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ORIGINAL RESEARCH

Characterizing Exposure to Physical Risk Factors during Veterinary Surgery with Wearable Sensors: A Pilot Study

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OCCUPATIONAL APPLICATIONS

Veterinarians provide comprehensive health services for animals, but despite exposure to similar occupational and safety hazards as medical physicians, physical risk factors for these doctors and healthcare teams have not been characterized. In this pilot study, we used wearable sensor technology and showed that veterinary surgeons commonly experience static and demanding postures while performing soft tissue and orthopedic surgeries. Observations showed that muscle activation was highest in the right trapezius. Job factors such as surgical role (attending vs. assisting) and surgical specialty (soft tissue vs. orthopedics) appeared to influence exposure to physical risk factors. These findings suggest a need to consider the unique demands of surgical specialties in order to address the key risk factors impacting injury risks among veterinarians. For example, static postures may be a priority for soft tissue surgeons, while tools that reduce force requirements are more pressing for orthopedic surgeons.

TECHNICAL ABSTRACT

Background: Although musculoskeletal fatigue, pain, and injuries are commonly reported among surgeons in veterinary medicine, few studies have objectively characterized the exposure to physical risk factors among veterinary surgeons. **Purpose:** This study aimed to characterize muscle activation and postures of the neck and shoulders during live veterinary surgeries in the soft tissue and orthopedic specialties. **Methods:** Forty-four ergonomic exposure assessments (exposures) were collected during 26 surgical procedures across five surgeons. Exposures were collected from both soft tissue ($n = 23$) and orthopedic ($n = 21$) specialties. Physical risk factors were characterized by: (1) directly measuring muscle activation and posture of the neck and shoulders, using surface electromyography and inertial measurement units, respectively; and (2) collecting self-reported workload, pain, and stiffness. **Results:** Across the 44 exposures, neck and back symptoms respectively worsened after the surgery in 27% and 14% of the exposures. Veterinary surgeons exhibited neck postures involving a mean of 17° flexion during the surgical procedures. Static postures were common, occurring during 53–80% of the procedures. Compared to soft tissue procedures (e.g., 13.2% MVC in the right trapezius), higher muscle activity was observed during orthopedic procedures (e.g., 27.6% MVC in the right trapezius). **Conclusions:** This pilot study showed that physical risk factors (i.e., muscle activity and posture of the neck/shoulder) can be measured using wearable sensors during live veterinary surgeries. The observed risk factors were similar to those documented for medical physicians. Further studies are needed to bring awareness to opportunities for improving workplace ergonomics in veterinary medicine and surgery.

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Veterinary surgery; musculoskeletal pain and stiffness; postures; muscle activity; wearable sensors

1. Introduction

Veterinary practitioners provide comprehensive medical, surgical, and preventative health services for their patients. Previously, human healthcare has focused research on the fields of ergonomics and occupational health to improve work safety for physicians. Despite similar risks and exposures to their human healthcare counterparts, ergonomics and occupational health research in veterinary care has not received the same attention.

In the United States, the American Veterinary Medical Association (AVMA) estimates that the veterinarian workforce consists of over 116,000 professionals (American Veterinary Medical Association, 2019),

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with an estimated 442,000 total professionals in veterinary medicine and animal care (NORA Healthcare and Social Assistance Sector 2013). Compared with other occupations, veterinary medicine and animal care has the 4th highest incidence rate for nonfatal occupational injuries and illnesses (Bureau of Labor Statistics, 2019). Additionally, the recent COVID-19 pandemic has led to an 11.4 million increase in United States households having new pets (Today's Veterinary Business, 2020). This dramatic increase in pet ownership undoubtedly increases the workload of veterinarians, and it is reasonable to expect the current workplace injury rates to also worsen. Despite high incidence rates for injuries (Bureau of Labor Statistics, 2016), little quantitative evidence exists to identify the unique challenges for ergonomics and workplace safety in veterinary workplaces (American Veterinary Medical Association, 2018).

