_MusAct(j+11*(i-1),18) = allmusac(16); % ExtCR_L

e_MusActR(j+11*(i-1),1) = [i];
e_MusActR(j+11*(i-1),2) = [j];
e_MusActR(j+11*(i-1),3) = allmusacR(1); % UpTrap_R
e_MusActR(j+11*(i-1),4) = allmusacR(2); % UpTrap_L
e_MusActR(j+11*(i-1),5) = allmusacR(3); % LowTrap_R
e_MusActR(j+11*(i-1),6) = allmusacR(4); % LowTrap_L
e_MusActR(j+11*(i-1),7) = allmusacR(5); % AntDelt_R
e_MusActR(j+11*(i-1),8) = allmusacR(6); % AntDelt_L
e_MusActR(j+11*(i-1),9) = allmusacR(7); % PostDelt_R
e_MusActR(j+11*(i-1),10) = allmusacR(8); % PostDelt_L
e_MusActR(j+11*(i-1),11) = allmusacR(9); % ErecSpinIlio_R
e_MusActR(j+11*(i-1),12) = allmusacR(10); % ErecSpinIlio_L
e_MusActR(j+11*(i-1),13) = allmusacR(11); % ErecSpinLong_R
e_MusActR(j+11*(i-1),14) = allmusacR(12); % ErecSpinLong_L
e_MusActR(j+11*(i-1),15) = allmusacR(13); % FlexCU_R
e_MusActR(j+11*(i-1),16) = allmusacR(14); % FlexCU_L
e_MusActR(j+11*(i-1),17) = allmusacR(15); % ExtCR_R
e_MusActR(j+11*(i-1),18) = allmusacR(16); % ExtCR_L

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e_MusActL(j+11*(i-1),1) = [i];
e_MusActL(j+11*(i-1),2) = [j];
e_MusActL(j+11*(i-1),3) = allmusacL(1); % UpTrap_R
e_MusActL(j+11*(i-1),4) = allmusacL(2); % UpTrap_L
e_MusActL(j+11*(i-1),5) = allmusacL(3); % LowTrap_R
e_MusActL(j+11*(i-1),6) = allmusacL(4); % LowTrap_L
e_MusActL(j+11*(i-1),7) = allmusacL(5); % AntDelt_R
e_MusActL(j+11*(i-1),8) = allmusacL(6); % AntDelt_L
e_MusActL(j+11*(i-1),9) = allmusacL(7); % PostDelt_R
e_MusActL(j+11*(i-1),10) = allmusacL(8); % PostDelt_L
e_MusActL(j+11*(i-1),11) = allmusacL(9); % ErecSpinIlio_R
e_MusActL(j+11*(i-1),12) = allmusacL(10); % ErecSpinIlio_L
e_MusActL(j+11*(i-1),13) = allmusacL(11); % ErecSpinLong_R
e_MusActL(j+11*(i-1),14) = allmusacL(12); % ErecSpinLong_L
e_MusActL(j+11*(i-1),15) = allmusacL(13); % FlexCU_R
e_MusActL(j+11*(i-1),16) = allmusacL(14); % FlexCU_L
e_MusActL(j+11*(i-1),17) = allmusacL(15); % ExtCR_R
e_MusActL(j+11*(i-1),18) = allmusacL(16); % ExtCR_L

% For refstrab, P2beg-end is the other side, P1beg-end is reach over.
% i.e. Patients left eye is examined by reaching over form patients right
% side, vs. going to patients left side to examine the left eye

e_AsymR(j+11*(i-1),1) = [i];
e_AsymR(j+11*(i-1),2) = [j];
e_AsymR(j+11*(i-1),3) = [Area_UpTrap_RR]/(mtime(P1end)-mtime(P1beg));
e_AsymR(j+11*(i-1),4) = [Area_UpTrap_RL]/(mtime(P2end)-mtime(P2beg));
e_AsymR(j+11*(i-1),5) = [Area_LowTrap_RR]/(mtime(P1end)-mtime(P1beg));
e_AsymR(j+11*(i-1),6) = [Area_LowTrap_RL]/(mtime(P2end)-mtime(P2beg));
e_AsymR(j+11*(i-1),7) = [Area_AntDelt_RR]/(mtime(P1end)-mtime(P1beg));
e_AsymR(j+11*(i-1),8) = [Area_AntDelt_RL]/(mtime(P2end)-mtime(P2beg));
e_AsymR(j+11*(i-1),9) = [Area_PostDelt_RR]/(mtime(P1end)-mtime(P1beg));
e_AsymR(j+11*(i-1),10) = [Area_PostDelt_RL]/(mtime(P2end)-mtime(P2beg));
e_AsymR(j+11*(i-1),11) = [Area_ErecSpinIlio_RR]/(mtime(P1end)-mtime(P1beg));
e_AsymR(j+11*(i-1),12) = [Area_ErecSpinIlio_RL]/(mtime(P2end)-mtime(P2beg));
e_AsymR(j+11*(i-1),13) = [Area_ErecSpinLong_RR]/(mtime(P1end)-mtime(P1beg));
e_AsymR(j+11*(i-1),14) = [Area_ErecSpinLong_RL]/(mtime(P2end)-mtime(P2beg));

e_AsymL(j+11*(i-1),1) = [i];
e_AsymL(j+11*(i-1),2) = [j];
e_AsymL(j+11*(i-1),3) = [Area_UpTrap_LR]/(mtime(P1end)-mtime(P1beg));
e_AsymL(j+11*(i-1),4) = [Area_UpTrap_LL]/(mtime(P2end)-mtime(P2beg));
e_AsymL(j+11*(i-1),5) = [Area_LowTrap_LR]/(mtime(P1end)-mtime(P1beg));
e_AsymL(j+11*(i-1),6) = [Area_LowTrap_LL]/(mtime(P2end)-mtime(P2beg));
e_AsymL(j+11*(i-1),7) = [Area_AntDelt_LR]/(mtime(P1end)-mtime(P1beg));
e_AsymL(j+11*(i-1),8) = [Area_AntDelt_LL]/(mtime(P2end)-mtime(P2beg));
e_AsymL(j+11*(i-1),9) = [Area_PostDelt_LR]/(mtime(P1end)-mtime(P1beg));
e_AsymL(j+11*(i-1),10) = [Area_PostDelt_LL]/(mtime(P2end)-mtime(P2beg));
e_AsymL(j+11*(i-1),11) = [Area_ErecSpinIlio_LR]/(mtime(P1end)-mtime(P1beg));
e_AsymL(j+11*(i-1),12) = [Area_ErecSpinIlio_LL]/(mtime(P2end)-mtime(P2beg));
e_AsymL(j+11*(i-1),13) = [Area_ErecSpinLong_LR]/(mtime(P1end)-mtime(P1beg));
e_AsymL(j+11*(i-1),14) = [Area_ErecSpinLong_LL]/(mtime(P2end)-mtime(P2beg));

e_Activation(j+11*(i-1),1) = [i];
e_Activation(j+11*(i-1),2) = [j];
e_Activation(j+11*(i-1),3) = [Area_UpTrap_R]/(mtime(P2)-mtime(P1));
e_Activation(j+11*(i-1),4) = [Area_UpTrap_L]/(mtime(P2)-mtime(P1));
e_Activation(j+11*(i-1),5) = [Area_LowTrap_R]/(mtime(P2)-mtime(P1));
e_Activation(j+11*(i-1),6) = [Area_LowTrap_L]/(mtime(P2)-mtime(P1));
e_Activation(j+11*(i-1),7) = [Area_AntDelt_R]/(mtime(P2)-mtime(P1));
e_Activation(j+11*(i-1),8) = [Area_AntDelt_L]/(mtime(P2)-mtime(P1));
e_Activation(j+11*(i-1),9) = [Area_ErecSpinIlio_L]/(mtime(P2)-mtime(P1));
e_Activation(j+11*(i-1),10) = [Area_ErecSpinIlio_R]/(mtime(P2)-mtime(P1));

