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ORIGINAL RESEARCH

A Comparison of Examination Equipment Used During Common Clinical Ophthalmologic Tasks

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OCCUPATIONAL APPLICATIONS Ophthalmologists and other eye-care physicians frequently use clinical examination equipment that restricts access to patients and requires the adoption of sustained, non-neutral working postures of the neck and shoulders. The use of ergonomic principles in the design of examination equipment could help reduce these physical demands, which may be partly responsible for the high prevalence of neck and shoulder pain among ophthalmologists. This study compared the effects of a set of this alternative "ergonomic" equipment to a set of conventional equipment on measures of neck and shoulder muscle activity and upper arm posture during simulations of common clinical ophthalmologic tasks. Results suggested that some aspects of the alternative equipment may help reduce exposures to sustained, non-neutral working postures of the neck and shoulder among ophthalmologists. Ophthalmologists and other eye-care physicians may consider implementing similar alternative equipment interventions into their practices.

TECHNICAL ABSTRACT ***Background:*** Ophthalmologists report a high prevalence of work-related musculoskeletal symptoms, particularly of the neck and shoulders. Improving the design of equipment used in the clinical environment may reduce exposures to physical risk factors (e.g., sustained muscular exertions and non-neutral postures) associated with neck and shoulder pain among ophthalmologists. ***Purpose:*** This study compares estimates of neck and shoulder muscle activity and upper arm posture during use of conventional and alternative examination equipment common in clinical ophthalmologic practice. ***Methods:*** Fifteen ophthalmologists performed one mock clinical examination using conventional equipment and one mock clinical examination using alternative equipment with the potential to reduce exposure to sustained muscular exertions and non-neutral upper arm postures. The alternative equipment included a slit lamp biomicroscope with inclined viewing oculars, adjustable elbow supports, and a wider tabletop with more room for supporting the arms in comparison to the conventional slit lamp biomicroscope. A wireless binocular indirect ophthalmoscope was also

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evaluated that had a more even weight distribution than the conventional design. Measurements of upper trapezius and anterior deltoid muscle activity, upper arm posture, and perceived usability were used to compare the conventional and alternative equipment. ***Results:*** In comparison to the conventional slit lamp biomicroscope, the alternative slit lamp biomicroscope led to (i) 12% to 13% reductions in upper trapezius muscle activity levels, (ii) a 9% reduction in left anterior deltoid muscle activity levels, and (iii) a 15% reduction in the percentage of work time spent with the left upper arm elevated in positions greater than 60°. In addition, participants rated the comfort and adjustability of both the alternative slit lamp biomicroscope and binocular indirect ophthalmoscope more favorably than the conventional equipment. ***Conclusions:*** The results suggest that the alternative slit lamp biomicroscope may help to reduce overall muscular demands and non-neutral postures of the neck and shoulder region among ophthalmologists.

KEYWORDS Healthcare ergonomics, musculoskeletal disorders, workplace and equipment design, physical ergonomics

INTRODUCTION

Work-related musculoskeletal disorders (MSDs) are prevalent among healthcare professionals (Waters et al., 2006; Ngan et al., 2010). Among healthcare and social assistance workers in the United States, MSDs accounted for 42% of non-fatal injuries and illnesses requiring days away from work with an incidence rate (55 cases per 10,000 full-time workers) higher than the rate for all private industries and second only to the transportation and warehousing industry (Bureau of Labor Statistics, 2013). Ophthalmologists and other eye-care physicians, in particular, report a high prevalence of musculoskeletal pain and other symptoms consistent with MSDs of the neck, shoulders, low back, and upper extremities (Chatterjee et al., 1994; Chams et al., 2004; Dhimitri et al., 2005; Marx et al., 2005; Long et al., 2011). Existing studies have reported prevalence estimates of neck symptoms ranging from 33% to 69% and upper extremity/shoulder symptoms ranging from 11% to 33% (Chatterjee et al., 1994; Chams et al., 2004; Dhimitri et al., 2005; Sivak-Callcott et al., 2010; Kitzmann et al., 2012). Recent evidence also suggests that eye-care physicians report musculoskeletal pain of the neck and upper extremity more frequently than peers in other medical specialties (Kitzmann et al., 2012).

While the economic consequences of MSDs are substantial (Bhattacharya, 2014), data examining the costs of MSDs specific to ophthalmologists are currently unavailable. However, in a sample of 47 Australian optometrists, about 30% reported taking time off work while remaining in the profession, and 45% reported seeking treatment for musculoskeletal pain "at least once every 3 months" (Long et al., 2014). Healthcare professionals in similar fields, such as dentistry, have also reported taking more sick leave, reducing their work hours, and even switching professions as a result of their musculoskeletal conditions (Osborn et al., 1990; Akesson et al., 1999; Garbin et al., 2011).

