Local Pressure Application Effects on Discomfort, Temperature, and Limb Oxygenation

Kenneth E. Games; Joni M. Lakin; John C. Quindry; Wendi H. Weimar; JoEllen M. Sefton

INTRODUCTION: Despite significant investment into the development and improvement of military helicopter seat systems, military aviators continue to report seat system related pain and discomfort during prolonged missions.

METHODS: Using a factorial repeated measures design, 15 healthy subjects completed the study, in which focal pressure was applied to two locations on the sitting surfaces of the body (ischial tuberosity and middle of the posterior thigh). Pressure was applied using a purpose-built pressure application system allowing subjects to sit in a position mimicking the sitting position in the UH-60 Black Hawk helicopter. The researchers measured pain using the Category Partitioning Scale and McGill Pain Questionnaire and vascular function using dynamic infrared thermography in the lower leg and pulse oximetry at the great toe. Data were collected before and during a 10-min application of focal pressure applied to either the ischial tuberosity or middle of the posterior thigh and at two different pressure magnitudes (36 or 44 kPa).

RESULTS: We found that during a 10-min pressure application, superficial skin temperature increased by 0.61°C, suggesting a decreased venous return during pressure application. We found that lower extremity blood oxygenation remained unchanged during pressure application. Subjects' reported pain increased during pressure application and was greater with 44 kPa of application compared to 36 kPa.

DISCUSSION: These results support the hypothesis that locally high pressure creates symptoms of discomfort and paresthesia. Research examining the effects of local pressure application on physiological and neurological function is needed.

KEYWORDS: military, aviators, operational load-bearing.

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Despite millions of dollars invested in helicopter seating research and development, helicopter pilots continue to complain of seat-related symptoms and paresthesia.[3] Approximately one-fifth of helicopter pilots report some level of pain, numbness, or tingling in the buttocks and lower extremities during prolonged flight.[16,20] This reported discomfort often extends beyond feeling pain during flight; pilots of rotary-wing aircraft have also been shown to experience more low back and pelvic musculoskeletal injuries than their fixed-wing counterparts.[18] Additionally, the discomfort associated with prolonged sitting impairs mission performance.[2,14] In fact, 34% of naval helicopter pilots reported that discomfort due to prolonged restricted sitting resulted in decreased situational awareness.[14] Discomfort from prolonged restricted sitting could interfere with the attentional capacity to perform a task. In practice, this could result in a decreased ability to perform a complex task (operating a helicopter) due to discomfort competing for a finite pool of attentional resources, and result in loss of equipment, injury, or death.

There is also a financial cost—it has been calculated that the annual cost of seat-related discomfort and injury (including medical care, lost time, and training) for Naval rotary-wing aviators is $10.6 million.[9] Studies examining the long-term costs associated with pain and injury resulting from the seat system found that the 5-yr cost (including medical, lost time,

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and training) was $54.8 million.[14] One study's estimated costs of pain and injury due to prolonged sitting suggest that each injury caused by the helicopter seat system costs $1500 per year.[15] It is important to understand the etiology of seat-related discomfort and temporary paresthesia in order to enable significant improvements to the helicopter seat system to be developed with the goal of reducing monetary costs and improving rotary-wing pilot performance and health.

Investigations into the effects of prolonged restricted sitting have primarily used subjective discomfort scales[8,12,13] and seat interface pressure techniques,[8,12,13] while investigations into possible etiology of the symptoms of discomfort and paresthesia have used neurological measures such as the Hoffmann reflex.[19] Previous work examining prolonged sitting in the UH-60 Black Hawk found that 4 h of restricted sitting increases discomfort and reported paresthesia and the authors hypothesized a mechanism, but this was not examined.[7] Other work using high-field magnetic resonance imaging found that, when pressure was applied to the buttocks and posterior thigh at a level similar to that found that in the UH-60 seat system, it resulted in significant soft tissue compression.[6] However, the imaging protocol was unable to distinguish vascular and nervous system structures from muscle and adipose tissue.[6] Building on previous prolonged sitting work and local pressure studies requires a connection between the measures used in prolonged sitting studies and local pressure studies. This would improve our understanding of the development of discomfort in both real world and experimental settings. Measures that can effectively be used in both the field setting and laboratory setting include: the Semmes-Weinstein monofilament test, the two-point discrimination test, dynamic infrared thermography, and lower extremity pulse oximetry. These tools have been used previously to monitor changes as a result of prolonged restricted sitting in a Black Hawk helicopter.[7] We can better understand the development of seat-related symptoms by using these same measures to examine a potential cause (local pressure application) of pilots' reported discomfort and temporary paresthesia, with the goal of decreasing injury and increasing combat effectiveness in today's rotary-wing aviators.