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e_RMS(j+11*(i-1),1) = [i];
e_RMS(j+11*(i-1),2) = [j];
e_RMS(j+11*(i-1),3) = [rms(UpTrap_R(P1EMG:P2EMG))/ebaseRMS(2)];
e_RMS(j+11*(i-1),4) = [rms(UpTrap_L(P1EMG:P2EMG))/ebaseRMS(3)];
e_RMS(j+11*(i-1),5) = [rms(AntDelt_R(P1EMG:P2EMG))/ebaseRMS(6)];
e_RMS(j+11*(i-1),6) = [rms(AntDelt_L(P1EMG:P2EMG))/ebaseRMS(7)];
e_RMS(j+11*(i-1),7) = [rms(ErecSpinIlio_R(P1EMG:P2EMG))/ebaseRMS(10)];
e_RMS(j+11*(i-1),8) = [rms(ErecSpinIlio_L(P1EMG:P2EMG))/ebaseRMS(11)];
e_RMS(j+11*(i-1),9) = [rms(ErecSpinLong_R(P1EMG:P2EMG))/ebaseRMS(12)];
e_RMS(j+11*(i-1),10) = [rms(ErecSpinLong_L(P1EMG:P2EMG))/ebaseRMS(13)];

e_RMS1(j+11*(i-1),1) = [i];
e_RMS1(j+11*(i-1),2) = [j];
e_RMS1(j+11*(i-1),3) = [rms(UpTrap_R(P1begEMG:P1endEMG)-ebaseavg(i))];
e_RMS1(j+11*(i-1),4) = [rms(UpTrap_L(P1begEMG:P1endEMG)-ebaseavg(i))];
e_RMS1(j+11*(i-1),5) = [rms(AntDelt_R(P1begEMG:P1endEMG)-ebaseavg(i))];
e_RMS1(j+11*(i-1),6) = [rms(AntDelt_L(P1begEMG:P1endEMG)-ebaseavg(i))];
e_RMS1(j+11*(i-1),7) = [rms(ErecSpinIlio_R(P1begEMG:P1endEMG)-ebaseavg(i))];
e_RMS1(j+11*(i-1),8) = [rms(ErecSpinIlio_L(P1begEMG:P1endEMG)-ebaseavg(i))];
e_RMS1(j+11*(i-1),9) = [rms(UpTrap_L(P1begEMG:P1endEMG)-
ebaseavg(i))/rms(UpTrap_R(P1begEMG:P1endEMG)-ebaseavg(i))];
e_RMS1(j+11*(i-1),10) = [rms(AntDelt_L(P1begEMG:P1endEMG)-
ebaseavg(i))/rms(AntDelt_R(P1begEMG:P1endEMG)-ebaseavg(i))];
e_RMS1(j+11*(i-1),11) = [rms(ErecSpinIlio_L(P1begEMG:P1endEMG)-
ebaseavg(i))/rms(ErecSpinIlio_R(P1begEMG:P1endEMG)-ebaseavg(i))];

e_RMS2(j+11*(i-1),1) = [i];
e_RMS2(j+11*(i-1),2) = [j];
e_RMS2(j+11*(i-1),3) = [rms(UpTrap_R(P2begEMG:P2endEMG)-ebaseavg(i))];
e_RMS2(j+11*(i-1),4) = [rms(UpTrap_L(P2begEMG:P2endEMG)-ebaseavg(i))];
e_RMS2(j+11*(i-1),5) = [rms(AntDelt_R(P2begEMG:P2endEMG)-ebaseavg(i))];
e_RMS2(j+11*(i-1),6) = [rms(AntDelt_L(P2begEMG:P2endEMG)-ebaseavg(i))];
e_RMS2(j+11*(i-1),7) = [rms(ErecSpinIlio_R(P2begEMG:P2endEMG)-ebaseavg(i))];
e_RMS2(j+11*(i-1),8) = [rms(ErecSpinIlio_L(P2begEMG:P2endEMG)-ebaseavg(i))];
e_RMS2(j+11*(i-1),9) = [rms(UpTrap_L(P2begEMG:P2endEMG)-
ebaseavg(i))/rms(UpTrap_R(P2begEMG:P2endEMG)-ebaseavg(i))];
e_RMS2(j+11*(i-1),10) = [rms(AntDelt_L(P2begEMG:P2endEMG)-
ebaseavg(i))/rms(AntDelt_R(P2begEMG:P2endEMG)-ebaseavg(i))];
e_RMS2(j+11*(i-1),11) = [rms(ErecSpinIlio_L(P2begEMG:P2endEMG)-
ebaseavg(i))/rms(ErecSpinIlio_R(P2begEMG:P2endEMG)-ebaseavg(i))];

end

end

function procEMG = EMGabsfilt(edata,~)
%This function takes EMG data, rectifies it, detrends it, and then low pass filters it

[row,col] = size(edata);

fs_e = 1925.926; % Sampling rate for EMG
f_nyq = fs_e/2; % Nyquist frequency

f_cutoff = 50; % 50 Hz cutoff frequency, Hodges 1996, Walter 1984

if nargin < 1
error('Please enter a vector of at least 1 column')
end

edatal = zeros(row,col); % Pre-allocated array for rectified
edatal2 = zeros(row,col); % Pre-allocated array for filtered
edatal3 = zeros(row,col); % Pre-allocated array for notched

```



```

for i = 1:col
    [b,a] = butter(2,[35 500]/f_nyq,'bandpass'); % 4th order butterworth filter, Bandpass
    between 35 Hz (Drake 2006) and 500 Hz (Seniam), takes care of ECG interference/contamination
    edata1(:,i) = filtfilt(b,a,edata(:,i)); % Filters the rectified data forward and backward
    Wn = [59*2/fs_e,61*2/fs_e];
    [B,A] = butter(4,Wn,'stop'); % I feel like this is a band stop
    edata2(:,i) = filtfilt(B,A,edata1(:,i));
    edata3(:,i) = abs(edata2(:,i)-mean(edata2(:,i))); % Full wave Rectify all EMG channels
    after removing mean value
    [B1,A1] = butter(4,1.25*f_cutoff/f_nyq);
    edata3(:,i) = filtfilt(B1,A1,edata3(:,i));

end

procEMG = edata3;

end

function [T1,T2,T3,T4] = findoveralProcframes(i,j)
% i = subjectfinder(i), j = trialfinder(j) T1 = start T pose, T2 = end T pose
% For 1,1+int1/2/3, T1-T2 = REye1 and T3-T4 = REye2 from Event Markers.pdf
% For 2,2+int1/2/3, T1-T2 = T3-T4 = Occ_Range
% For 3,3+int1/2, T1-T2 = LEye_Range and T3-T4 = R_Eye_Range

load eventmarkers.mat

    if j <= 4
        T1 = eventmarkers(j+11*(i-1),10); T2 = eventmarkers(j+11*(i-1),11);
        T3 = eventmarkers(j+11*(i-1),12); T4 = eventmarkers(j+11*(i-1),13);
    elseif j > 4 && j <=8
        T1 = eventmarkers(j+11*(i-1),5); T2 = eventmarkers(j+11*(i-1),6);
        T3 = eventmarkers(j+11*(i-1),5); T4 = eventmarkers(j+11*(i-1),6);
    else
        T1 = eventmarkers(j+11*(i-1),5); T2 = eventmarkers(j+11*(i-1),6);
        T3 = eventmarkers(j+11*(i-1),7); T4 = eventmarkers(j+11*(i-1),8);
    end

end

function [T1,T2] = findTposerange(i,j)
% i = subjectfinder(i), j = trialfinder(j) T1 = start T pose, T2 = end T pose
load eventmarkers.mat
T1 = eventmarkers(j+11*(i-1),1); T2 = eventmarkers(j+11*(i-1),2);
end

function [T1,T2] = StartProc2StartTframes(i,j)
% i = subjectfinder(i), j = trialfinder(j) T1 = start T pose, T2 = end T pose
% For 1,1+int1/2/3, T1-T2 = REye1 and T3-T4 = REye2 from Event Markers.pdf
% For 2,2+int1/2/3, T1-T2 = T3-T4 = Occ_Range
% For 3,3+int1/2, T1-T2 = LEye_Range and T3-T4 = R_Eye_Range

load eventmarkers.mat

    if j <= 8
        T1 = eventmarkers(j+11*(i-1),4); T2 = eventmarkers(j+11*(i-1),7);
    else
        T1 = eventmarkers(j+11*(i-1),4); T2 = eventmarkers(j+11*(i-1),9);
    end

end

```

```

function headangles = neckangle(LSHO,RSHO,LFHD,RFHD,LBHD,RBHD,C7,CLAV,i1,j1)
% i and j from OphthAnalyze, i = subject number from subfinder(i), j = trial number from
trialfinder(j)

if nargin <= 8
    T1 = 1;
    T2 = 100;
else
    [T1,T2] = findTposerange(i1,j1);
end