Current research investigating occupational health of veterinary practitioners primarily focuses on potential psychological, environmental, and physical job hazards. Numerous studies have shown that veterinarians are at risk for burnout, fatigue, stress, and depression (Bartram et al., 2009; Gardner & Hini, 2006; Hansez et al., 2008). Additionally, veterinarians experience environmental hazards that can impact their respiratory health, are at-risk for various infections, and commonly suffer injuries inflicted by their unpredictable animal patients (Elbers et al., 1996; Nienhaus et al., 2005). With respect to musculoskeletal injuries specifically, discomfort and/or injuries were experienced by an alarming 93–96% of veterinarians and 62% of veterinary ultrasonographers (Epp & Waldner, 2012; Liu et al., 2018; Randall et al., 2012; Scuffham, 2009; Scuffham et al., 2010). A survey of 867 veterinarians showed that the effects of musculoskeletal injuries extended beyond the workplace; 67% of participants experienced musculoskeletal discomforts that affected normal day-to-day activities (Scuffham et al., 2010). Another study surveying 806 veterinarians in Canada found that 34% of respondents experienced back injuries (Epp & Waldner, 2012). In separate survey study of 149 veterinary surgeons, over 75% reported neck/back/shoulder pain during or after laparoscopic surgery (Jones, 2020). Reported risk factors for such injuries included increasing age, female sex, previous injuries, work dissatisfaction, poor chair height, non-neutral hand postures, and shoulder abduction (Randall et al., 2012; Scuffham et al., 2010). Existing studies have focused on general veterinary practitioners and presented self-reported data. Few studies, though, have investigated related issues in veterinary surgery specialties.

Veterinary surgeons perform technically challenging procedures, and after standing at the operating table for a long duration of time daily, it is reasonable to expect occupational related injuries similar to those reported by human physicians and surgeons. There are some unique challenges that exist within the veterinary surgical workplaces, though, such as widely variable patients (size, species, etc.), varying veterinary environment, lack of ergonomic interventions, and equipment constraints. In a pilot study, electromyography (EMG) was used to compare muscle activity between techniques during simulated surgical training tasks with veterinary students (Kilkenny et al., 2017); laparoscopic techniques were found to require higher average muscle activity than open techniques in simulation. In another study with 12 veterinarians, investigators observed high muscle activity in the trapezius muscles during simulated suturing (Tapia-Araya et al., 2016). These studies provided preliminary insights into muscular workload in veterinary surgery. However, the simulation environments and skills tasks used in these studies may not accurately represent the exposures, duration of exposures, and the tasks/environmental constraints of live surgeries. In addition, existing studies have not explored job factors such as surgical techniques (open/laparoscopic/robotic) and surgical roles (attending/assisting), which are widely acknowledged to influence surgeon physical risk factors in live surgical operations for human patients (Armijo et al., 2019; Athanasiadis et al., 2021; Catanzarite et al., 2018; Monfared et al., 2019).

Continuous in-the-field measurements can measure the actual worker's experience during work and enable the development of targeted interventions for the workplace. Specifically, wearable sensors have been shown to be feasible and effective for assessing complex tasks in the sterile surgical environment for human patients (Lee et al., 2009; Szeto et al., 2009; Yu et al., 2017). However, there is a paucity of literature assessing physical risk factors of veterinary surgeons, and to our knowledge none using sensor methodology. This study aimed to better understand the physical risk factors in veterinary surgery and to identify the effects of veterinary job factors, specifically to characterize the muscle activation and posture of the neck and shoulders and how these exposures relate to ergonomics and work-related injury/stress during live veterinary surgeries. A subset of the current results were previously reported in Asadi et al. (2018).

Table 1. Summary of participant details.

	Soft tissue surgeons ($n = 3$; 3 females)			Orthopedic surgeons ($n = 2$; 1 female and 1 male)		
	Mean (SD)	Min	Max	Mean (SD)	Min	Max
Age (years)	32.3 (2.3)	31	35	31.5 (0.5)	31	32
Years of experience (years)	4 (1.7)	3	6	3.5 (2.5)	1	6
Height (m)	1.7 (0.04)	1.6	1.7	1.7 (0.03)	1.70	1.75
Mass (kg)	60.1 (1.1)	58.9	61.2	88.9 (26.8)	62.1	116
Glove size (no units)	6.3 (0.3)	6	6.5	6.8 (0.8)	6	7.5

Note that glove size is unitless, but is typically associated with hand circumference.