A primary hypothesis explaining the development of discomfort and temporary paresthesia is that local pressure compresses the neurological and vascular structures.[6,7,19] Therefore, the purpose of this study was to determine if 10 min of local pressure application at two anatomic locations in contact with the seat pan and at two different magnitudes results in changes to subjective discomfort scores and vascular function in the lower extremities. We hypothesized that the higher pressure application would elicit greater changes in measures of discomfort, blood oxygenation, and superficial skin temperature.

METHODS

Experimental Design

This study used a 2 × 2 × 2 factorial repeated measures crossover design. The independent variables were location (ischial tuberosity and posterior thigh), pressure magnitude (36 kPa and 44 kPa), and time (pre-pressure and during pressure). The dependent variables included Category Partitioning Scale scores (CPS), McGill Pain Questionnaire (MPQ) (descriptor, visual analog scale, and present pain intensity) scores, dynamic infrared thermography (lateral lower leg and anterior lower leg) mean temperatures, and pulse oximetry (percent oxygen saturation) levels.

Subjects

There were 16 male volunteers who responded to advertisements (flyers and group presentations) to participate in the study. Of those, 15 healthy male subjects (age = 23.4 ± 3.1 yr) completed the study (one did not attend the data collection session and no data were collected). Subjects met U.S. Army flight standards for anthropometry and bodyweight. Subjects were screened via an 18-point health questionnaire and reported no history of cardiovascular, neurological, or metabolic disease in the past 2 yr; no history of surgery or fracture in the lumbar spine or lower extremities in the past 2 yr; no current history of low back pain or lower extremity injury; and no current use of prescription or nonprescription pain relievers. The study protocol was approved in advanced by the U.S. Army Medical Research and Material Command and the Auburn University's Institutional Review Boards. Each subject provided written informed consent before participating.

Equipment

A purpose-built pressure application apparatus was designed to apply 36 and 44 kPa of pressure to the ischial tuberosity and posterior thigh of participants in a seated position. The system consisted of a step motor secured to an extendable metal rod and load cell with a custom-built, round pressure application head 25.52 cm^2 in area. The unit (**Fig. 1A**) was controlled using custom-written computer software and operated through a laptop computer (Dell Latitude D430, Dell Inc., Round Rock, TX).

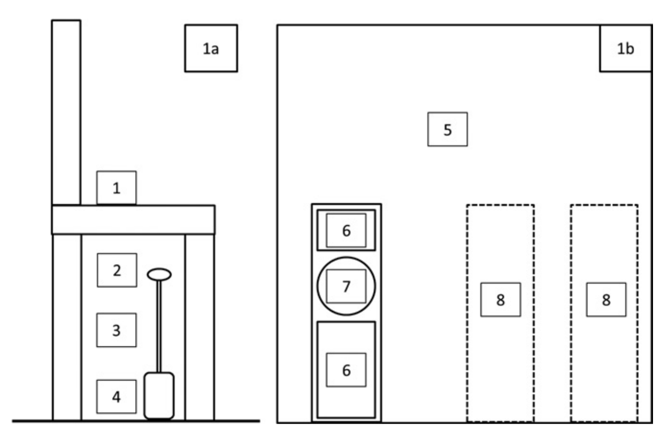

Fig. 1. A) Schematic diagram of local pressure application apparatus: 1: seat pan; 2: application head positioning under seat pan; 3: application rod; 4: step motor. B) Schematic diagram of seat pan with application head exposed for application to the right posterior thigh condition: 5: seat pan cover; 6: exposure slat covers; 7: application head; 8: exposure slat cutouts to account for different leg positioning and subject size.

The seat was built of wood and consisted of an 80.01 × 55.88 cm (height × width) seat back and a 50.80 × 55.88 cm (depth × width) seat pan. The seat pan was comprised of 14 removable slats which allowed the pressure application head to apply pressure to the area of interest while still supporting the participant (**Fig. 1B**). The foot rest was a 91.44 × 50.80 × 35.56 cm (length × width × height) box with an adjustable crank lift to accommodate participants of different heights.