Several studies have reported associations between physical risk factors and MSDs among workers in occupations similar to ophthalmology, including dental hygienists (Hayes, Cockrell, & Smith, 2009; Hayes, Smith, & Taylor, 2013), hospital physicians (Hengel et al., 2011), and surgeons (Gofrit et al., 2008; Szeto et al., 2009; Stomberg et al., 2010; Sivak-Callcott et al., 2011; Nimbarte et al., 2013). Ophthalmologists may be at risk for developing MSDs due to their exposure to physical risk factors, such as sustained muscular exertions and/or non-neutral working postures (van der Windt et al., 2000; Svendsen et al., 2004; Vieria & Kumar, 2004; da Costa & Vieira, 2010; Silverstein et al., 2008). As in laparoscopic surgery, ophthalmologists are often challenged by having restricted access to the patient, a limited ability to reposition their equipment, and the need to simultaneously focus instruments while manipulating controls (Berguer et al., 1999; van Veelen et al., 2004; Matern, 2009). However, unlike laparoscopic surgery (Berguer & Smith, 2006; Trejo et al., 2007; Matern, 2009; Van der Schatte Olivier et al., 2009), little empirical information is available to assist practitioners in the identification and control of exposures to physical risk factors in the ophthalmic clinical environment.

Two clinical instruments commonly used during eye examinations that may expose ophthalmologists to physical risk factors are the slit lamp biomicroscope and the binocular indirect ophthalmoscope. A conventional slit lamp biomicroscope is operated by looking through viewing oculars with 0° of inclination (with respect to horizontal) while adjusting the instrument's position and focus using one or both hands. This task often requires an ophthalmologist to sustain a position of non-neutral neck flexion to obtain a clear view into the patient's eye through the viewing oculars. Ophthalmologists will also frequently hold an external lens up to the patient's eye, requiring prolonged periods of upper arm elevation.

The binocular indirect ophthalmoscope is commonly used while the patient lies supine or sits upright in the examination chair, depending on the personal preferences of the ophthalmologist and/or positioning restrictions of the patient. The ophthalmologist moves around the patient to obtain views into the eye from various angles using a handheld lens. Use of a conventional binocular indirect ophthalmoscope may result in exposure to prolonged periods of neck flexion and upper arm elevation. Furthermore, the design of a conventional binocular indirect ophthalmoscope may require elevated levels of neck and shoulder muscle activity to support the weight of the device, which is often concentrated on the ophthalmologist's forehead.

Alternative ophthalmologic examination equipment has recently become available that has the potential to reduce exposure to physical risk factors in the clinical environment. This alternative equipment includes a slit lamp biomicroscope with wider tabletop, inclined ocular adaptors, adjustable height elbow supports, a pneumatic examination stool with adjustable body support, and a wireless binocular indirect ophthalmoscope. The wider slit lamp biomicroscope tabletop and elbow supports provide an ophthalmologist a means to more comfortably rest the arms during use of the instrument and may minimize shoulder discomfort or fatigue, while the inclined oculars may promote less biomechanically stressful neck postures. The stool can be adjusted to provide support of the arms or back depending on the preference of the ophthalmologist and may provide an additional method for resting the arms during a clinical examination. In comparison to the conventional binocular indirect ophthalmoscope, the wireless binocular indirect ophthalmoscope has a more even weight distribution, which may reduce biomechanical loading of the neck/shoulder region. The wireless capability of the binocular indirect ophthalmoscope also allows for more access to the patient.

The objective of this study was to compare the levels of muscle activity and upper arm elevation associated with the use of conventional and alternative examination equipment during common clinical ophthalmologic tasks. In particular, it was hypothesized that the alternative examination equipment would reduce the overall demands of the upper trapezius and anterior deltoid muscles during a common ophthalmologic exam in comparison to the conventional equipment. It was also hypothesized that the alternative examination equipment would lead to a reduction in the percentage of time spent working with the upper arms elevated in comparison to the conventional equipment.

METHODS

Study Design

Two mock clinical examinations were conducted by a convenience sample of 15 ophthalmologists (10 male, 5 female; all right-hand dominant), which included a combination of 9 faculty, 2 fellows, and 4 residents (mean age = 41.9 years, $SD = 11.9$) who were recruited from the University of Iowa Hospitals and Clinics (UIHC) Department of Ophthalmology. Participants reported no history of physician-diagnosed MSDs in the neck/shoulder region and no episodes of neck/shoulder pain within 14 days prior to participation. All study procedures were approved by the University of Iowa Institutional Review Board, and informed consent was obtained prior to participation.

Participants had a median height of 1.8 m (range of 1.6–1.9 m), a median body mass of 68.1 kg (range of 56.8–104.4 kg), and a median body mass index of 23.3 kg/m^2 (range of 21.5–32.1 kg/m^2). The participants reported a median of 10 years of clinical experience (range of 2–36 years). Fifteen potential participants were excluded based on either self-reported histories of physician-diagnosed MSDs in the neck/shoulder region or self-reported episodes of neck/shoulder pain within 14 days prior to expressing interest in participating.