% STEP 1
% C7 marker is the posterior base of neck - this should be the AP pivot
% Define a virtual vector during T-pose representing a line between C7 and the midpoint %of the
posterior back of the head (b/n RBHD & LBHD)
% Note about T-Pose:
% T-Pose was not at the very beginning of the Trials, so a range of T-pose
% frames will be defined. E.g. for Subject036, Trial 1, range is 577:677,
% will be defined by findTposerange(i,j)

BHD_dist = mean(LBHD(T1:T2,:) - RBHD(T1:T2,:),1); % distance between RBHD and LBHD at T-Pose
MBHD = (RBHD + LBHD)/2; %overall midpoint (posterior) of head markers RBHD LBHD
MBHD1 = mean(RBHD(T1:T2,:),1) + BHD_dist/2; % midpoint between posterior head markers for this
first part i.e. T-Pose
k = MBHD1 - mean(C7(T1:T2,:));
k = k./sqrt(k(1)^2+k(2)^2+k(3)^2);

% STEP 2
% Define a localizing coordinate system using head markers during T-pose. This is a
% non-anatomical CS used only for transforming the head axis defined above

FHD_dist = mean(LFHD(T1:T2,:) - RFHD(T1:T2,:),1); % distance between RFHD and LFHD (add
meanremove later)
MFHD = (RFHD + LFHD)/2; %overall midpoint (anterior) of head markers RFHD LFHD
MFHD1 = mean(RFHD(T1:T2,:),1) + FHD_dist/2; % midpoint between anterior head markers for this
first part i.e. T-Pose

ihead_loc_init = MFHD1 - MBHD1; % initial AP axis
vtemp = mean(LFHD(T1:T2,:),1) - MBHD1;
khead_loc_init = cross(vtemp,ihead_loc_init);
jhead_loc_init = cross(khead_loc_init,ihead_loc_init);
ihead_loc_init =
ihead_loc_init./sqrt(ihead_loc_init(1)^2+ihead_loc_init(2)^2+ihead_loc_init(3)^2);
jhead_loc_init =
jhead_loc_init./sqrt(jhead_loc_init(1)^2+jhead_loc_init(2)^2+jhead_loc_init(3)^2);
khead_loc_init =
khead_loc_init./sqrt(khead_loc_init(1)^2+khead_loc_init(2)^2+khead_loc_init(3)^2);

%STEP 3: Transform head axis defined in STEP 1 from global coordinates into
%localizing coordinates as defined in STEP 2

Thead_loc_init = [ihead_loc_init;jhead_loc_init;khead_loc_init];
kheadL = Thead_loc_init*k';

%STEP 4: Define localizing head coordinate system for entire trial (same
%process as in STEP 2, except now for the whole trial duration

ihead_loc = MFHD - MBHD;
vtemp = LFHD - MBHD;
khead_loc = cross(vtemp,ihead_loc);
jhead_loc = cross(khead_loc,ihead_loc);

```

```

ihead_loc = [ihead_loc(:,1)./sqrt(ihead_loc(:,1).^2+ihead_loc(:,2).^2+ihead_loc(:,3).^2)
ihead_loc(:,2)./sqrt(ihead_loc(:,1).^2+ihead_loc(:,2).^2+ihead_loc(:,3).^2)
ihead_loc(:,3)./sqrt(ihead_loc(:,1).^2+ihead_loc(:,2).^2+ihead_loc(:,3).^2)];
jhead_loc = [jhead_loc(:,1)./sqrt(jhead_loc(:,1).^2+jhead_loc(:,2).^2+jhead_loc(:,3).^2)
jhead_loc(:,2)./sqrt(jhead_loc(:,1).^2+jhead_loc(:,2).^2+jhead_loc(:,3).^2)
jhead_loc(:,3)./sqrt(jhead_loc(:,1).^2+jhead_loc(:,2).^2+jhead_loc(:,3).^2)];
khead_loc = [khead_loc(:,1)./sqrt(khead_loc(:,1).^2+khead_loc(:,2).^2+khead_loc(:,3).^2)
khead_loc(:,2)./sqrt(khead_loc(:,1).^2+khead_loc(:,2).^2+khead_loc(:,3).^2)
khead_loc(:,3)./sqrt(khead_loc(:,1).^2+khead_loc(:,2).^2+khead_loc(:,3).^2)];

%STEP 5: Define local coordinate system for shoulders:
%Origin = Shoulder midpoint
%+i = lateral right
%+j = anterior
%+k = superior

jbody = CLAV - C7; % AP vec for shoulder - clavical to C7
ibody_temp = RSHO-LSHO; % ML vec temp right shoulder to left shoulder
kbody = cross(ibody_temp,jbody);
ibody = cross(jbody,kbody);
ibody = [ibody(:,1)./sqrt(ibody(:,1).^2+ibody(:,2).^2+ibody(:,3).^2)
ibody(:,2)./sqrt(ibody(:,1).^2+ibody(:,2).^2+ibody(:,3).^2)
ibody(:,3)./sqrt(ibody(:,1).^2+ibody(:,2).^2+ibody(:,3).^2)];
jbody = [jbody(:,1)./sqrt(jbody(:,1).^2+jbody(:,2).^2+jbody(:,3).^2)
jbody(:,2)./sqrt(jbody(:,1).^2+jbody(:,2).^2+jbody(:,3).^2)
jbody(:,3)./sqrt(jbody(:,1).^2+jbody(:,2).^2+jbody(:,3).^2)];
kbody = [kbody(:,1)./sqrt(kbody(:,1).^2+kbody(:,2).^2+kbody(:,3).^2)
kbody(:,2)./sqrt(kbody(:,1).^2+kbody(:,2).^2+kbody(:,3).^2)
kbody(:,3)./sqrt(kbody(:,1).^2+kbody(:,2).^2+kbody(:,3).^2)];

%STEP 6: Transform head long axis from localizing coordinate system (from
%STEP 2) back into global coordinates

for i = 1:length(LSHO)
    Thead_loc = [ihead_loc(i,:);jhead_loc(i,:);khead_loc(i,:)];
    kHead = Thead_loc'*kheadL;

%STEP 8: Use head global long axis and head markers to define remaining axes of anatomical head
coordinate system

    jHead = MFHD(i,:) - MBHD(i,:);
    iHead = cross(jHead,kHead);
    jHead = cross(kHead,iHead);
    iHead = iHead./sqrt(iHead(1)^2+iHead(2)^2+iHead(3)^2);
    jHead = jHead./sqrt(jHead(1)^2+jHead(2)^2+jHead(3)^2);

%STEP 9: Define 3x3 coordinate system matrices for shoulders, head
%use these to define rotational transformation matrices
%linking subject head and shoulders (RSub);

    Tbody = [ibody(i,:);jbody(i,:);kbody(i,:)];
    TheadSub = [iHead;jHead;kHead'];
    RSub = TheadSub*Tbody';

%STEP 10:

%STEP 10: Extract head angles from rotation matrices (alpha =
%head flexion/extension; beta = lateral flexion; gamma = rotation)

    betaHead(i) = asind(RSub(3,1));
    gammaHead(i) = -asind(RSub(2,1)/cosd(betaHead(i)));
    alphaHead(i) = asind(RSub(3,2)/-cosd(betaHead(i)));

end

```

```

%STEP 11: Subtract initial mean off of angles so they start at zero; package into
%'angles' variable for export

alphaHead = alphaHead - mean(alphaHead(1:100));
betaHead = betaHead - mean(betaHead(1:100));
gammaHead = gammaHead - mean(gammaHead(1:100));
headangles = [alphaHead(:) betaHead(:) gammaHead(:)];

end

function [fdata]=filter_data(data, freq_cutoff, freq_collect,order)

    if nargin < 4
        order = 2;
    end

    dim = size(data);
    icol = dim(2); % Gets the columns for data

% Create a 2nd order lowpass Butterworth filter

    freq_half=freq_collect/2;
    [b,a]=butter(order,freq_cutoff/freq_half);

    [n,m]=size(data);
    n_2=2*n; % this is used in the reflection
    n_3=3*n; % this is used in the reflection

    for f=1:icol %f=[icol]
        dim=data(n:-1:1,f);
        temp2=[dim;data(:,f);dim];
        temp3=filter(b,a,temp2);
        temp4=filter(b,a,temp3(n_3:-1:1,1));
        temp5=temp4(n_3:-1:1,1);
        fdata(:,f)=temp5(n+1:n_2,1);
        clear temp1 temp2 temp3 temp4 temp5;
    end;

function ROM = rom(vec,col)
% Range of Motion calculation. Please enter a vector.
% If you have multiple columns, please specify no. of columns
% Otherwise 1 column will be specified by default

if nargin < 2
    col = 1;
elseif nargin < 1
    error('Please enter a vector of at least 1 column')
end

for i = 1:col

    ROM(i) = max(vec(:,i))-min(vec(:,i));

end

end

```

```

function NonNeutralPercent = nonneutral(T1,T2,P1,P2,mtime,anglevecs)
% Calculates what percent of time an angular timeseries spends in
% "non-neutral" position. This is defined by > 20 deg flexion and any extension

    for i = 1:3
        T_pose_angle = anglevecs(T1:T2,i);

        T_pose_angle_mean_plus_N_SD = mean(T_pose_angle)+20; % more than 20 flexion
        T_pose_angle_mean_minus_N_SD = mean(T_pose_angle);% any extension

        NonNeutralPercent(i) = ( sum(anglevecs(P1:P2,i) >= T_pose_angle_mean_plus_N_SD) +
sum(anglevecs(P1:P2,i) <= T_pose_angle_mean_minus_N_SD) ) / (0.01*length(mtime));
        end

end

function [area_ago,area_ant,cocon,rho] = cocontraction(ago,ant)
% Function cocontraction calculates the % cocontraction of an agonist and
% and antagonist pair of muscles.
%
% Sample input ----> Cocon_per = cocontraction(LTA,LSO)
%
% Please note that there is no specific order of the agonist and
% antagonist, they just both need to be the pair of inputs
%
% Author: Safeer Farrukh Siddicky
% University of Missouri-Kansas City

ago = abs(ago); ant = abs(ant); % Rectify all EMG signals

area_ago = trapz(ago); area_ant = trapz(ant); % Calculate the area of the agonist and
antagonist muscle EMG profiles

com = zeros(length(ago),1); % Initialize vector for inputting data points where the area of
activation is common to both muscles

    for i =1:length(ago) % Indexed to all EMG data points
        if ago(i)>ant(i) % The point of this conditional is to find the area
common to both muscle activities
            com(i) = ant(i); % Since all data is rectified, essentially the data
points of the lower graph is taken
        elseif ant(i)>ago(i) % And compiled into the vector "com".
            com(i) = ago(i);
        end
    end

    com_area = trapz(com); % The area common to both muscle EMG profiles for both
muscles is just the area under % this new com data set

    cocon = 100*((2*com_area)/(area_ago+area_ant)); % This is the cocontraction formula
obtained from

                                %Winter
                                %Biomechanics
                                %book

rho = corr(abs(ago),abs(ant)); % Correlation between the two muscles

if nargout == 1
    cocon;
end

end

```

```

function ActivationTime = musclective(i,j,P1,P2,etime,musclevects,ebasedata,N)
% Calculates what percent of time an EMG timeseries spends in
% "activated" state. This is defined by 3 SD from "resting" EMG
% Update 08/02 - using Baseline EMG readings from Baseline trial,

[T1,T2] = findEMGbasemarker(i,j); % This is the window of EMG frames that
% I found all EMG waveforms were at a "resting" level

P1temp = size(find(etime<=P1/120)); % Converts MoCap frames to EMG frames
P1 = P1temp(1);

P2temp = size(find(etime<=P2/120)); % Converts MoCap frames to EMG frames
P2 = P2temp(1);

[~,veccols] = size(musclevects);
ActivationTime = zeros(1,veccols);
for n = 1:veccols
    EMGBaseline = musclevects(T1:T2,n); % resting level for each trial
    EMGBaseline_mean_plus_N_SD = mean(EMGBaseline)+N*std(EMGBaseline);
    above_thresh = musclevects(P1:P2,n) > EMGBaseline_mean_plus_N_SD; % Logicals where musclevect
greater than 3 SD
    win = 200; % sliding window, back to 50, 200
    inwin = conv(double(above_thresh), ones(1,win),'same'); % sliding window, outputs how many
samples in each window above 3SD
    ActivationTime(n) = sum(inwin>=.7*win)/(0.01*length(etime));
% ActivationTime(n) = sum(inwin>=.7*win)/(0.01*length(etime(P1:P2)));
end