The CPS was utilized to examine local pressure intensity level and perceived discomfort.[4,17] The tool consists of a vertical scale divided into five categories: "very slight," "slight," "medium," "severe," and "very severe."[17] Each category is subdivided into 10 scale points, with numbers above 50 provided to avoid the ceiling effect in the case of extreme pain or discomfort.[17] Subjects were asked to rate their discomfort in one of the five categories, then instructed to "fine tune" their discomfort rating using the numerical scale within each category.[17]

The 17-point MPQ evaluated the sensory, affective, and current pain intensities.[10] The questionnaire consists of 11 sensory dimension descriptors and 4 affective dimension descriptors.[10] Each descriptor was ranked on an intensity scale of 0 = none, 1 = mild, 2 = moderate, and 3 = severe.[10] One 10-cm visual analog scale and one Present Pain Intensity question were also presented as part of the MPQ to indicate overall discomfort intensity.[10]

A digital infrared camera (FLIR T420, FLIR Systems Inc., Wilsonville, OR) was used to measure noncontact, superficial temperatures (°C) in the lower leg. Anterior and lateral infrared images were taken 1 m from the dominant leg of subjects. The mean temperature of the lateral and anterior ankle was analyzed using the mean temperature function (FLIR ExaminIR, version 1.40.12.44, FLIR Systems Inc.). Mean temperature values for regions of interest at the anterior and lateral ankle were measured using the Glamorgan Protocol.[1] The anterior ankle region of interest included the width of the ankle with upper and lower edges at the tip of the medial malleolus and the tip of the navicular bone, respectively.[1] The lateral ankle region of interest included the entire anterior to posterior thickness at the level of the lateral malleolus.[1]

A pulse oximeter (Nonin Onyx Vantage 9590, Nonin Medical Inc., Plymouth, MN) was secured to the great toe of the dominant leg. Percent oxygen saturation was recorded using the spot check method.[21] Following a 5-s analysis period, percent blood oxygen (%SpO_2) was recorded. The pulse oximeter was removed following every data collection time point.

Procedures

Subjects reported to the laboratory two times with a minimum of 24 h between sessions. Testing order was randomized (computerized random number generator, TI-83 Plus, Texas Instruments Inc., Dallas, TX) into two conditions: a pressure magnitude of 36 kPa (condition A) completed on one day and a pressure magnitude of 44 kPa (condition B) completed on the other day. Within each condition, pressure application location order was randomized between the ischial tuberosity (location A) and the middle of the posterior thigh (location B).

Subjects sat in the local pressure application apparatus. The seat's design allowed for local pressure to be applied only to the location of interest while still supporting the participants' bodyweight. Data were collected at baseline and during the final 3 min of the pressure application protocol. During pressure application, participants were asked to sit quietly with their head facing forward.

Local pressure was applied to the ischial tuberosity and the midpoint of the posterior thigh on the dominant lower extremity of participants. The two locations were chosen based on previous research.[19] The ischial tuberosity was located using palpation by a trained investigator and marked with adhesive tape. The midpoint of the posterior thigh was defined as the distance from the greater trochanter to the lateral epicondyle between the medial and lateral edges of the posterior thigh. A trained investigator measured the distance between the greater trochanter and the lateral epicondyle (both determined by palpation) using a fabric tape measure. The distance was rounded to the nearest half centimeter and marked with permanent marker. The distance between the medial and lateral borders of the thigh was measured in the same manner with the permanent marker line demarcating the midpoint of the femur along its long axis. This point was marked with permanent marker and served as the location for posterior thigh pressure application. Prior to local pressure application, these locations were visually confirmed.

During the testing procedure, subjects were asked to sit on the pressure application chair barefoot with the appropriate slats removed and pressure application head correctly positioned. The participant was instructed to sit upright and as far back in the chair as possible. Baseline measures of CPS, MPQ, dynamic infrared thermography, and pulse oximetry were taken. Local pressure was applied at the specified amplitude (36 kPa or 44 kPa) for a total time of 10 min. During the pressure application the magnitude of the pressure was maintained to within 5% of the set value. Follow-up measurements began 7 min into the pressure application protocol to allow investigators to complete all data collection before the 10 min total pressure application time expired. Following 10 min of pressure application, the pressure magnitude was decreased to zero and the participants were given a 15-min break, during which participants were permitted to stand and walk around the laboratory. The 15-min break allowed time for participants to recover from any numbness or tingling which may have occurred during testing and allowed for the investigators to reposition the pressure application head to the next pressure application location. The randomization of pressure magnitude and location precluded an order effect and ensured that pressure was not applied to the same location twice during a single data collection session. Following the 15-min break, participants were asked to again sit in the pressure application seat. Once in position, the protocol was repeated on the untested location at the same pressure magnitude. During the second session, the above protocol was repeated at the other pressure application magnitude (36 kPa or 44 kPa).