Mock Clinical Examinations

Participants performed one mock clinical examination in a room with conventional equipment available in all examination rooms at the UIHC ophthalmology clinic (i.e., the conventional condition) and one mock clinical examination in a second room with alternative equipment (i.e., the alternative condition). Patients for the mock clinical examinations used an identical script and were coached on how to perform. Each patient presented a chief complaint of floaters in both eyes for the past 1 year, with no change in the quantity, no flashes of lights, and no vision changes. Floaters are undissolved gel particles that occasionally float in the liquid center of the vitreous humour, the thick fluid or gel that fills the eye. Floaters are typically the result of natural aging. All patients had both eyes dilated. Participants were instructed to examine the patient as they normally would in the clinic environment for both room conditions (i.e., they were not instructed to examine the patient in any particular manner or order), except that they must complete all clinical tasks in each room. Participants were also instructed to use the binocular indirect ophthalmoscope in each room with the patient in the same position (i.e., patient lay supine or sat upright in each room condition).

Clinical tasks performed by each participant in each examination room included (1) initial patient interview and associated "documentation" (i.e., using computer or completing paperwork), (2) fitting the patient to the slit lamp biomicroscope, (3) examining the patient using the slit lamp biomicroscope without the use of a handheld lens, (4) examining the patient using the slit lamp biomicroscope with the use of a handheld lens in the right hand, (5) examining the patient using the slit lamp biomicroscope with the use of a handheld lens in the left hand, (6) putting away the slit lamp biomicroscope, (7) putting on the indirect ophthalmoscope, (8) examining the patient with the indirect ophthalmoscope, (9) removing the indirect ophthalmoscope, and (10) patient exit interview and associated documentation.

In the room with the conventional equipment, use of personal equipment, such as a handheld lens case or the slit lamp biomicroscope, as a means to support the arms during the exams was permitted. In the room with the alternative equipment, participants were instructed to use the provided alternative equipment. A block randomization procedure was used to counterbalance the order of room presentation, and digital video recordings were obtained for each mock examination. The conventional examination room was equipped with a pneumatic examination stool (Reliance model 1020B, Haag-Streit USA, Mason, Ohio, USA), a slit lamp biomicroscope with straight (0° of inclination) viewing oculars (Haag Streit PN 900.7.2.6989, Haag-Streit USA, Mason, Ohio, USA), and a binocular indirect ophthalmoscope (Heine Omega 180, Heine USA LTD, Dover, New Hampshire, USA). The alternative examination room was equipped with a pneumatic examination stool with adjustable body support (Reliance model 5356, Haag-Streit USA, Mason, Ohio, USA), a slit lamp tabletop (Reliance Xoma, Haag-Streit USA, Mason, Ohio, USA) with adjustable elbow supports for use while examining a patient with a handheld lens, a slit lamp biomicroscope with inclined ocular adaptors (Haag Streit PN 09007.8, Haag-Streit USA, Mason, Ohio, USA), and a wireless binocular indirect ophthalmoscope (Keeler Vantage Plus Wireless PN 1205P1020, Keeler USA, Broomall, Pennsylvania, USA; Fig. 1). Participants were initially unfamiliar with the equipment in the alternative examination room. Thus, each participant was given time to inspect and test the alternative equipment prior to beginning study procedures. Features of the alternative equipment that differed from the conventional equipment were highlighted, and any questions participants had were addressed. Following each mock examination, participants completed a short usability survey regarding the equipment in that particular examination room.

Instrumentation Methods

Surface electromyography (EMG) was used to record bilateral myoelectric activity of the upper trapezius and anterior deltoid muscles. For the upper trapezius muscles, preamplified surface EMG electrodes (model DE2.3, Delsys Inc., Boston, MA, USA) were secured to the skin slightly lateral of the midpoint between the acromion and the seventh cervical vertebra. Electrodes

FIGURE 1 **Participants examining a mock patient. Top left: conventional examination condition slit-lamp biomicroscope table with straight (0° of inclination) oculars, no elbow supports, and a non-adjustable stool. Top right: alternative examination condition slit-lamp biomicroscope table with inclined oculars, padded elbow supports, and pneumatic stool with adjustable body support. Bottom left: conventional examination condition binocular indirect ophthalmoscope. Bottom right: alternative examination condition wireless binocular indirect ophthalmoscope.**

for the deltoid muscles were located approximately 4 cm below the midpoint between the acromion and the deltoid tubercle of the clavicle (Criswell, 2010). The electrodes had dual, bipolar, 10 × 1-mm silver bars, an inter-electrode distance of 10 mm, differential amplification with a gain of 1000, and a 20–450-Hz bandwidth. A reference electrode was placed over the non-dominant clavicle. The electrodes were connected to a surface EMG instrumentation amplifier (Bagnoli-16, Delsys Inc., Boston, MA, USA), and the raw EMG signals were sampled at 1000 Hz and stored to a desktop computer workstation for signal processing and analysis. Final electrode placement was verified by examining EMG signal quality during manually resisted isometric contractions.