end

```

REFERENCES

- [1] T. Morse, H. Bruneau, C. Michalak-Turcotte, M. Sanders, N. Warren, J. Dussetschleger, U. Diva, M. Croteau, and M. Cherniack, "Musculoskeletal disorders of the neck and shoulder in dental hygienists and dental hygiene students." *Journal of Dental Hygiene*, vol. 81, no. 1, p. 10, 2007.
- [2] T. Rambabu and K. Suneetha, "Prevalence of work related musculoskeletal disorders among physicians, surgeons and dentists: a comparative study." *Annals of Medical and Health Sciences Research*, vol. 4, no. 4, pp. 578–82, 2014.
- [3] B. Valachi and K. Valachi, "Preventing musculoskeletal disorders in clinical dentistry: strategies to address the mechanisms leading to musculoskeletal disorders." *Journal of the American Dental Association (1939)*, vol. 134, no. 12, pp. 1604–12, 2003.
- [4] A. Chatterjee, W. Ryan, and E. Rosen, "Back Pain in Ophthalmologists," *Eye*, vol. 8, pp. 473–474, 1994.
- [5] H. Chams, S. F. Mohammadi, and A. Moayyeri, "Frequency and assortment of self-report occupational complaints among Iranian ophthalmologists: a preliminary survey." *Medscape General Medicine*, vol. 6, no. 4, p. 1, 2004.
- [6] K. C. Dhimitri, G. McGwin Jr., S. F. McNeal, P. Lee, P. Morse, M. Patterson, F. D. Wertz, and J. L. Marx, "Symptoms of musculoskeletal disorders in ophthalmologists," *American Journal of Ophthalmology*, vol. 139, no. 1, pp. 179–181, 2005.
- [7] J. A. Sivak-Callcott, S. R. Diaz, A. M. Ducatman, C. L. Rosen, A. D. Nimbarte, and J. a. Sedgeman, "A survey study of occupational pain and injury in ophthalmic plastic surgeons." *Ophthalmic plastic and reconstructive surgery*, vol. 27, no. 1, pp. 28–32, 2011.
- [8] J. N. Hyer, R. M. Lee, H. R. Chowdhury, H. B. Smith, A. Dhital, and M. Khandwala, "National survey of back & neck pain amongst consultant ophthalmologists in the United Kingdom," *International Ophthalmology*, vol. 35, no. 6, pp. 769–775, 2015.
- [9] M. M. Statham, A. L. Sukits, M. S. Redfern, L. J. Smith, J. C. Sok, and C. A. Rosen, "Ergonomic analysis of microlaryngoscopy," *The Laryngoscope*, vol. 120, no. 2, pp. 297–305, 2010.
- [10] A. Aarås, "Relationship between trapezius load and the incidence of musculoskeletal illness in the neck and shoulder," *International Journal of Industrial Ergonomics*, vol. 14, no. 4, pp. 341–348, 1994.

- [11] N. B. Fethke, M. C. Schall, E. M. Determan, and A. S. Kitzmann, “Neck and shoulder muscle activity among ophthalmologists during routine clinical examinations,” *International Journal of Industrial Ergonomics*, vol. 49, pp. 53–59, 2015.
- [12] World Health Organization, *International Statistical Classification of Diseases and Related Health Problems, ICD-10*, 1992, vol. 41.
- [13] R. Horton, “GBD 2010: Understanding disease, injury, and risk,” *The Lancet*, vol. 380, no. 9859, pp. 2053–2054, 2012.
- [14] GBD 2016 Disease and Injury Incidence and Prevalence Collaborators, “Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990-2016: A systematic analysis for the Global Burden of Disease Study 2016,” *The Lancet*, vol. 390, no. 10100, pp. 1211–1259, 2017.
- [15] Bone and Joint Initiative USA, “The Burden of Musculoskeletal Diseases in the United States (BMUS),” p. 247, 2014.
- [16] A. D. Woolf and B. Pfleger, “Burden of major musculoskeletal conditions,” *Bulletin of the World Health Organization*, vol. 81, no. 9, pp. 646–656, 2003.
- [17] Z. Szubert, W. Sobala, and Z. Zycinska, “The effect of system restructuring on absenteeism due to sickness in the workplace. I. Sickness absenteeism during the period 1989-1994,” *Medycyna Pracy*, vol. 48, no. 1, pp. 543–51, 1997.
- [18] G. Tellnes and T. Bjerkedal, “Epidemiology of Sickness Certification: A methodological approach based on a study from Buskerud county in Norway,” *Scandinavian Journal of Public Health*, vol. 17, no. 3, pp. 245–251, 1989.
- [19] NIOSH, *Musculoskeletal Disorders and Workplace Factors. NIOSH Publication 97-141, second ed. US Department of Health and Human Services, Cincinnati, OH.*, 1997.
- [20] W. E. Hoogendoorn, M. N. M. Van Poppel, P. M. Bongers, B. W. Koes, and L. M. Bouter, “Physical load during work and leisure time as risk factors for back pain,” *Scandinavian Journal of Work, Environment and Health*, vol. 25, no. 5, pp. 387–403, 1999.
- [21] N. R. Council and I. of Medicine, “Musculoskeletal disorders and the workplace: Low back and upper extremities,” *Theoretical Issues in Ergonomics Science*, vol. 2, no. 2, pp. 142–152, 2001.
- [22] P. Côté, G. van der Velde, J. D. Cassidy, L. J. Carroll, S. Hogg-Johnson, L. W. Holm, E. J. Carragee, S. Haldeman, M. Nordin, E. L. Hurwitz, J. Guzman, and P. M. Peloso, “The Burden and Determinants of Neck Pain in Workers. Results of the Bone and Joint Decade 2000-2010 Task Force on Neck

- Pain and Its Associated Disorders,” *Journal of Manipulative and Physiological Therapeutics*, vol. 32, no. 2, 2009.
- [23] J. Mayer, T. Kraus, and E. Ochsmann, “Longitudinal evidence for the association between work-related physical exposures and neck and/or shoulder complaints: A systematic review,” *International Archives of Occupational and Environmental Health*, vol. 85, no. 6, pp. 587–603, 2012.
- [24] E. W. Bakker, A. P. Verhagen, E. van Trijffel, C. Lucas, and B. W. Koes, “Spinal mechanical load as a risk factor for low back pain: a systematic review of prospective cohort studies,” *Spine*, vol. 34, no. 8, pp. E281–93, 2009.
- [25] P. Coenen, M. Douwes, S. van den Heuvel, and T. Bosch, “Towards exposure limits for working postures and musculoskeletal symptoms – a prospective cohort study,” *Ergonomics*, vol. 59, no. 9, pp. 1182–1192, 2016.
- [26] D. M. Roffey, E. K. Wai, P. Bishop, B. K. Kwon, and S. Dagenais, “Causal assessment of awkward occupational postures and low back pain: results of a systematic review,” *Spine Journal*, vol. 10, no. 1, pp. 89–99, 2010.
- [27] G. A. M. Ariëns, P. M. Bongers, M. Douwes, M. C. Miedema, W. E. Hoogendoorn, G. Van der Wal, L. M. Bouter, and W. Van Mechelen, “Are neck flexion, neck rotation, and sitting at work risk factors for neck pain? Results of a prospective cohort study,” *Occupational and Environmental Medicine*, vol. 58, no. 3, pp. 200–207, 2001.
- [28] J. Wahlström, M. Hagberg, A. Toomingas, and E. Wigaeus Tornqvist, “Perceived muscular tension, job strain, physical exposure, and associations with neck pain among VDU users; a prospective cohort study,” *Occupational and Environmental Medicine*, vol. 61, no. 6, pp. 523–528, 2004.
- [29] J. J. Luime, J. I. Kuiper, B. W. Koes, J. A. Verhaar, H. S. Miedema, and A. Burdorf, “Work-related risk factors for the incidence and recurrence of shoulder and neck complaints among nursing-home and elderly-care workers,” *Scandinavian Journal of Work, Environment and Health*, vol. 30, no. 4, pp. 279–286, 2004.
- [30] M. Marcus, F. Gerr, C. Monteilh, D. J. Ortiz, E. Gentry, S. Cohen, A. Edwards, C. Ensor, and D. Kleinbaum, “A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders,” *American Journal of Industrial Medicine*, vol. 41, no. 4, pp. 236–249, 2002.
- [31] J. H. Andersen, A. Kaergaard, S. Mikkelsen, U. F. Jensen, P. Frost, J. P. Bonde, N. Fallentin, and J. F. Thomsen, “Risk factors in the onset of neck/shoulder pain in a prospective study of workers in industrial and service companies,” *Occupational and Environmental Medicine*, vol. 60, no. 9, pp. 649–654, 2003.

