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Micromovements and discomfort associated with flight mission with helmet operation tasks with different levels of cognitive workload☆

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ABSTRACT

When performing stationary tasks under elevated cognitive workload, individuals must perform continual muscle contractions to maintain stability of the body, resulting in fatigue of the postural muscles. When the muscles perform these contractions in a prolonged manner, the body potentially responds through small changes in body movements—micromovements that may lead to discomfort. The study purpose was to evaluate impact of cognitive load on micromovements. The micromovements were measured during three different cognitive workloads; low, medium, and high. The NASA-TLX score was used to evaluate the perceived mental workload and discomfort was assessed by visual analog scale. In total, 60 subjects (30 males and 30 females) were recruited and performed cognitive tasks that simulated flight operations such as changing the radio frequency based on air traffic control messages, balancing the fuel levels in simulated fuel tanks, and aiming a reticle in a designated moving target using the cyclic control. Cognitive load was defined by the frequency of events. Micromovements were defined by changes in the center of pressure (COP) of the seat pan and COP standard deviation. It was found that the high cognitive workloads had the highest NASA-TLX scores including mental demands, temporal demands, and effort. The neck area had the highest overall levels of discomfort followed by upper back. The highest standard deviation for COP shift and number of micromovements occurred for medium cognitive workloads. While there were some interesting trends, few trends reached a statistical significance due to high variability among subjects for the outcome variables.

1. Introduction

When performing stationary tasks such as sitting at a computer workstation or controlling an aircraft, the individual may perform continual and sustained muscle contractions to maintain the posture as well as complete cognitive tasks (McLean et al., 2001; Leyman et al., 2004; Au and Keir, 2007; Wang et al., 2011; Roman-Liu et al., 2013; Bloemsaat et al., 2005). One potential adaptation to compensate for sustained muscle contractions is performing micromovements during such prolonged static postures (Arippa et al., 2022, O'Sullivan et al., 2012). Micromovements during seated postures include small movements (fidgeting) of the trunk, neck, and upper extremities that require posture stabilizing muscles to increase exertions for short periods of time (O'Sullivan et al., 2012; Schneider et al., 2023). Significant muscle groups that experience micromovements include the cervical extensors, lumbar erector spine, upper trapezius, and wrist and finger extensors (McLean et al., 2001; Schneider et al., 2023). Increases in localized discomfort can potentially cause more micromovements through changes in posture (e.g. fidgeting or shifting of the body). For example, during a study of 32 participants conducting standing tasks, approximately 56% utilized micromovements to adjust the body, resulting in decreased discomfort (Gallagher and Callaghan, 2015). Small movements resulting from discomfort may have been a direct result from the sustained static postures.

Increased cognitive load has been found to increase muscle activity which can further exacerbate sustained muscle contractions in

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prolonged static tasks. According to a study conducted by Leyman and associates (2004), increased cognitive workload resulted in increased activity in the right trapezius (by 61%) as well as the lower cervical erector spine muscles (6%–11%). Other studies found increased cognitive workloads producing higher muscle responses and coactivity (Au and Keir, 2007; Biondi et al., 2021; Wang et al., 2011; Roman-Liu et al., 2013; Bloemsaat et al., 2005), indicating the potential for increased joint loading and micromovements.

A potential mechanism for micromovements may be discomfort that arises as the muscle fatigues from extended static postures. As prolonged postures continue to be sustained with elevated muscle activity, discomfort begins to set in as a result of the lactic acid accumulation and blood vessel compression (Anghel et al., 2007; Arippa et al., 2022, O'Sullivan et al., 2012). Gallagher and associates (2015) found that individuals who develop low back pain during prolonged standing fidgeted less (8–10 per 15 min) as compared to those who did not suffer pain (13 per min). These differences were particularly found in the first 30 min of prolonged standing (Gallagher and Callaghan, 2015). Microbreaks have been found to alleviate discomfort from increased muscle activity during prolonged static tasks (Strøm et al., 2009). In a sense, micromovements may be the body's way to induce microbreaks into the musculoskeletal system to combat discomfort.