All EMG recordings were processed and analyzed with custom LabVIEW (version 2013, National Instruments, Inc., Austin, TX, USA) and MATLAB (r2013b, The Math Works, Inc., Natick, MA, USA) software. Electrocardiogram artifacts, transient artifacts, and other potential sources of interference (e.g., 60 Hz) were managed using procedures described previously (Fethke et al., 2011). Each raw EMG recording was then converted to instantaneous root-mean-square (RMS) amplitude using a 100-sample moving window with a 50-sample overlap.

The RMS EMG amplitudes recorded during the mock examinations were normalized as a percentage of the RMS EMG amplitude observed during submaximal, isometric reference contractions (percent of reference voluntary exertion [%RVE]). Submaximal contractions were used instead of maximal voluntary contractions (MVC) because participants may have difficulty generating maximum contractions in a time efficient manner (Mathiassen et al. 1995; Hägg et al., 1997) and to minimize the risk of discomfort and injury during normalization procedures (Nieminen et al., 1993; Attebrant et al., 1995; Bao et al., 1995; Mathiassen et al., 1995).

For the upper trapezius, reference contractions were obtained while participants held a 2-kg weight in each hand with the upper arms elevated to 90° in the frontal plane (i.e., humeral abduction), elbows fully extended, and forearms pronated (Mathiassen et al., 1995). For the anterior deltoid, participants held a 2-kg weight in each hand with the upper arms flexed forward to 90° of elevation and the elbows fully extended (Cook et al., 2004; Yoo, Jung, Jeon, & Lee, 2010; Rota et al., 2013). Three repetitions of each submaximal reference contraction were performed with a 1-min rest period between repetitions. Participants maintained each submaximal reference contraction for 15 sec, and the mean RMS amplitude of the middle 10 sec was calculated. For each muscle separately, the average of the mean RMS EMG amplitudes of the three reference contractions was used as the RVE activation level. A baseline RMS EMG amplitude level was also measured by having participants sit in a relaxed posture with the upper back and arms supported for 60 sec. The baseline level was defined as the lowest RMS amplitude during the 60-sec recording period and was quadratically subtracted from all subsequent RMS EMG amplitude values (Thorn et al., 2007).

Upper arm elevation angles with respect to the gravity vector (vertical) were estimated using two inertial measurement units (IMUs; I2M Motion Tracking, Series SXT, Nexgen Ergonomics, Inc., Pointe Claire, Quebec, Canada). Each IMU was a small (48.5 × 36 × 12 mm) wireless, battery-powered unit that measured and stored acceleration (triaxial, ±6 g), angular velocity (triaxial, ±2000° s^{-1}), magnetic field strength (triaxial, ±6 Gauss), and local sensor spatial orientation in the form of quaternions. One IMU was secured to the skin of the lateral aspect of each upper arm approximately one-half the distance between the lateral epicondyle and the acromion. The IMU data streams were sampled at 128 Hz and stored to on-board flash memory. The IMU data files were then downloaded to a desktop computer workstation and synchronized with the EMG recordings using a custom LabVIEW program.

A custom complementary weighting algorithm developed in MATLAB was used to transform the raw IMU data into upper arm elevation angles. In this study, upper arm elevation refers to either forward flexion or abduction of the upper arm. In contrast to estimating elevation angles solely from the orientation of the IMU's accelerometer with respect to gravity (Douphrate et al., 2012), the complementary weighting algorithm adjusted the elevation angle estimate at each sample using the angular velocity information from the IMU's gyroscope with the following equation:

$$\theta_n = (1 - K)[\theta_{n-1} + (\omega_n \times dt)] + K(\alpha_n), \qquad (1)$$

where θ_n is the complementary elevation angle estimate at the current sample, $\theta_{(n-1)}$ is the complementary elevation angle estimate at the previous sample, ω_n is the angular velocity at the current sample, α_n is the elevation angle at the current sample based solely on the orientation of the accelerometer with respect to gravity, and dt is the time between samples. The algorithm's coefficient (K) weighted the relative influence of the angular velocity and the accelerometer-based elevation angle on the resulting complementary elevation angle estimate. Although there are no widely accepted guidelines for selecting the weighting coefficient, a value of 0.01 provided a sufficient acceleration reference to compensate for the drift that occurs when a raw gyroscope signal is integrated (Luinge & Veltink, 2005).

The complementary weighting algorithm approach was used in lieu of a solely accelerometer-based approach, as the accuracy of accelerometer-based estimates have been observed to be less accurate under dynamic working conditions (Hansson et al. 2001; Brodie et al., 2008; Amasay et al. 2009; Godwin et al., 2009). Details of the mathematics of complementary weighting are found elsewhere (Higgins, 1975; Wagenaar et al., 2011; El-Gohary & McNames, 2012).