2. Methods

2.1. Participants

This study was approved by Purdue University's institutional review board (#1608018023), and each participant provided written consent. Approximately 1000 surgery procedures are performed annually at the university's small animal hospital, of which 53.5% were soft tissue procedures and 34.9% were orthopedic procedures. Procedures were sampled evenly from both specialties to provide a broader scope of ergonomic risk factors in the veterinary surgery occupation. During each procedure, surgeons performed either attending or assisting roles. The "attending" role was typically performed by experienced surgeons. The "assisting" role was typically performed by residents or veterinary medicine students. All procedures required attending and/or assisting surgeons, and exposures were collected by the research team over the study period.

Forty-four ergonomic exposure assessments (or exposures) from 26 surgical procedures were collected. Thirteen procedures were from soft tissue specialties, and 13 were from orthopedic specialties (Table 1). Procedures were performed by five different surgeons (80% right hand dominant); note that all actively-practicing surgeons during the study period participated. Operative duration for the 13 soft tissue procedures had a mean and standard deviation (SD) of 94 (44) minutes. The 13 orthopedic procedures lasted 83 (39) minutes. Roughly half (52%) of the exposures were collected from the 1st surgical operation of the day. One-fourth were from the 2nd operation performed by the surgical team after the first operation was completed, and the rest were from the 3rd operation. In general, there was a 30–75 minute break between the surgical operations to allow time for patient recovery, client communications, personnel breaks, and anesthetic preparation for the upcoming surgery.

Exposures for both attending and assisting surgeons were collected simultaneously for 10 soft tissue and eight orthopedic surgeries (i.e., 36 surgeon exposures). There were three soft tissue and five orthopedic procedures where only the attending surgeon was captured. This created a total of 44 surgeon exposures. Motion tracking metrics and surveys were collected for all 44 surgeon exposures. EMG measures were collected in 40 exposure assessments due to time constraints and study team availability (two study team members were needed to collect all measures for both surgeons simultaneously).

2.2. Data Collection

In this observational pilot study, diverse subjective and objective measures were obtained. A body-part pain and stiffness survey was used, adapted from previous work (Abdelrahman et al., 2016), and given to the surgeons prior to scrubbing into the surgery and immediately after procedure completion. Specifically, the surgeon reported "No," "Slight," or "Substantial" pain and stiffness in specified body areas (i.e., hands, shoulders, neck, and lower back). The SURG-TLX (Wilson et al., 2011) questionnaire was given to surgeons immediately after surgery. Surgeons reported workload on a scale from 0 to 20, with 0 being very low and 20 being very high. They reported the perceived workload of the procedure using six sub-scales: mental demand, physical demand, temporal demand, situational stress, task complexity, and distractions.

Muscle activations were collected using surface EMG (DataLITE, Biometrics, Ltd, Newport, UK). Four EMG sensors were located on the middle trapezius (approximately at 50% of the distance between the medial border of the scapula and the spine, at the level of T3) and middle deltoid (approximately located from the acromion to the lateral epicondyle of the elbow) using SENIAM (Surface ElectroMyoGraphy for the Noninvasive Assessment of Muscles) recommendations (SENIAM, 1999). These were reported to be the major muscles that activate during shoulder elevation and neck flexion (Asadi et al., 2021; Stephenson et al., 2019). The EMG sensors were calibrated using maximum voluntary contractions (MVCs) of the shoulder muscles using a protocol published

Figure 1. Surgeon wearing the wireless sensors used to record motion (sensors with black straps) and muscle activity (not seen, on the posterior side of the surgeon) during surgery.

previously (Domkin et al., 2016). Specifically, three MVCs lasting for 5 seconds each were performed. The three MVCs (with a minimum of 1-minute rest between each) were averaged to calculate the average MVC. This average MVC was used to normalize the EMG results as further described in the data analysis section.