The combination of posture and cognitive workload further exacerbates musculoskeletal discomfort and micromovements. Researchers (Baker et al., 2018, Gallagher and Callaghan, 2015; Arippa et al., 2022, O'Sullivan et al., 2012) have shown prolonged standing accompanied by increased levels of cognitive demand resulted in increased discomfort. Baker and associates (2018) also reported that individuals exposed to prolonged standing produced movements within the musculoskeletal system. Thus, dual demands on the individual may produce increased body responses and specifically micromovements.

The neck and upper back may be particularly susceptible to both micromovements and cognitive workloads, especially when wearing heavy helmets such as military aviators. The impact of a military aviator helmet was found to be high with respect to posture, muscle activation, and discomfort (Knight and Baber 2004). While the physical demands that result from wearing a helmet have been measured (Knight and Baber, 2004), the interaction between these physical demands with cognitive workloads is poorly understood. Davis and associates (2002) have shown that cognitive workloads produce a synergistic effect to physical demands. Le and associates (2021) also showed that visual stressors were associated with increased cognitive workload. The synergistic effect of both physical and cognitive workloads may have impact on micromovements.

The proposed study investigated how cognitive demands impacted micromovements and whether discomfort plays a role in the development of micromovements. The study objectives were: 1) determine the level of mental demand, physical demand, temporal demand, performance, effort, and frustration for the different cognitive workloads, 2) determine the impact of cognitive workload on micromovements and 3) determine the relationship between cognitive workload and body discomfort.

2. Methods

2.1. Overview

A laboratory simulation of an H-60 helicopter seat and controls was used to employ different flight tasks and was conducted in a single session. This simulation was not a flight simulation (e.g. flying the helicopter) but rather responding to task controls for helicopter pilots. The subjects performed different tasks in three cognitive workload settings: low, medium, and high. All participants wore the same helmet for all workload tasks to investigate the interaction of physical demands with the cognitive workload conditions. Participants completed a practice session prior to actual collection to allow familiarity with each of the three workload settings. During these tasks, micromovements of the body were measured through pressure mapping at the seat. After the completion of each task, subjects completed a NASA-TLX and VAS discomfort survey. A within-subjects design was utilized to control for differences in body-size and other subject-specific factors. The protocol and consent process were reviewed by NAMRU-D's Institutional Review Board (primary) and University of Cincinnati's Institutional Review Board (secondary).

2.2. Participants

Sixty (30 males and 30 females) participants were recruited from Wright-Patterson Air Force Base and the surrounding area to participate in a study to investigate cervical spine loading as a function of cognitive workload defined by the combination of tasks commonly seen in helicopter flight (i.e., tracking, communications, resource management). The participants were between the ages of 19–48 years. Only two participants had flying experience but none of the subjects had specific experience in tasks utilized in the 3 cognitive tasks. Of the two that had flying experience, one was a former military helicopter pilot, now commercial airline pilot and the second had approximately 100 flight hours with visual flight rules. Prior to the study, a screening survey was completed to ensure no existence of confounding conditions, including neck pain within previous 6 months and previous surgeries. This survey also determined if a subject was able to sit in a static position for prolonged time. A complete summary of the anthropometry of the subjects is in Table 1.

2.3. Study design

There was one ***independent variable*** for this study: cognitive workload level. The cognitive workload had three levels: low, medium, and high. The different cognitive workloads were achieved by changing the complexity and frequency of the simulated flight tasks using Modifiable Multitasking Environment (modME) software (Blaha et al., 2018). The basic task was a cockpit mock-up of an H-60 helicopter complete with rudder pedals, a cyclic, collective, knee-board keypad, and a display screen resembling the setup of cockpit gauges (Fig. 1). All modME tasks consisted of tracking, communication, resource management, and vigilance (Blaha et al., 2018). Workload was modulated by adjusting the frequency of the tasks. Tracking consisted of using the cyclic control to position a reticle in a red circle and clicking on the red circle so that it

Table 1
Summary of the anthropometry for the participants.