Summary Measures

The duration of each mock examination and of each clinical task within each mock examination was calculated through use of an event marker (digitized simultaneously with the surface EMG recordings) and the digital video recordings. Summary measures of normalized RMS EMG and shoulder elevation recordings were calculated across each entire mock examination and separately for each clinical task within each mock examination. For surface EMG, the arithmetic mean of the normalized RMS EMG amplitude (in %RVE) was calculated for each muscle. For upper arm elevation, posture categories were used to describe percent time with the upper arms elevated >60° (Hooftman et al., 2009; Wahlström et al., 2010; Douphrate et al., 2012). The usability survey assessed participants' perceptions of the slit lamp biomicroscope, indirect binocular ophthalmoscope, and pneumatic stool regarding such attributes as comfort and adjustability. Participants' ratings of equipment attributes were obtained using discrete 0- to 5-point scales with verbal anchors at 0 (poor) and 5 (excellent).

Statistical Analyses

Each mock examination was parsed according to the above-described clinical task, with an entire exam comprising all tasks. Postural data were successfully obtained for all participants. For one participant, surface EMG data were lost due to instrumentation failure. Means and standard deviations were calculated for each summary measure and for each clinical task by examination room condition. Paired *t*-tests (2-tailed) were used to compare the muscle activity and upper arm elevation summary measures between the examination rooms. Comparisons of each clinical task between the examination room conditions were planned a priori; therefore, no adjustment was made for multiple comparisons (i.e., each comparison was evaluated for statistical significance using a *p*-value of 0.05). The Wilcoxon signed rank test was used to compare results of the equipment usability surveys between the examination rooms. All statistical analyses were conducted with SAS, version 9.3 (SAS Institute, Cary, NC, USA).

RESULTS

Mock Examination Duration

In general, longer full examination and clinical task durations were observed during the alternative equipment condition in comparison to the conventional equipment condition (Table 1). Statistically significant differences were observed for the clinical tasks of fitting a patient to the slit lamp biomicroscope, slit lamp biomicroscope use when not holding a lens, and indirect ophthalmoscope use. Although the average duration of the full mock examination was longer for the alternative equipment condition in comparison to the conventional equipment condition, the difference was not statistically significant.

Surface EMG

Across an entire exam, the alternative equipment condition resulted in small (<4%RVE) but statistically significant reductions in the average mean RMS upper trapezius EMG amplitude in comparison to the conventional equipment condition (Table 2). The alternative equipment condition also resulted in a statistically significant reduction in the average mean RMS amplitude of the left anterior deltoid across an entire exam in comparison with the conventional equipment condition.

The alternative equipment condition resulted in reductions in muscle activity levels in comparison to the conventional equipment condition for the majority of clinical tasks and muscle groups examined (Table 2). In most cases, the reductions were small and not statistically significant. However, use of the alternative slit

TABLE 1 **Mean (*SD*) of clinical task duration (seconds) by examination room condition**

Clinical task	Conventional	Alternative	p^a
Entire exam	461.0 (135.4)	514.9 (114.9)	0.07
Initial interview Documentation	88.9 (40.1)	88.5 (40.6)	0.97
Fitting patient to slit lamp	27.0 (15.6)	38.7 (16.9)	0.01
Slit lamp use (no lens)	29.4 (18.9)	37.4 (18.6)	0.03
Slit lamp use (lens in right hand)	28.9 (19.7)	33.1 (15.4)	0.19
Slit lamp use (lens in left hand)	32.2 (25.4)	36.1 (19.3)	0.45
Putting away slit lamp	21.8 (24.3)	20.1 (13.0)	0.79
Putting on indirect lamp	37.0 (16.8)	34.7 (13.8)	0.38
Indirect lamp use	89.0 (74.9)	99.7 (79.8)	0.03
Putting away indirect lamp	20.4 (16.2)	19.3 (6.2)	0.75
Exit interview Documentation	86.3 (48.8)	107.2 (43.6)	0.09

[a] *p*-Values are obtained from paired *t*-tests.

TABLE 2 Mean (*SD*) of mean normalized RMS surface electromyography amplitudes[a] by clinical task and examination room condition[b]