Statistical Analysis

Data were collected and electronically transferred into a custom database (Microsoft Excel 2010, Microsoft Corp., Redmond, WA), and analyzed using Statistical Package for Social Sciences version 19 (IBM SPSS Statistics 19, IBM Corp., Somers, NY). Descriptive statistics (mean ± SD) were calculated. Multiple factorial repeated measures ANOVAs were performed. Appropriate follow-up ANOVAs and dependent *t*-tests with Holm's sequential Bonferroni adjustments were performed. Significance levels were set a priori at $P \leq 0.05$.

RESULTS

No significant three-way interaction was found following a 2 × 2 × 2 factorial repeated measures ANOVA for the CPS scores [Wilks' $\Lambda = 0.83$; $F(1,14) = 2.94$, $P = 0.108$; $\eta_p^2 = 0.17$]. There were significant magnitude × time [Wilks' $\Lambda = 0.55$; $F(1,14) = 11.39$, $P = 0.005$; $\eta_p^2 = 0.45$] and location × time [Wilks' $\Lambda = 0.40$; $F(1,14) = 20.76$, $P < 0.0001$; $\eta_p^2 = 0.60$] two-way interactions for CPS scores. Follow-up tests revealed that CPS scores were higher (indicating more discomfort) at the posterior thigh during both the 36 kPa and 44 kPa pressure applications than at the ischial tuberosity during the same pressure application magnitudes. (**Fig. 2**)

The descriptor scores for the MPQ yielded a significant location × time two-way interaction [Wilks' $\Lambda = 0.44$; $F(1,14) = 17.79$, $P = 0.001$; $\eta_p^2 = 0.56$]. Follow-up *t*-tests were significant (range of *P*-values = 0.016 – <0.0001), indicating MPQ scores were higher during pressure application regardless of magnitude or location. The visual analog scale scores for the MPQ yielded significant magnitude × time [Wilks' $\Lambda = 0.54$; $F(1,14) = 11.58$, $P = 0.004$; $\eta_p^2 = 0.45$] and location × time [Wilks' $\Lambda = 0.55$; $F(1,14) = 11.23$, $P = 0.005$; $\eta_p^2 = 0.44$] two-way interactions. All follow-up *t*-tests were significant (range of *P*-values = 0.024–0.001), revealing increased pain at both the ischial tuberosity and posterior thigh during pressure application, but higher reported pain at the posterior thigh during 44 kPa of pressure application. (**Fig. 3**) The present pain intensity scores for the MPQ yielded significant magnitude × time [Wilks' $\Lambda = 0.57$; $F(1,14) = 10.33$, $P = 0.006$; $\eta_p^2 = 0.43$] and location × time [Wilks' $\Lambda = 0.72$; $F(1,14) = 5.56$, $P = 0.033$; $\eta_p^2 = 0.28$] two-way interaction effects. Follow-up *t*-tests were significant (range of *P*-values = 0.019 – <0.0001), indicating increased pain at both the ischial tuberosity and posterior thigh during 36 and 44 kPa of pressure application compared to baseline.