Neck/shoulder postures were collected using inertial measurement units (IMUs). Two sets of IMUs (Opal System, APDM, Inc., Portland, OR, USA) with a total of five sensors in each set were used to measure the upper-body motion of the attending and assisting surgeons. IMU sensors were placed on the head, chest, left, and right biceps (Figure 1). Once in the operating room, the IMU sensors were calibrated with a modified I-Pose (e.g., standard I-pose with elbows at 90 degrees) where the surgeon held their forearms at right angles to maintain sterility while at the patient's bedside. This calibration pose event was marked using the marker button on an IMU. The procedure duration was also captured using a marker sensor measuring from the procedure cut time and to time when the surgeons left the procedure.

2.3. Study Procedures

Before every surgery (pre-surgery), a body-part musculoskeletal pain and stiffness survey was administered. Then, wearable sensors (e.g., EMG and IMU sensors) were placed using adhesive tapes for EMG sensors and straps for IMU sensors. Immediately following the surgery, the body-part musculoskeletal pain and stiffness survey (identical to the pre-surgery survey) was administered, along with the SURG-TLX questionnaire. Sensors were then removed.

2.4. Data Analysis

The frequency of worsening musculoskeletal stiffness was calculated as the difference between post- and pre-surgery for each body part. Specifically, when stiffness ratings changed from either 'No' to 'Slight'/'Substantial' or from 'Slight' to 'Substantial' between pre- and post-surgical surveys, a categorical variable was labeled as 'stiffness increased' (Yu et al., 2017). This approach was used to account for any stiffness that was already present at the start of the procedure.

IMU data were analyzed with MATLAB, using raw outputs from each IMU as quaternions. Quaternion outputs were transformed into Euler angles as described previously (Henderson, 1977), and the order of operations used is included in the Appendix. Biomechanical posture angles were calculated from the Euler angles using definitions from the International Society of Biomechanics (Wu et al., 2002, 2005). Then, using a calibration posture, posture movements (i.e., changes in joint angles over time) were calculated.

Flexion angles are reported for the neck. For the shoulders, angles are reported as elevation. Percentage time spent in demanding postures was also calculated, defined as angles outside the range of the recommended limits as described by McAtamney and Corlett (1993), specifically $>10^\circ$ neck flexion, $>20^\circ$ torso flexion, and $>45^\circ$ shoulder elevation. Static postures were calculated, and defined as the percentage of time that joint movement velocity was less than $1^\circ/s$ (Szeto et al., 2012; Yu et al., 2017).

Biometrics Analysis software (EMG Software, Biometrics, Ltd, Newport, UK) was used to process raw EMG data for each muscle group as follows: rectified, high/low, high pass with 60 Hz cut off, and RMS following methods described previously (Domkin et al., 2016). Muscle activity for each of the four observed muscle groups was normalized to values from each participant's MVC and are reported as %MVC. Due the pilot nature of this study and small sample size, only qualitative analyses are reported.

3. Results

3.1. Self-Reported Metrics

At least one musculoskeletal symptom was reported after the surgery in 70% of the collected exposures (31/44). The back and neck were the most frequent body regions experiencing symptoms (Table 2(a)).

Table 2. Summary across all 44 collected exposures of preoperative and postoperative measures of: (a) musculoskeletal stiffness experienced during surgery; and (b) postoperative musculoskeletal stiffness in veterinary surgical sub-specialties and roles.

a)	Preoperative (%)			Postoperative (%)			Frequency pain increased after surgery (%)
(n = 44)	No	Slight	Substantial	No	Slight	Substantial	
L. hand/wrist stiffness	100	0	0	95.5	4.5	0	4.5
R. hand/wrist stiffness	100	0	0	97.7	2.3	0	2.3
L. shoulder/arm stiffness	81.8	18.2	0	75.0	25.0	0	6.8
R. shoulder/arm stiffness	81.8	18.2	0	75.0	25.0	0	6.8
L. shoulder/arm pain	97.7	2.3	0	95.5	4.5	0	4.5
R. shoulder/arm pain	97.7	2.3	0	90.9	9.1	0	9.1
Neck stiffness	72.7	27.3	0	50.0	50.0	0	27.3
Neck pain	95.5	4.5	0	79.5	18.2	2.3	15.9
Back stiffness	68.2	31.8	0	56.8	40.9	2.3	13.6
Back pain	81.8	18.2	0	77.3	20.5	2.3	9.1