Clinical task	Right upper trapezius			Left upper trapezius		
	Conventional	Alternative	*p*	Conventional	Alternative	*p*
Entire exam	26.3 (4.9)	22.6 (6.9)	0.01	27.8 (9.1)	25.1 (10.8)	<0.005
Initial interview documentation	18.9 (10.0)	14.5 (7.1)	<0.005	15.2 (10.0)	14.3 (10.8)	0.51
Fitting patient to slit lamp	35.3 (14.4)	41.3 (13.1)	0.21	38.2 (16.8)	41.7 (13.6)	0.14
Slit lamp use (no lens)	39.1 (23.7)	34.8 (15.8)	0.32	42.0 (30.1)	40.2 (22.9)	0.57
Slit lamp use (lens in right hand)	24.0 (17.3)	10.9 (7.5)	0.02	35.1 (22.9)	17.4 (10.2)	<0.005
Slit lamp use (lens in left hand)	29.8 (20.9)	18.4 (14.3)	0.01	22.4 (14.1)	13.7 (11.9)	0.03
Putting away slit lamp	27.8 (10.5)	29.4 (14.1)	0.69	33.6 (10.6)	28.9 (14.6)	0.22
Putting on indirect lamp	39.5 (15.3)	37.7 (15.3)	0.62	37.0 (15.9)	33.2 (12.1)	0.36
Indirect lamp use	28.1 (15.7)	29.6 (23.4)	0.68	39.8 (28.0)	40.5 (30.2)	0.81
Putting away indirect lamp	35.4 (11.2)	32.5 (14.2)	0.57	35.4 (12.9)	33.3 (14.1)	0.42
Exit interview documentation	19.0 (11.6)	14.2 (5.4)	0.20	17.5 (12.4)	12.7 (6.6)	0.14
	Right anterior deltoid			**Left anterior deltoid**		
	Conventional	Alternative	*p*	Conventional	Alternative	*p*
Entire exam	19.9 (9.6)	19.0 (9.6)	0.41	22.6 (8.8)	20.9 (8.1)	0.03
Initial interview documentation	9.6 (6.5)	10.1 (8.3)	0.65	20.4 (14.2)	17.7 (9.9)	0.27
Fitting patient to slit lamp	20.8 (7.9)	22.6 (8.5)	0.20	23.4 (7.5)	27.1 (9.9)	0.10
Slit lamp use (no lens)	17.6 (14.0)	16.1 (7.8)	0.56	23.1 (11.6)	25.2 (10.2)	0.31
Slit lamp use (lens in right hand)	27.2 (20.5)	15.5 (11.5)	0.05	17.3 (14.1)	13.0 (7.9)	0.12
Slit lamp use (lens in left hand)	20.2 (14.5)	13.5 (8.4)	0.01	22.8 (16.4)	20.5 (20.1)	0.70
Putting away slit lamp	22.2 (15.7)	25.6 (16.1)	0.16	23.6 (15.2)	23.5 (10.3)	0.98
Putting on indirect lamp	28.6 (10.2)	28.7 (14.5)	0.95	29.7 (14.8)	26.8 (10.4)	0.34
Indirect lamp use	40.1 (34.5)	40.8 (42.3)	0.81	33.1 (14.9)	32.5 (15.8)	0.77
Putting away indirect lamp	32.1 (28.4)	28.5 (13.5)	0.61	27.4 (22.4)	23.7 (14.6)	0.53
Exit interview documentation	12.0 (6.8)	10.8 (5.6)	0.46	16.7 (9.4)	13.0 (6.3)	0.01

[a]Expressed as %RVE.
[b]*p*-Values are obtained from paired *t*-tests for $N = 14$ participants.

lamp biomicroscope while holding an external lens to the patient's eye was associated with substantial reductions in right and left upper trapezius muscle activity and in right anterior deltoid activity. The observed reductions depended on the hand in which the external lens was held (i.e., reduced right upper trapezius mean RMS amplitude when holding the external lens with the right hand).

For the clinical task of initial interview documentation, the alternative equipment condition resulted in a statistically significant reduction in the average mean RMS amplitude of the right upper trapezius in comparison to the conventional equipment condition. Additionally, the alternative equipment condition resulted in a statistically significant reduction in the average mean RMS amplitude of the left anterior deltoid in comparison to the conventional equipment condition for the clinical task of exit interview documentation.

Upper Arm Elevation

For the upper arms, the alternative equipment condition generally resulted in small, non-statistically significant reductions in the percentage of time elevated >60° in comparison to the conventional equipment condition (Table 3). However, a statistically significant reduction in the percentage of time with the left upper arm elevated >60° was observed for the clinical task of holding an external lens to the patient's eye with the left hand. Conversely, a statistically significant increase in the percentage of time with the left upper arm elevated >60° was observed when fitting the patient to the slit lamp biomicroscope in the alternative equipment condition in comparison to the conventional equipment condition.

Participant Survey

For all equipment attributes examined, participants rated the alternative examination equipment more

TABLE 3 Mean (*SD*) of mean percent of time with shoulder elevated by clinical task and examination room condition[a]

	Right upper arm elevation			Left upper arm elevation		
Clinical task	Conventional	Alternative	*p*	Conventional	Alternative	*p*
Entire exam	15.6 (9.7)	12.9 (7.1)	0.13	16.0 (7.1)	15.3 (8.9)	0.66
Initial interview documentation	1.9 (3.5)	1.9 (2.1)	0.93	1.6 (3.3)	1.2 (3.5)	0.42
Fitting patient to slit lamp	9.7 (12.0)	6.3 (6.7)	0.18	15.6 (15.3)	24.9 (13.0)	<0.005
Slit lamp use (no lens)	6.0 (12.4)	2.4 (3.2)	0.23	12.0 (14.0)	17.9 (21.2)	0.21
Slit lamp use (lens in right hand)	71.3 (32.2)	52.4 (44.6)	0.10	10.8 (21.4)	5.4 (19.3)	0.49
Slit lamp use (lens in left hand)	9.1 (7.2)	7.7 (18.2)	0.73	76.5 (18.7)	52.7 (39.9)	0.03
Putting away slit lamp	14.3 (25.2)	10.4 (15.6)	0.50	2.6 (4.3)	3.5 (5.1)	0.52
Putting on indirect lamp	24.8 (12.8)	22.4 (12.2)	0.44	18.8 (13.6)	19.8 (18.8)	0.84
Indirect lamp use	32.8 (35.1)	31.5 (37.4)	0.54	38.2 (32.9)	35.7 (36.1)	0.63
Putting away indirect lamp	15.5 (20.9)	17.1 (14.0)	0.74	18.1 (25.5)	10.2 (7.5)	0.23
Exit interview documentation	3.3 (7.1)	1.5 (2.3)	0.41	0.8 (1.7)	1.0 (2.4)	0.79