- [32] M. W. Stomberg, S. E. Tronstad, K. Hedberg, J. Bengtsson, P. Jonsson, L. Johansen, and B. Lindvall, “Work-related musculoskeletal disorders when performing laparoscopic surgery,” *Surgical Laparoscopy Endoscopy & Percutaneous Techniques*, vol. 20, no. 1, pp. 49–53, 2010.
- [33] C. Esposito, A. E. Ghoneimi, A. Yamataka, S. Rothenberg, M. Bailez, M. Ferro, P. Gamba, M. Castagnetti, G. Mattioli, P. Delagausie, D. Antoniou, P. Montupet, A. Marte, A. Saxena, M. Bertozzi, P. Philippe, F. Varlet, H. Lardy, A. Caldamone, A. Settini, G. Pelizzo, F. Becmeur, M. Escolino, T. D. Pascale, A. Najmaldin, and F. Schier, “Work-related upper limb musculoskeletal disorders in paediatric laparoscopic surgery. A multicenter survey,” *Journal of Pediatric Surgery*, vol. 48, no. 8, pp. 1750–1756, 2013.
- [34] F. Gobba, M. Bacis, E. Capodaglio, P. De Michieli, F. Larese, and V. Occhionero, “Risks of repetitive movements in health personnel,” *Giornale italiano di medicina del lavoro ed ergonomia*, vol. 32, no. 3, pp. 223–226, 2010.
- [35] V. Occhionero, L. Korpinen, and F. Gobba, “Upper limb musculoskeletal disorders in healthcare personnel,” *Ergonomics*, vol. 57, no. 8, pp. 1166–91, 2014.
- [36] T. Morse, H. Bruneau, and J. Dussetschleger, “Musculoskeletal disorders of the neck and shoulder in the dental professions,” *Work*, vol. 35, no. 4, pp. 419–429, 2010.
- [37] L. Crawford, G. Gutierrez, and P. Harber, “Work environment and occupational health of dental hygienists: A qualitative assessment,” *Journal of Occupational and Environmental Medicine*, vol. 47, no. 6, pp. 623–632, 2005.
- [38] M. J. Hayes, J. A. Taylor, and D. R. Smith, “Predictors of work-related musculoskeletal disorders among dental hygienists,” *International Journal of Dental Hygiene*, vol. 10, no. 4, pp. 265–269, 2012.
- [39] A. S. Kitzmann, N. B. Fethke, K. H. Baratz, M. B. Zimmerman, D. J. Hackbarth, and K. M. Gehrs, “A survey study of musculoskeletal disorders among eye care physicians compared with family medicine physicians,” *Ophthalmology*, vol. 119, no. 2, pp. 213–20, 2012.
- [40] T. R. Waters, V. Putz-Anderson, A. Garg, and L. J. Fine, “Revised NIOSH equation for the design and evaluation of manual lifting tasks,” *Ergonomics*, vol. 36, no. 7, pp. 749–776, 1993.
- [41] S. H. Snook and V. M. Ciriello, “The design of manual handling tasks: Revised tables of maximum acceptable weights and forces,” *Ergonomics*, vol. 34, no. 9, pp. 1197–1213, 1991.

- [42] G. David, V. Woods, G. Li, and P. Buckle, “The development of the Quick Exposure Check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders,” *Applied Ergonomics*, vol. 39, no. 1, pp. 57–69, 2008.
- [43] O. Karhu, P. Kansi, and I. Kuorinka, “Correcting working postures in industry: A practical method for analysis,” *Applied Ergonomics*, vol. 8, no. 4, pp. 199–201, 1977.
- [44] L. McAtamney and E. Nigel Corlett, “RULA: a survey method for the investigation of work-related upper limb disorders,” *Applied Ergonomics*, vol. 24, no. 2, pp. 91–99, 1993.
- [45] S. Hignett and L. McAtamney, “Rapid Entire Body Assessment (REBA),” *Applied Ergonomics*, vol. 31, no. 2, pp. 201–205, 2000.
- [46] E. P. Takala, I. Pehkonen, M. Forsman, G. Å. Hansson, S. E. Mathiassen, W. P. Neumann, G. Sjøgaard, K. B. Veiersted, R. H. Westgaard, and J. Winkel, “Systematic evaluation of observational methods assessing biomechanical exposures at work,” *Scandinavian Journal of Work, Environment and Health*, vol. 36, no. 1, pp. 3–24, 2010.
- [47] B. G. Branson, K. B. Williams, K. K. Bray, S. L. McIlroy, and D. Dickey, “Validity and reliability of a dental operator posture assessment instrument (PAI),” *Journal of Dental Hygiene*, vol. 76, no. IV, pp. 255–261, 2002.
- [48] J. S. Nield-Gehrig, *Fundamentals of Periodontal Instrumentation*. Lippincott Williams & Wilkins, 2000.
- [49] S. E. Olitsky, M. Simmer-Beck, and B. G. Branson, “A tool for evaluating ergonomic posture during strabismus surgery,” *Journal of American Association for Pediatric Ophthalmology and Strabismus*, vol. 19, no. 4, p. e30, 2015.
- [50] C. M. Dalton and J. Nantel, “Substantiating appropriate motion capture techniques for the assessment of Nordic walking gait and posture in older adults.” *Journal of Visualized Experiments*, no. 111, 2016.
- [51] B. Dowling and G. S. Fleisig, “Kinematic comparison of baseball batting off of a tee among various competition levels,” *Sports Biomechanics*, vol. 15, no. 3, pp. 255–69, 2016.
- [52] G. Faber, C. Chang, I. Kingma, J. Dennerlein, and J. van Dieen, “Estimating 3D L5/S1 moments and ground reaction forces during trunk bending using a full-body ambulatory inertial motion capture system,” *Journal of Biomechanics*, vol. 49, no. 6, pp. 904–12, 2016.

- [53] S. S. Paul, M. E. Lester, K. B. Foreman, and L. E. Dibble, “Validity and reliability of two-dimensional motion analysis for quantifying postural deficits in adults with and without neurological impairment,” *Anatomical Record*, vol. 299, no. 9, pp. 1165–73, 2016.
- [54] E. E. Pavan, C. A. Frigo, and A. Pedotti, “Influence of an eccentric load added at the back of the head on head-neck posture,” *Gait and Posture*, vol. 38, no. 4, pp. 951–955, 2013.
- [55] Y. V. Kolwadkar, S. I. Brown, R. J. Abboud, and W. Wang, “Comparison of two actuation systems for laparoscopic surgical manipulators using motion analysis,” *Surgical Endoscopy and Other Interventional Techniques*, vol. 25, no. 3, pp. 964–974, 2011.
- [56] G. M. Saleh, V. Gauba, D. Sim, D. Lindfield, M. Borhani, and S. Ghousayni, “Motion analysis as a tool for the evaluation of oculoplastic surgical skill,” *Archives of Ophthalmology*, vol. 126, no. 2, p. 213, 2008.
- [57] G. M. Saleh, A. Litwin, and J. R. O. Collin, “Kinematic Analysis in Oculoplastic Reconstructive Surgery,” *Archives of Ophthalmology*, vol. 130, no. 12, pp. 1570–1574, 2014.
- [58] G. M. Saleh, D. Lindfield, D. Sim, E. Tsesmetzoglou, V. Gauba, D. S. Gartry, and S. Ghousayni, “Kinematic analysis of surgical dexterity in intraocular surgery.” *Archives of Ophthalmology*, vol. 127, no. 6, pp. 758–62, 2009.
- [59] J. P. Hubschman, J. Son, B. Allen, S. D. Schwartz, and J.-L. Bourges, “Evaluation of the motion of surgical instruments during intraocular surgery.” *Eye*, vol. 25, no. 7, pp. 947–53, 2011.
- [60] G. M. Saleh, G. Voyatzis, Y. Voyazis, J. Hance, J. Ratnasothy, and A. Darzi, “Evaluating surgical dexterity during corneal suturing.” *Archives of Ophthalmology*, vol. 124, no. 9, pp. 1263–6, 2006.
- [61] T. N. Hanvold, M. Wærsted, A. M. Mengshoel, E. Bjertness, H. Stigum, J. Twisk, and K. B. Veiersted, “The effect of work-related sustained trapezius muscle activity on the development of neck and shoulder pain among young adults.” *Scandinavian Journal of Work, Environment & Health*, vol. 39, no. 4, pp. 390–400, 2013.
- [62] P. Rempel, I. Janowitz, M. Alexandre, D. L. Lee, and D. Rempel, “The effect of two alternative arm supports on shoulder and upper back muscle loading during pipetting,” *Work*, vol. 39, no. 2, pp. 195–200, 2011.