(b)	Postoperative musculoskeletal stiffness in sub-specialties and surgical roles (%)			
	Soft Tissue (n = 23)	Orthopedic (n = 21)	Attending (n = 28)	Assisting (n = 16)
Neck stiffness	30	71	46	56
Neck pain	4	38	29	6
Back stiffness	22	67	50	31
Back pain	13	33	32	6

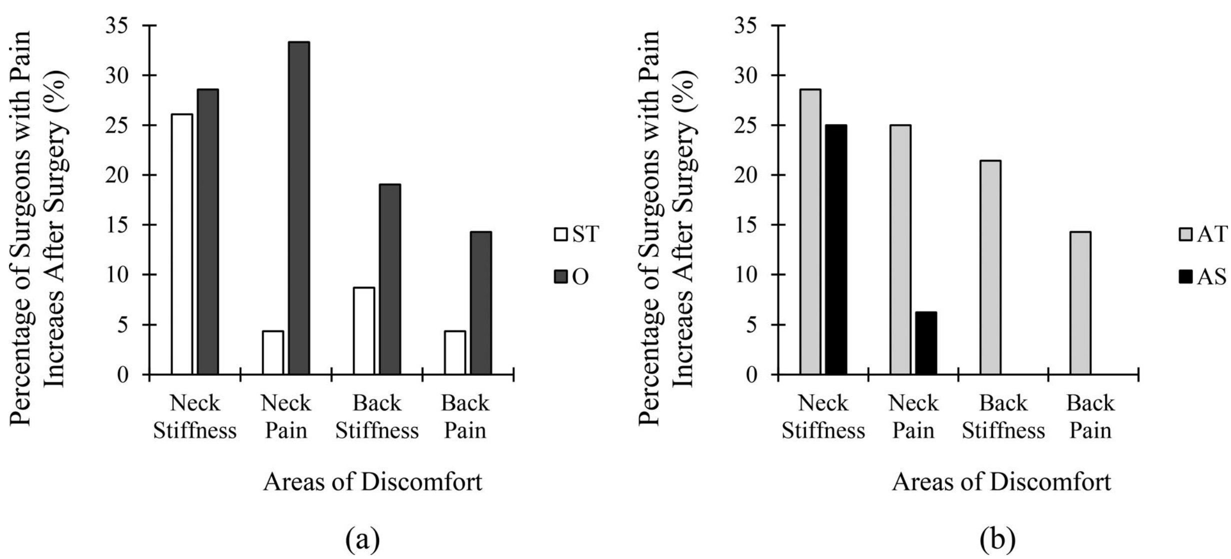

Figure 2. Percentage of procedures where pain increased postoperatively for (a) soft tissue (ST) ($n = 23$) and orthopedic (O) ($n = 21$) surgeons, and (b) attending (AT) ($n = 28$) and assisting (AS) ($n = 16$) surgeons.

Postoperative musculoskeletal symptoms were reported more frequently in orthopedic procedures than soft tissue procedures (Table 2(b)). Except for neck stiffness, postoperative symptoms were more frequently reported by attending surgeons than assisting surgeons (Table 2(b)).

Musculoskeletal stiffness increases (difference between post- and pre-surgery) varied by surgical specialty (Figure 2(a)) and surgical role (Figure 2(b)). Increases in musculoskeletal symptoms were more frequent during orthopedic procedures than soft tissue procedures (Figure 2(a)). Surgeons in attending roles reported increases in symptoms more frequently than surgeon in assisting roles (Figure 2(b)). No increases in back stiffness and pain were reported by surgeons in assisting roles.

3.2. Posture and Kinematic Metrics

Body posture angles, percent time observed in static postures, and percent time observed in demanding postures were summarized between specialties and surgery roles (Figure 3). Participants had a mean (SD) of 16.7° (14.0°) neck flexion. Both shoulders averaged 22.3° elevation. Surgeons were static for the majority of the procedure (53.4–79.9% of the procedure time). Demanding postures were more prevalent when surgeons were performing attending than assisting roles

3.3. Muscle Activity

Muscle activities were 2.8–34.8%MVC across all participants and muscle groups. Average muscle activity