[a] *p*-Values are obtained from paired *t*-tests for $N = 15$ participants.

favorably than the conventional examination room equipment (Table 4). Statistically significant differences were observed for ease of moving and adjustability of the slit lamp biomicroscope, comfort and adjustability of the indirect lamp, and comfort and adjustability of the pneumatic stool.

DISCUSSION

Occupational exposure to sustained muscular exertions and non-neutral working postures has been associated with the development of musculoskeletal pain and other symptoms consistent with MSDs in healthcare workers (Waters et al., 2006; Ngan et al., 2010). In particular, working with the upper arms elevated in positions >60° may be hazardous, as the space between the humeral head and the acromion narrows such that pressure on the supraspinatus tendon is greatest (National Institute for Occupational Safety and Health [NIOSH], 1997). The increased pressure may lead to degenerative changes of the tendons of the rotator cuff, predisposing workers to tears (Armstrong et al., 1993; Svendsen et al., 2004). Improving the ergonomics of the equipment used in the clinical environment has been suggested as one method of minimizing exposures to risk factors, such as sustained muscular exertion and non-neutral postures, experienced by ophthalmologists and other eye-care physicians (Marx, 2012). The alternative examination equipment used in this study may reduce the muscular effort required of the upper trapezius and right anterior deltoid muscles during a common ophthalmologic exam. Furthermore, the results suggest that use of the alternative examination equipment may reduce the percentage of work time spent with the upper arms elevated in positions >60° during use of the slit lamp biomicroscope while holding an external lens.

TABLE 4 Mean (*SD*) of examination room equipment attribute ratings

Attribute	Conventional	Alternative	*p*[a]
Slit lamp			
Ease of moving	3.3 (0.8)	4.3 (0.8)	<0.01
Comfort	3.4 (0.8)	3.8 (0.8)	0.25
Adjustability	3.0 (0.8)	4.1 (0.8)	<0.01
Indirect lamp			
Comfort	2.9 (1.0)	4.7 (0.5)	<0.01
Adjustability	2.9 (1.2)	4.6 (0.5)	<0.01
Pneumatic stool			
Control	3.8 (0.8)	3.8 (1.1)	0.84
Comfort	3.5 (0.5)	4.0 (0.9)	0.05
Adjustability	3.3 (0.7)	3.9 (1.0)	0.05

[a] *p*-Values are obtained from Wilcoxon signed rank tests for $N = 15$ participants.

Specifically, the clinical task of using the alternative slit lamp biomicroscope while holding an external lens resulted in substantial reductions in upper trapezius (both right and left) and right anterior deltoid EMG amplitude and the percentage of time with the left upper arm elevated >60° in comparison to use of the conventional slit lamp biomicroscope. Participant use of elbow supports on the extended slit lamp tabletop while examining a patient with a handheld lens may explain the reductions. Previous research during sedentary and manual work has suggested that arm supports may lead to improvements in subjective comfort and reductions of muscle activity in the shoulder and upper extremity (Milerad & Ericson, 1994; Feng et al., 1997; Odell et al., 2007). Haddad et al. (2012) observed reductions of upper trapezius activity to less than 5% of an MVC when an ergonomically designed chair with arm supports was used by dentists.

Review of the video recordings showed that 8 of the 15 participants used either their personal handheld lens case ($n = 2$) or the slit lamp biomicroscope table itself ($n = 6$) to support their arms while examining the patient using the slit lamp biomicroscope with the use of a handheld lens in the conventional equipment condition. The elbow supports provided in the alternative equipment condition were used by all participants. Exploratory comparisons suggested that muscle activity levels among participants using a lens case or the slit lamp biomicroscope tabletop for elbow support during the conventional equipment condition were not meaningfully different than muscle activity levels observed during the alternative equipment condition (data not shown). Thus, the reductions in muscle activity levels observed during use of alternative slit lamp biomicroscope among the full study sample appear to be strongly influenced by the absence of elbow supports among some participants during the conventional equipment condition.

Use of the alternative binocular indirect ophthalmoscope examined in this study did not result in any statistically significant reductions of muscle activity or percentage of time with the upper arms elevated. Despite these findings, statistically significant differences in participants' ratings of the comfort and adjustability of the binocular indirect ophthalmoscope were observed, suggesting that the alternative equipment was preferred by the ophthalmologists in comparison to the conventional equipment. Additional examination of the potential biomechanical advantages of use of the alternative binocular indirect ophthalmoscope is recommended.