Anterior ankle temperatures revealed no significant three-way interaction [Wilks' $\Lambda = 0.93$; $F(1,14) = 0.840$, $P = 0.343$; $\eta_p^2 = 0.064$]. Additionally, no two-way interactions were found: location × time [Wilks' $\Lambda = 1.00$; $F(1,14) = 0.001$, $P = 0.976$; $\eta_p^2 = 0.00$], magnitude × time [Wilks' $\Lambda = 0.96$; $F(1,14) = 0.562$, $P = 0.466$; $\eta_p^2 = 0.039$], or magnitude × location [Wilks' $\Lambda = 1.00$; $F(1,14) > 0.001$, $P = 0.994$; $\eta_p^2 = 0.00$]. Test for main effects revealed a significant effect of time [Wilks' $\Lambda = 0.23$; $F(1,14) = 45.42$, $P > 0.001$; $\eta_p^2 = 0.76$], but not for location [Wilks' $\Lambda = 0.96$; $F(1,14) = 2.14$, $P = 0.165$; $\eta_p^2 = 0.133$] or magnitude [Wilks' $\Lambda = 0.94$; $F(1,14) = 0.83$, $P = 0.377$; $\eta_p^2 = 0.056$]. A follow-up pairwise comparison of the two data collection time points revealed a significant increase in anterior ankle skin temperature during pressure application [$t(14) = -0.61$; $P > 0.001$]. These data reveal that during the 10-min application period, superficial ankle skin temperature was increased. Lateral ankle skin temperatures revealed no significant three-way interaction [Wilks' $\Lambda = 0.87$; $F(1,14) = 1.940$, $P = 0.185$; $\eta_p^2 = 0.12$]. No two-way interactions were found: location × time [Wilks' $\Lambda = 0.94$; $F(1,14) = 0.79$, $P = 0.388$; $\eta_p^2 = 0.054$], magnitude × time [Wilks' $\Lambda = 0.96$; $F(1,14) = 0.584$, $P = 0.457$; $\eta_p^2 = 0.04$], or magnitude × location [Wilks' $\Lambda = 0.974$;

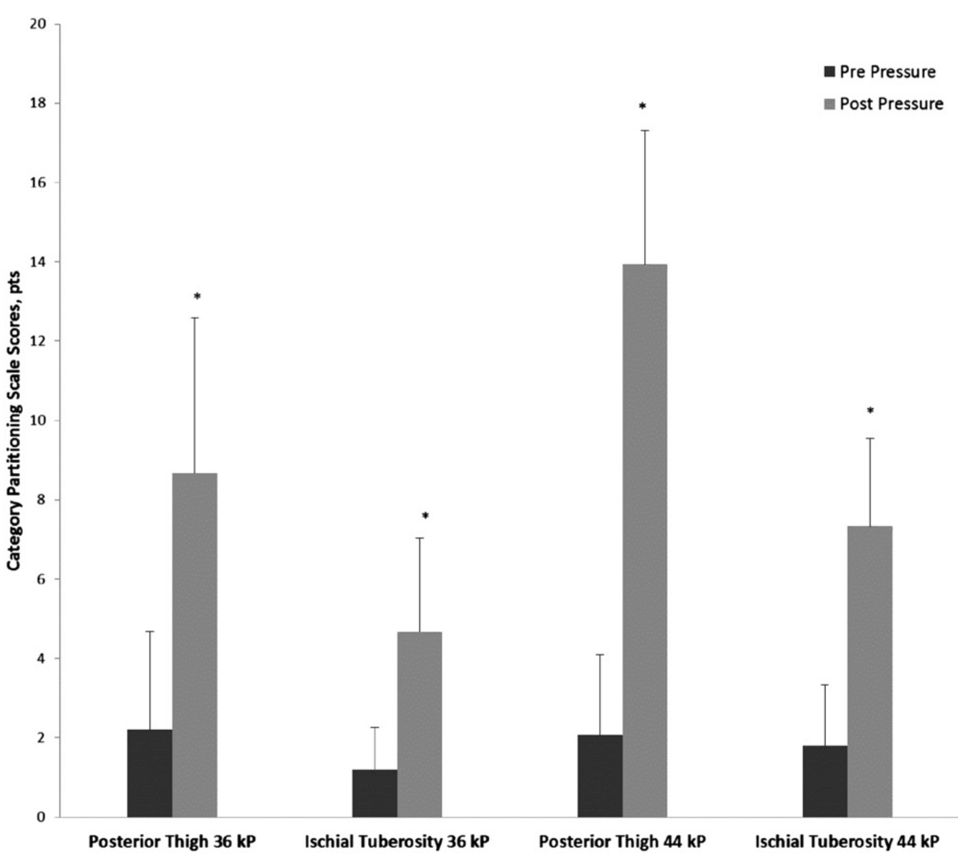

Fig. 2. Category Partitioning Scale scores indicating pain level across the four treatment conditions. kP: kilopascals; $*P < 0.05$; error bars represent 95% confidence interval.