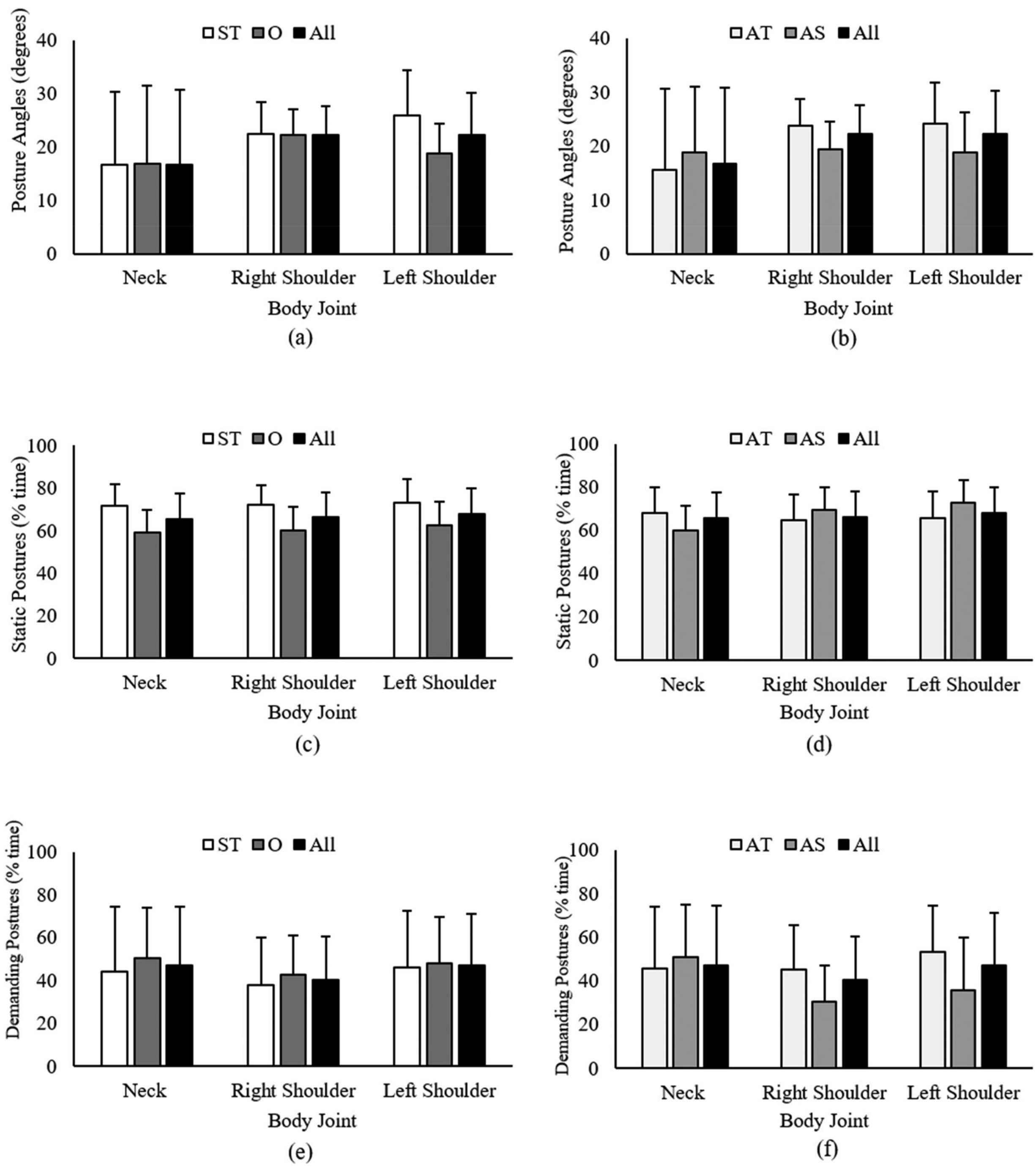

Figure 3. (a, b) Mean posture angles, (c, d) frequency of static postures, and (e, f) demanding postures (soft tissue (ST): $n = 21$, orthopedic (O) $n = 21$, Attending (AT): $n = 28$, Assisting (AS): $n = 14$).

was higher during orthopedic procedures than soft tissue procedures (Figure 4(a)). For both assisting and attending surgeons, muscle activity was highest for the right trapezius (Figure 4(b)).