- [63] J. Gonçalves, C. Moriguchi, K. Takekawa, H. Gil Coury, and T. Sato, “The effects of forearm support and shoulder posture on upper trapezius and anterior deltoid activity,” *Journal of Physical Therapy Science*, vol. 29, no. 5, pp. 793–798, 2017.

- [64] B. D. Owen, K. Keene, and S. Olson, "An ergonomic approach to reducing back/shoulder stress in hospital nursing personnel: A five year follow up," *International Journal of Nursing Studies*, vol. 39, no. 3, pp. 295–302, 2002.
- [65] C. M. Wetzel, R. L. Kneebone, M. Woloshynowych, D. Nestel, K. Moorthy, J. Kidd, and A. Darzi, "The effects of stress on surgical performance," *American Journal of Surgery*, vol. 191, no. 1, pp. 5–10, 2006.
- [66] R. Randell, S. Honey, N. Alvarado, A. Pearman, J. Greenhalgh, A. Long, P. Gardner, A. Gill, D. Jayne, and D. Dowding, "Embedding robotic surgery into routine practice and impacts on communication and decision making: a review of the experience of surgical teams," *Cognition, Technology and Work*, vol. 18, no. 2, pp. 423–437, 2016.
- [67] E. C. Lee, A. Rafiq, R. Merrell, R. Ackerman, and J. T. Dennerlein, "Ergonomics and human factors in endoscopic surgery: A comparison of manual vs telerobotic simulation systems," *Surgical Endoscopy and Other Interventional Techniques*, vol. 19, no. 8, pp. 1064–1070, 2005.
- [68] A. Kanji, R. S. Gill, X. Shi, D. W. Birch, and S. Karmali, "Robotic-assisted colon and rectal surgery: a systematic review," *The International Journal of Medical Robotics and Computer Assisted Surgery*, vol. 7, no. 4, pp. 401–407, 2011.
- [69] K. Kanteshwari, R. Sridhar, A. K. Mishra, R. Shirahatti, R. Maru, and P. Bhusari, "Correlation of awareness and practice of working postures with prevalence of musculoskeletal disorders among dental professionals," *General Dentistry*, vol. 59, no. 6, pp. 476–483, 2011.
- [70] M. J. Hayes and D. Cockrell, "An international review of musculoskeletal disorders in the dental hygiene profession," *International Dental Journal*, vol. 60, no. 6, pp. 343–352, 2010.
- [71] B. Valachi, "Move to improve your health: the research behind static postures," *Dentistry Today*, vol. 30, no. 5, pp. 144–7, 2011.
- [72] B. Valachi, "Little things can make a big difference," *Dentistry Today*, vol. 29, no. 3, pp. 140,2–3, 2010.
- [73] B. Valachi, "Balancing your musculoskeletal health: preventing and managing work-related neck pain," *Journal of the Massachusetts Dental Society*, vol. 55, no. 3, pp. 24–6, 2006.
- [74] A. Gandavadi, J. R. E. Ramsay, and F. J. T. Burke, "Assessment of dental student posture in two seating conditions using RULA methodology - a pilot study." *British Dental Journal*, vol. 203, no. 10, pp. 601–5, 2007.

- [75] B. Valachi and K. Valachi, "Operator seating: the tall and short of it," *Dentistry Today*, vol. 24, no. 1, pp. 108–10, 2005.
- [76] R. Dable, P. Wasnik, B. Yeshwante, S. Musani, A. Patil, and S. Nagmode, "Postural assessment of students evaluating the need of ergonomic seat and magnification in dentistry," *Journal of Indian Prosthodontic Society*, vol. 14, no. 1, pp. 51–8, 2014.
- [77] M. Eichenberger, P. Perrin, S. T. Ramseyer, and A. Lussi, "Visual acuity and experience with magnification devices in Swiss dental practices." *Operative Dentistry*, vol. 40, no. 4, pp. 142–9, 2015.
- [78] S. A. Farook, R. J. Stokes, A. K. J. Davis, K. Sneddon, and J. Collyer, "Use of dental loupes among dental trainers and trainees in the UK." *Journal of investigative and clinical dentistry*, vol. 4, no. 2, pp. 120–123, 2013.
- [79] M. J. Hayes, P. G. Osmotherly, J. A. Taylor, D. R. Smith, and A. Ho, "The effect of loupes on neck pain and disability among dental hygienists," *Work*, vol. 53, no. 4, pp. 755–762, 2016.
- [80] S. B. Hoerler, B. G. Branson, A. M. High, and T. V. Mitchell, "Effects of dental magnification lenses on indirect vision: a pilot study." *Journal of Dental Hygiene*, vol. 86, no. 4, pp. 323–30, 2012.
- [81] J. P. Maillet, a. M. Millar, J. M. Burke, M. a. Maillet, W. a. Maillet, and N. R. Neish, "Effect of magnification loupes on dental hygiene student posture." *Journal of Dental Education*, vol. 72, no. 1, pp. 33–44, 2008.
- [82] P. Perrin, M. Eichenberger, K. W. Neuhaus, and A. Lussi, "Visual acuity and magnification devices in dentistry," *Swiss Dental Journal SSO*, vol. 126, no. 126, pp. 222–228, 2016.
- [83] B. Valachi, "Magnification in dentistry: how ergonomic features impact your health," *Dentistry Today*, vol. 28, no. 4, pp. 132,4,6–7, 2009.
- [84] L. Roach, "Seven Risk Factors for Injury, and Seven Solutions: Ergonomics, Part Two," *EyeNet Magazine*, vol. 9, 2009.
- [85] S. Honavar, "Head up, heels down, posture perfect: Ergonomics for an ophthalmologist," *Indian Journal of Ophthalmology*, vol. 65, no. 8, p. 647, 2017.
- [86] G. A. Hawker, S. Mian, T. Kendzerska, and M. French, "Measures of adult pain: Visual Analog Scale for Pain (VAS Pain), Numeric Rating Scale for Pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form-36 Bodily Pain Scale (SF-36 BPS), and Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP)," *Arthritis Care and Research*, vol. 63, no. 11, 2011.

- [87] H. Snellen, *Probekbuchstaben Zur Bestimmung Der Sehstärke*. Van De Weijer, 1862.
- [88] P. A. Harris, R. Taylor, R. Thielke, J. Payne, N. Gonzalez, and J. G. Conde, “Research Electronic Data Capture (REDCap) - a metadata driven methodology and workflow process for providing translational research informatic support.” *Journal of Biomedical Informatics*, vol. 42, no. 2, pp. 377–381, 2009.
- [89] H. Hermens, B. Freriks, R. Merletti, G. G. Hägg, D. Stegeman, J. Blok, G. Rau, and C. Disselhorst-Klug, *SENIAM : European recommendations for surface electromyography*. Netherlands: Roessingh Research and Development, 1999.
- [90] G. K. Cole, B. M. Nigg, J. L. Ronsky, and M. R. Yeadon, “Application of the joint coordinate system to three-dimensional joint attitude and movement representation: a standardization proposal.” *Journal of biomechanical engineering*, vol. 115, no. 4A, pp. 344–349, 1993.
- [91] J. D. Drake and J. P. Callaghan, “Elimination of electrocardiogram contamination from electromyogram signals: An evaluation of currently used removal techniques,” *Journal of Electromyography and Kinesiology*, vol. 16, no. 2, pp. 175–187, 2006.
- [92] P. W. Hodges and B. H. Bui, “A comparison of computer-based methods for the determination of onset of muscle contraction using electromyography,” *Electroencephalography and Clinical Neurophysiology - Electromyography and Motor Control*, vol. 101, no. 6, pp. 511–519, 1996.
- [93] Bureau of Labor Statistics US Department of Labor, “Nonfatal Occupational Injuries and Illnesses Requiring Days-Away-from-Work in 2014,” *Bureau of Labor Statistics US Department of Labor*, vol. 2014, no. 202, pp. 1–92, 2015.
- [94] G. H. Staude, “Precise onset detection of human motor responses using a whitening filter and the log-likelihood-ratio test,” *IEEE Transactions on Biomedical Engineering*, vol. 48, no. 11, pp. 1292–1305, 2001.
- [95] A. P. Stylianou, C. W. Luchies, and M. F. Insana, “EMG onset detection using the maximum likelihood method.” in *Proceedings of the 2003 summer bioengineering conference*, vol. 0, no. 1, 2003, pp. 1075–76.