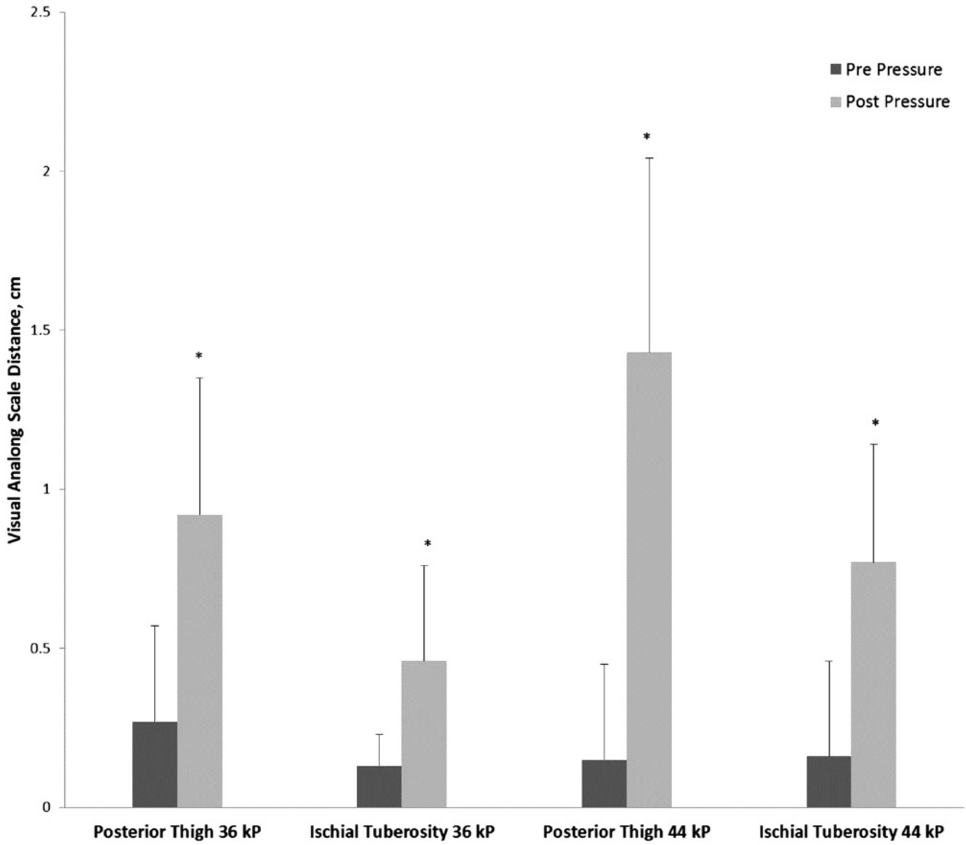

Fig. 3. Visual Analog Scale scores indicating pain level across the four treatment conditions. kP: kilopascals; cm: centimeters; *$P < 0.05$; error bars represent 95% confidence interval.

$F(1,14) = 0.37$, $P = 0.55$; $\eta_p^2 = 0.026$]. Additionally, no significant main effects were found for magnitude [Wilks' $\Lambda = 0.99$; $F(1,14) = 0.11$, $P = 0.740$; $\eta_p^2 = 0.008$], location [Wilks' $\Lambda = 0.89$; $F(1,14) = 1.66$, $P = 0.21$; $\eta_p^2 = 0.10$], or time [Wilks' $\Lambda = 0.81$; $F(1,14) = 3.25$, $P = 0.093$; $\eta_p^2 = 0.18$]. These data indicate that skin temperature at the lateral ankle does not change as a result of pressure application.

Percent oxygen saturation of the dominant foot great toe did not yield significant three-way or two-way interaction effects: magnitude × location × time [Wilks' $\Lambda = 0.93$; $F(1,14) = 1.03$, $P = 0.327$; $\eta_p^2 = 0.069$], location × time [Wilks' $\Lambda = 0.99$; $F(1,14) = 0.036$, $P = 0.852$; $\eta_p^2 = 0.003$], magnitude × time [Wilks' $\Lambda = 0.99$; $F(1,14) = 0.09$, $P = 0.758$; $\eta_p^2 = 0.007$], or magnitude × location [Wilks' $\Lambda = 0.85$; $F(1,14) = 2.52$, $P = 0.135$; $\eta_p^2 = 0.15$]. There were also no significant main effects of magnitude [Wilks' $\Lambda = 0.94$; $F(1,14) = 0.840$, $P = 0.375$; $\eta_p^2 = 0.057$], location [Wilks' $\Lambda = 0.95$; $F(1,14) = 0.76$, $P = 0.40$; $\eta_p^2 = 0.051$], or time [Wilks' $\Lambda = 0.98$; $F(1,14) = 0.27$, $P = 0.61$; $\eta_p^2 = 0.019$]. These data suggest that local pressure application to the posterior thigh or ischial tuberosity does not alter limb oxygen saturation when measured with pulse oximetry.