4. Discussion

Our results show that musculoskeletal pain and stiffness are frequently reported among veterinary surgeons (Table 2(a) and Figure 2). In many procedures, we found that pain increased during the course of the surgery (Figure 2). Among all body regions, symptoms were especially concentrated in the neck and back regions (Table 2(a) and Figure 2). Potential factors that can contribute to musculoskeletal symptoms in the surgical specialties may be related to procedure duration (which averaged over 1.5 hours) and exposure to prolonged and sustained biomechanical loads (Figure 3). These findings are consistent with the symptoms reported among veterinarians (Epp &

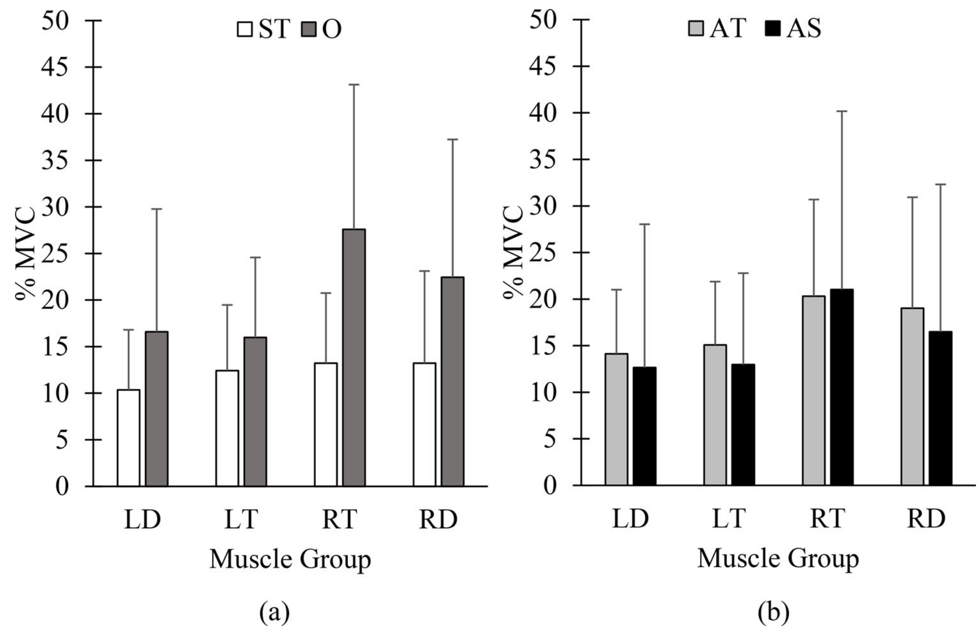

Figure 4. Mean and standard deviation of muscle activity as % Maximum Voluntary Contraction (%MVC) per muscle group (LD = Left Deltoid, LT = Left Trapezius, RT = Right Trapezius, RD = Right Deltoid for soft tissue (ST), orthopedic (O), attending (AT) and assisting (AS) surgeons).

Waldner, 2012) and human medicine (Soueid et al., 2010; Szeto et al., 2009).

This study also highlights the ability of wearable sensors to characterize multiple physical risk factors simultaneously. This allows for a more comprehensive understanding of the contributors to musculoskeletal symptoms, which are often multifactorial. The preliminary contrasts between orthopedic and soft tissue sub-specialties are one example illustrating the relationship between work, muscle activity, and posture. Orthopedic surgery (i.e., procedures of joints and/or bones) generally occurs at smaller sites; however, there is often more body strength required in positioning the patient or reduction at the surgical site. The additional strength requirements are further supported by differences in muscle activity on the dominant arm (Figure 4(a)). The different task demands involve more frequent whole-body movement, resulting in a lower observed static posture frequency than soft tissue procedures. These differences reinforce that ergonomic interventions may not be optimal across all specialties. There is a need to consider the unique demands of surgical specialties to address the key risk factors impacting workplace safety (e.g., static postures may be a priority for soft tissue surgeons, while tools that reduce force requirements are more relevant to orthopedic surgeons).