- [96] X. Li, P. Zhou, and A. S. Aruin, “Teager-kaiser energy operation of surface EMG improves muscle activity onset detection,” *Annals of Biomedical Engineering*, vol. 35, no. 9, pp. 1532–1538, 2007.
- [97] T. L. Guidotti, “Occupational repetitive strain injury,” *American Family Physician*, vol. 45, no. 2, pp. 585–592, 1992.

- [98] B. G. Branson, M. A. Black, and M. Simmer-Beck, "Changes in posture: A case study of a dental hygienist's use of magnification loupes," *Work*, vol. 35, no. 4, pp. 467–476, 2010.
- [99] B. G. Branson, K. K. Bray, C. Gadbury-Amyot, L. A. Holt, N. T. Keselyak, T. V. Mitchell, and K. B. Williams, "Effect of magnification lenses on student operator posture," *Journal of Dental Education*, vol. 68, no. 3, pp. 384–389, 2004.
- [100] D. Jonker, B. Rolander, I. Balogh, L. Sandsjö, K. Ekberg, and J. Winkel, "Rationalisation in public dental care - impact on clinical work tasks and mechanical exposure for dentists - a prospective study." *Ergonomics*, vol. 56, no. 2, pp. 303–13, 2013.
- [101] E. Rafeemanesh, Z. Jafari, F. O. Kashani, and F. Rahimpour, "A study on job postures and musculoskeletal illnesses in dentists." *International Journal of Occupational Medicine and Environmental Health*, vol. 26, no. 4, pp. 615–620, 2013.
- [102] A. J. van der Beek and M. H. Frings-Dresen, "Assessment of mechanical exposure in ergonomic epidemiology." *Occupational and environmental medicine*, vol. 55, no. 5, pp. 291–9, 1998.
- [103] D. Blanc, P. Farre, and O. Hamel, "Variability of musculoskeletal strain on dentists: An electromyographic and goniometric study," *International Journal of Occupational Safety and Ergonomics*, vol. 20, no. 2, pp. 295–307, 2014.
- [104] S. J. Howarth, D. E. Grondin, N. J. La Delfa, J. Cox, J. R. Potvin, and C. J. samuel Howarth, "Working position influences the biomechanical demands on the lower back during dental hygiene," *Ergonomics*, vol. 59, no. 4, pp. 545–555, 2016.
- [105] R. Pope-Ford and Z. Jiang, "Neck and shoulder muscle activation patterns among dentists during common dental procedures," *Work*, vol. 51, no. 3, pp. 391–399, 2015.
- [106] V. Tran, R. Turner, A. MacFadden, S. M. Cornish, D. Esliger, K. Komiyama, and P. D. Chilibeck, "A dental stool with chest support reduces lower back muscle activation," *International Journal of Occupational Safety and Ergonomics*, vol. 22, no. 3, pp. 301–304, 2016.
- [107] M. A. Mansueto, "A clinician's guide to purchasing surgical loupes," *Texas Dental Journal*, pp. 174–186, 2007.
- [108] G. Christensen, "Clinical guidelines for selecting loupes," *Clinicians Report*, vol. 9, no. 8, pp. 1–2, 2016.

- [109] ExamVision. (2016) Magnification loupes and lighting system. [Online]. Available: <http://www.exam-vision.com>
- [110] B. Valachi, “Three ergonomic mistakes that could end your dental career,” *Dental Products Report*, 2015. [Online]. Available: <http://www.dentalproductsreport.com/dental/article/3-ergonomic-mistakes-could-end-your-dental-career>
- [111] S. C. Puthenveetil, C. P. Daphalapurkar, W. Zhu, M. C. Leu, X. F. Liu, J. K. Gilpin-Mcminn, and S. D. Snodgrass, “Computer-automated ergonomic analysis based on motion capture and assembly simulation,” *Virtual Reality*, pp. 1–10, 2015.
- [112] J. M. Baker and R. A. Meals, “A practical guide to surgical loupes,” *Journal of Hand Surgery*, vol. 22, no. 6, pp. 967–974, 1997.
- [113] D. A. Ross, S. Ariyan, R. Restifo, and C. T. Sasaki, “Use of the Operating Microscope and Loupes for Head and Neck Free Microvascular Tissue Transfer,” *Archives of Otolaryngology–Head & Neck Surgery*, vol. 129, no. 2, p. 189, 2003.
- [114] S. J. Stanbury and J. Elfar, “The use of surgical loupes in microsurgery,” *Journal of Hand Surgery*, vol. 36, no. 1, pp. 154–156, 2011.
- [115] P. M. Jarrett, “Intraoperative magnification: Who uses it?” *Microsurgery*, vol. 24, no. 6, pp. 420–422, 2004.
- [116] J. A. Sivak-Callcott, S. R. Diaz, A. M. Ducatman, C. L. Rosen, A. D. Nimbarte, and J. A. Sedgeman, “A survey study of occupational pain and injury in ophthalmic plastic surgeons.” *Ophthalmic Plastic and Reconstructive Surgery*, vol. 27, no. 1, pp. 28–32, 2011.
- [117] C. Wei and A. Y. Wu, “Surgical loupe usage among oculoplastic surgeons in North America,” *Canadian Journal of Ophthalmology*, vol. 53, no. 2, pp. 139–144, 2018.
- [118] R. G. Hart and J. Hall, “The value of loupe magnification: an underused tool in emergency medicine,” *American Journal of Emergency Medicine*, vol. 25, no. 6, pp. 704–707, 2007.
- [119] H. Schoeffl, D. Lazzeri, R. Schnelzer, S. M. Froschauer, and G. M. Huemer, “Optical magnification should be mandatory for microsurgery: Scientific basis and clinical data contributing to quality Assurance,” *Archives of Plastic Surgery*, vol. 40, no. 2, pp. 104–108, 2013.
- [120] S. SE, F. JL, and S. HE, “Enhanced visualization using magnification systems.” *Journal of Dental Hygiene*, vol. 71, no. 5, pp. 202–206, 1997.

- [121] M. J. Hayes, J. A. Taylor, and D. R. Smith, “Introducing loupes to clinical practice: dental hygienists experiences and opinions,” *International Journal of Dental Hygiene*, vol. 14, no. 3, pp. 226–230, 2016.
- [122] A. D. Nimbarte, M. Zreiqat, M. Chapman, J. A. Sivak-callcott, W. Virginia, and O. S. Drive, “Physical risk factors for neck pain among oculoplastic surgeons,” in *Proceedings of the 2012 Industrial and Systems Engineering Research Conference*, 2012.
- [123] H. Babar-Craig, G. Banfield, and J. Knight, “Prevalence of back and neck pain amongst ENT consultants: national survey.” *The Journal of laryngology and otology*, vol. 117, no. 12, pp. 979–82, 2003.
- [124] J. Mamoun, M. Wilkinson, and R. Feinbloom, “Surgical and dental ergonomic loupes – magnification and microscope design principles – technical aspects and clinical usage of keplerian and galilean binocular surgical loupe telescopes used in dentistry or medicine,,” *Open Access Lecture No. 2*, 2013.
- [125] S. L. Delp, F. C. Anderson, A. S. Arnold, P. Loan, A. Habib, C. T. John, E. Guendelman, and D. G. Thelen, “OpenSim: Open source to create and analyze dynamic simulations of movement,” *IEEE transactions on bio-medical engineering*, vol. 54, no. 11, pp. 1940–1950, 2007.
- [126] J. L Marx, F. D Wertz, and K. C Dhimitri, “Work-related musculoskeletal disorders in ophthalmologists,” *Techniques in Ophthalmology*, vol. 3, pp. 54–61, 2005.
- [127] S. Corazza, L. Mündermann, and T. Andriacchi, “Markerless motion capture methods for the estimation of human body kinematics,” in *9th international symposium on the 3D analysis of human movement*, 2006.
- [128] E. Stone and M. Skubic, “Evaluation of an inexpensive depth camera for in-home gait assessment,” *Journal of Ambient Intelligence and Smart Environments*, vol. 3, no. 4, pp. 349–361, 2011.
- [129] R. Clark, Y. H. Pua, K. Fortin, C. Ritchie, K. E. Webster, L. Denehy, and A. L. Bryant, “Validity of the Microsoft Kinect for assessment of postural control,” *Gait and Posture*, vol. 36, no. 3, pp. 372–377, 2012.
- [130] B. F. Mentiplay, R. a. Clark, A. Mullins, A. L. Bryant, S. Bartold, and K. Paterson, “Reliability and validity of the Microsoft Kinect for evaluating static foot posture.” *Journal of foot and ankle research*, vol. 6, no. 1, p. 14, 2013.

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