DISCUSSION

This study examined the effects of local pressure application applied at two locations (ischial tuberosity and the posterior thigh) and at two pressure magnitudes (36 and 44 kPa) on subjective discomfort scores, total limb blood oxygenation levels, and superficial skin temperature. This study revealed that local application of pressure on the sitting surfaces of the buttocks and posterior thigh increases subjective discomfort and increases superficial skin temperature at the anterior ankle.

CPS scores increased with all pressure application locations and magnitudes across 10 min of pressure application. Our data reveal that all pressure application conditions significantly increased discomfort when compared to baseline measures. Pressure applied to the posterior thigh at 36 kPa resulted in a statistically significant 5.5 point increase in discomfort, while pressure applied at 44 kPa to the posterior thigh significantly increased discomfort by 7.5 points. Similarly, pressure applied to the ischial tuberosity at a magnitude of 36 kPa increased discomfort by 3.1 points compared to baseline, while 44 kPa of pressure magnitude produced an increase of 4.2 points. Our data indicated that pressure application to the posterior thigh increases discomfort more than pressure application at the ischial tuberosity. Additionally, 44 kPa of pressure application elicited higher levels of discomfort compared to 36 kPa of pressure. This supports our hypothesis that greater magnitudes of force applied at the posterior thigh would result in greater discomfort compared to the ischial tuberosity. Our hypothesis is based on the underlying anatomy at both of the pressure application sites. The ischial tuberosities are bony prominences which are designed to bear weight during sitting. Whereas, pressure application to the posterior thigh could result in compression of nervous and vascular system tissues (the sciatic nerve and femoral vein, respectively). Previous work examined the effects of local pressure application on discomfort using 9 min of local pressure applied to the posterior thigh or ischial tuberosity at a magnitude of 28 kPa.[19] In that work, subject comfort was assessed using a 1-10 scale in which 10 represented "extremely comfortable" and 1 represented "pain and distress."[19] No significant differences were found between the posterior thigh pressure application condition scores (7.00) and the ischial tuberosity condition scores (7.80).[19] The present study found that pressure application location is an important factor in perceived discomfort. We suspect the differences between this study and previous work are a result of the higher pressure magnitudes applied to the test locations.

Subjective discomfort levels measured with the MPQ also demonstrated that local pressure application increases levels of subjective discomfort. The visual analog scale portion of the MPQ supports the hypothesis that local pressure application to the posterior thigh at higher pressure magnitude elicits greater discomfort. We found that 44 kPa of pressure applied to the posterior thigh resulted in a statistically significant 0.5 cm greater increase in reported discomfort compared to 36 kPa of pressure applied to the posterior thigh. The ischial tuberosity visual analog scale scores were 0.3 cm greater following 10 min of 44 kPa pressure application compared to 36 kPa of pressure application; however, these were not statistically different. The third portion of the MPQ, the present pain intensity score, supports that local pressure application to the ischial tuberosity and posterior thigh results in higher levels of perceived discomfort compared to baseline measures. Present pain intensity scores increased significantly with 36 kPa of pressure by 0.4 points when applied to the posterior thigh and increased significantly by 0.3 points when applied to the ischial tuberosity. Likewise, present pain intensity scores during 44 kPa of pressure application significantly increased by 1 point when applied to the posterior thigh and significantly increased by 0.53 points when applied to the ischial tuberosity. Together the MPQ data suggest that local pressure application at 36 and 44 kPa to the buttocks and posterior thigh increases subjective discomfort, and this increased discomfort may be greater when applied at the posterior thigh at 44 kPa of pressure, although this is inconclusive. Previous seating research using pressure mapping pads found "hot spots" of high pressure located under the ischial tuberosities.[3,8,13] In this project, we found that isolated local pressure application to the ischial tuberosity increased discomfort using multiple measures of subjective discomfort. This discomfort could interfere with mission success and task performance.