The role within the surgical team has been shown to impact exposure to physical risk factors for injuries (Cavuoto et al., 2017; Gerbrands et al., 2004; Papp et al., 2009; Yu et al., 2016b, 2017). For example, the required tasks while assisting in the surgery can increase assisting surgeon's risk for injuries, e.g., holding static positions, exerting constant force for tissue retraction, and assuming non-neutral positioning to accommodate the needs of the attending surgeon. Interestingly, attending surgeons were the roles more frequently reporting stiffness and increases in stiffness after surgery (Figure 2(b)). The kinematic data (Figure 3) can partially explain some of the observed differences in self-reported stiffness; however, consideration of additional risk factors (e.g., subject factors and demographics) is likely needed to better understand symptom differences between surgical roles. Nonetheless, these findings suggest ergonomic interventions should differ between attending and assisting surgeons.

Although the present work measured musculoskeletal stiffness after a procedure and potential contributors to poor biomechanics in veterinary surgery, this is a preliminary pilot study. Further work is needed to confirm the findings at other institutions and more broadly in the field. One limitation of the current dataset was that some exposures were collected from multiple cases on the same day. While musculoskeletal fatigue may be negligible due to the breaks in between the surgical operations, the impacts of prolonged surgical operations on EMG and posture measurements have been highlighted previously (Asadi et al., 2021; Rodrigues Armijo et al., 2020; Yoon et al., 2016). The present preliminary work was limited by the small sample size of surgeons from one large veterinary hospital; however, the musculoskeletal symptoms were consistently reported across the observed 44 exposures. Another limitation of this methodology is the potential noise in our sensor measurements due to the presence of the electrocardiogram and/or electromagnetic interference. The operating room contains many instruments for anesthesia and surgery, some of which may contain sources for interference; further work is needed to determine the impact of the interference on our measurements. Finally, although work environments and caseloads are likely similar for other institutions with veterinary surgical specialties, additional work is needed to determine the generalizability of the present findings.

In conclusion, parallels in musculoskeletal pain and pain locations between surgeons in medicine and veterinary care are likely due to similarities in surgical work. Regardless of patient type, animal or human, surgical work demands frequent complex and delicate dissections and reconstructions. The need for visibility is critical for all surgical procedures. Therefore, surgeons and their assistants may need to hold static positions for prolonged periods to allow the surgical dissection/manipulations to occur and ensure optimal positioning during the procedure. In addition, the key surgical instrumentation and environment are also similar regardless of patient types. However, while guidelines, interventions, and innovations in instrument designs (e.g., robotic techniques) are being explored in medicine (Greenberg, 2018; Hallbeck et al., 2017; Park et al., 2017; Yu et al., 2016a), solutions and training guidelines do not yet exist for veterinary surgery. The results of the present study contribute to this gap in the literature by measuring risk factors and task contributors that can inform future training and intervention developments. It is hoped that this research will continue to improve the occupational health, and potentially patient safety, in the veterinary sector.

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Conflict of Interest

The authors declare no conflicts of interest.

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Appendix

Order of operations for transforming quaternion output to Euler angles

$$M = M(q_1\, q_2\, q_3\, q_4)$$

$$M = \begin{bmatrix} q_1^2 + q_2^2 - q_3^2 - q_4^2 & 2(q_2\, q_3 - q_1\, q_4) & 2(q_2\, q_4 + q_1 q_3 \\ 2(q_2 q_3 + q_1\, q_4) & q_1^2 - q_2^2 + q_3^2 - q_4^2 & 2(q_3 q_4 - q_1\, q_2 \\ 2(q_2\, q_4 - q_1\, q_3 & 2(q_3\, q_4 + q_1\, q_2 & q_1^2 - q_2^2 - q_3^2 + q_4^2 \end{bmatrix}$$

$$M = M(Z(\theta_1).X(\theta_2).Y(\theta_3), \text{using } ZXY \text{ order}$$

$$\textit{Axial Rotation Sequesnce}:\ 3.\,1.2$$

$$M = \begin{bmatrix} \ldots & -\sin(\theta_1)\cos(\theta_2) & \ldots \\ \ldots & -\cos(\theta_1)\cos(\theta_2) & \ldots \\ -\cos(\theta_2)\sin(\theta_3) & \sin(\theta_2) & \cos(\theta_2\cos\theta_3) \end{bmatrix}$$