There were several limitations to this study. First, the study sample was a convenience sample of predominantly experienced ophthalmologists in an academic setting who may or may not have adjusted their behaviors over time in response to the conditions of their work environment. The non-random selection of participants may have led to sample distortion, making the findings less generalizable to the entire population of ophthalmologists, including those in private practice.

For the clinical task of initial interview documentation, the alternative equipment condition resulted in a statistically significant reduction in the average mean RMS amplitude of the right upper trapezius in comparison to the conventional equipment condition. Additionally, for the clinical task of exit interview documentation, the alternative equipment condition resulted in a statistically significant reduction in the average mean RMS amplitude of the left anterior deltoid in comparison to the conventional equipment condition. Reductions for these clinical tasks were not expected as all documentation equipment, such as the computer used by the ophthalmologists, was identical in both conditions. Differences in mean RMS EMG amplitude between the conventional and alternative equipment conditions may have occurred as a result of differences in communication styles between participants. In particular, some participants engaged in lengthy conversation (e.g., more than 2 minutes in duration) with the patients during the clinical task of exit interview documentation, which occurred more frequently during the alternative equipment condition than during the conventional equipment condition. Review of video recordings obtained during experimental procedures suggested that when such conversations occurred, participants were sitting with the arms generally relaxed. Therefore, longer exit interview documentation durations during the alternative equipment condition likely led to longer periods of low EMG activity and the lower mean RMS EMG amplitudes observed for each muscle (although the difference was statistically significant only for the left anterior deltoid).

For the clinical task of fitting a patient to the slit lamp biomicroscope, a statistically significant increase in the duration of the task was observed between the conventional and alternative room conditions. It is anticipated that this difference was a result of the ophthalmologists' unfamiliarity with the alternative equipment, and it is recognized that this limitation may have affected the estimates of average mean RMS muscle activity and percentage of time with the upper arm elevated $>60°$. In particular, a statistically significant increase in the percentage of time with the left upper arm elevated $>60°$ was observed for this clinical task, revealing a potential trade-off in the use of the alternative equipment. However, estimates of the average mean RMS amplitude for fitting the patient to the slit lamp biomicroscope in the alternative equipment condition were not statistically significant for the four muscles examined in comparison to the conventional equipment condition. It is suspected that the percentage of time with the left upper arm elevated >60° is likely an artifact of the increased duration fitting the patient to the slit lamp biomicroscope, which, with increased familiarity to the equipment, would decrease.

While the mock clinical examinations used in this study provided a stable test environment for comparisons of the conventional and alternative examination conditions, they may have removed many of the complexities ordinarily observed in a live clinical environment, such as occupational psychosocial stress. Previous studies of musculoskeletal outcomes among ophthalmologists have observed positive associations between stress levels and the prevalence of neck, upper extremity, and lower back symptoms (Dhimitri et al., 2005; Kitzmann et al., 2012). Since information about occupational psychosocial stress was not collected in this study, it is unknown if the generally positive effects of the alternative examination equipment examined will transfer to the live environment.

Although the sample size of 15 ophthalmologists was sufficient for detecting differences in several EMG and posture summary measures, the clinical relevance of the observed reductions is unknown. For example, despite observing statistically significant reductions in upper trapezius (both right and left) and right anterior deltoid EMG amplitude during use of the alternative slit lamp biomicroscope while holding an external lens, the reductions of muscular exertion for this clinical task may not lead to the reduction of musculoskeletal symptoms among ophthalmologists. Future work should examine similar clinical equipment prospectively, where associations between musculoskeletal outcomes and exposure to physical risk factors, such as muscular exertion and non-neutral postures, may be estimated following extended use of both conventional and alternate equipment configurations. Finally, non-neutral postures of the neck (e.g., protraction/retraction and flexion/extension) may also contribute to biomechanical loading during clinical ophthalmologic practice, particularly during use of the slit lamp biomicroscope. Future studies evaluating examination equipment commonly used in clinical ophthalmologic practice should attempt to characterize exposure to non-neutral postures of the neck.

To the best knowledge of the authors, this is the first study comparing estimates of muscle activity and upper arm elevation during use of conventional and alternative examination equipment for common clinical ophthalmologic tasks. While recommendations about ideal clinician positions during use of the slit lamp biomicroscope and binocular indirect ophthalmoscope are available (Woolley & Kitzmann, 2011), no published empirical evidence exists to support them or compare them with alternative instruments. This study contributes results from which practitioners can construct initial, evidence-based recommendations for the prevention of musculoskeletal symptoms and disorders among the broader population of ophthalmologic specialists.

CONFLICT OF INTEREST

The authors declare no conflict of interest. Equipment used in this study was obtained from Haag-Streit USA/Reliance Medical Products, Mason, OH, USA. Haag-Streit USA/Reliance Medical Products had no role in the design or conduct of this research.

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