Superficial skin temperature measurements found that anterior ankle temperature increased during the 10 min of pressure application at all pressure magnitudes and locations. The temperature increased by 0.61°C across the 10-min pressure application time period and had a large effect size of 0.76. Previous work has shown that an increase of 0.5°C is clinically significant.[11] Superficial skin temperature has been shown to be a noncontact, indirect measure of skin blood perfusion.[11] These results suggest that skin blood flow is increased with local pressure application. We suspect that this increase in superficial skin blood flow was a result of decreased venous return due to decreased lower extremity muscle contractions and occlusion of the venous return from the periphery near the sitting surface of the body. The veins have a very low intravessel pressure (5-10 mmHg),[5] and we suspect that the extravenous pressure from sitting was large enough to occlude primary routes of venous return such as the femoral vein. Additionally, following 3-5 min of inactivity, the lower extremity veins are filled and serve as a reservoir for blood.[5] This would suggest that halfway through the 10-min pressure application session, the lower extremity venous system would be filled with warm arterial blood. The short 10-min testing period may not have allowed for adequate heat exchange between the warmed lower leg and the ambient air, resulting in the observed increase in temperature at the 10-min data collection time point. This is the first study to examine the effects of local pressure application on superficial skin temperature in a functional, seated position. We hypothesize that if we continued to measure superficial skin temperature, we would see a gradual decrease in skin temperature over time due to loss of heat between the skin's surface and the ambient air. Previous work has shown that with 4 h of prolonged restricted sitting in a Black Hawk helicopter seat, superficial skin temperature decreases significantly.[7] In this previous work, temperature was measured every 30 min, so no observations of the immediate effects of sitting on skin temperature are available. Future work should track the effects of local pressure application and recovery from local pressure application on superficial skin temperature to better understand changes occurring at the onset of pressure application and during the recovery from pressure application.

Our results suggest that that the reported discomfort and temporary paresthesia in the lower extremity are not due to areas of localized high seat interface pressure altering blood oxygenation levels. Pulse oximetry results revealed that oxygen saturation of the dominant limb of participants did not change as a result of local pressure application to the ischial tuberosity or posterior thigh. These data suggest that local pressure application does not alter limb oxygenation levels at the levels we tested in the current study. To our knowledge, this was the first study to examine changes in limb oxygenation levels during local pressure application to the posterior thigh or ischial tuberosity. Our results are in line with previous work assessing blood oxygenation levels during sitting.[7,13] In a study of 8 h of prolonged restricted sitting in an F-16 ejection seat, no significant change in gastrocnemius muscle oxygenation levels were found when measured by near infrared thermography.[13] Another study examining the effects of 4 h of restricted sitting in Black Hawk helicopter seats found no significant change in total limb oxygen saturation when measured with pulse oximetry.[7] These combined works suggest that that the reported discomfort and temporary paresthesia in the lower extremities are not due to areas of localized high seat interface pressure altering blood oxygenation levels. However, this interpretation has limitations. None of the existing research has used a model in which participants actively use their legs and feet to operate the antitorque pedals in a rotary-wing aircraft. Actively contracting muscle tissue requires nutrients and oxygen for steady, prolonged activities. Rotary-wing pilots must actively contract the lower extremity muscles during flight. If there is an occlusion of fresh blood due to areas of high pressure from prolonged sitting, it is possible that a decrease in oxygen saturation could occur. This diminished oxygen saturation could, in part, be responsible for the reported discomfort and paresthesia in Black Hawk helicopter pilots during prolonged flight. Future research should test this hypothesis by measuring oxygen saturation during a bout of prolonged restricted sitting and with local pressure application while participants complete activities similar to operating helicopter antitorque pedals.

Prolonged restricted sitting in rotary-wing aviators has been shown to increase discomfort and the symptoms of temporary paresthesia. One hypothesis as to the cause of this reported discomfort and temporary paresthesia is that areas of locally high pressure are created during prolonged sitting, which in turn compresses vascular and neurological structures. We tested this hypothesis by applying two magnitudes of pressure at two locations. We found that local application increases subjective discomfort and increases superficial skin temperature at the anterior ankle. These results support the hypothesis that locally high pressure creates symptoms of discomfort and paresthesia. However, research examining the effects of local pressure application on physiological and neurological function is needed. Moreover, work must be completed to determine if the changes observed in the present study lead to decreases in performance and therefore negatively affect mission efficacy.

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