Anthropometric Characteristics	Average (Standard Deviation)
Gender	Male: 30 Female: 30
Preferred Handedness	Right: 55 Left: 5
Helmet Size	Small: 10 Medium: 31 Large: 13 Extra-Large: 6
Age	30.7 years (8.4)
Body Weight	78.5 kg (16.8)
Standing Height	171.6 cm (8.8)
Shoulder Height	140.1 cm (16.5)
Leg Height	91.5 cm (5.2)
Arm Length	70.7 cm (5.2)
Hand Length	19.0 cm (1.5)
Waist Depth	21.6 cm (3.7)
Waist Breadth	29.1 cm (4.2)
Waist Circumference	85.8 cm (13.5)
Head Depth	19.2 cm (1.1)
Head Breadth	15.3 cm (0.8)
Head Circumference	56.4 cm (2.6)
Neck Circumference	36.2 cm (5.1)

Fig. 1. Picture of H-60 cockpit setup.

turned green. When the target circle turned green, the software registered this as an accomplished task, and the user had to follow the circle using the cyclic control until a different circle turned red. Communication consisted of changing the frequency to a designated level when directed by a recorded radio transmission. The subject only needed to change the frequency when the recorded radio transmission gave the designated call sign assigned to that subject. Resource management involved balancing the simulated fuel tanks. This involved pressing certain keys on keyboard that was strapped to the subject's leg. In order to balance the amount of fuel in the fuel tanks, the subjects had to activate fuel pumps between various fuel tanks. The balancing of the fuel tanks occurred when the fuel level was between set amounts (Fig. 2). While the primary task across all settings was tracking with cyclic control, the frequency of discrete events increased with workload assignment. Discrete events included communications (radio frequency change), vigilance, and resource management (fuel tanks).

The ***dependent variables*** were cognitive workload condition, discomfort, and body micromovements. The NASA-TLX rates the perceived cognitive workload of a task based on the following subscales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration (Hart and Staveland, 1988; Noyes and Bruneau, 2007). While sub-scales have been utilized to analyze various tasks, the sum of all sub-scales provides an overall demand scale (Galy et al., 2018). Others have shown the NASA-TLX measures to be viable metrics for demands in simulations (Harris et al., 2020). Body discomfort was assessed by an 11-point Visual Analog Scale (VAS) (0-none, 10-unbearable) for each body region (neck, shoulders, lower back, upper back, hands, and wrists) was completed immediately after each task completion (Arendt-Nielsen et al., 2011; Ritter et al., 2006). The VAS has been found to correlate strongly with other pain and discomfort scales and measures (Ohnhaus and Adler, 1975; Thong et al., 2018).

Micromovements of the whole body were measured using pressure between the body and the seat. The Center of Pressure (COP) was measured by the XSENSOR pad and pressure monitoring software (XSENSOR Technology Corporation, Calgary, AB, Canada). The tracking of the COP allowed for the distance in the medial-lateral (M-L), anterior-posterior (A-P), and resultant (RES) directions to be quantified. Four summary metrics were calculated from the COP tracing data: 1) standard deviation (SD) of M-L ($SD_{M\text{-}L}$), 2) SD of A-P ($SD_{A\text{-}P}$), 3) SD of RES (SD_{RES}), and 4) number of occurrences of a change in COP_{RES}. The COP_{RES} was calculated by determining the resultant distance for $COP_{M\text{-}L}$ and $COP_{A\text{-}P}$, allowing standard deviation to be calculated. The number of occurrences of a change in COP_{RES} was determined by identifying any change of 1 mm over the entire trial, which indicates how often shifts in the body occurred.

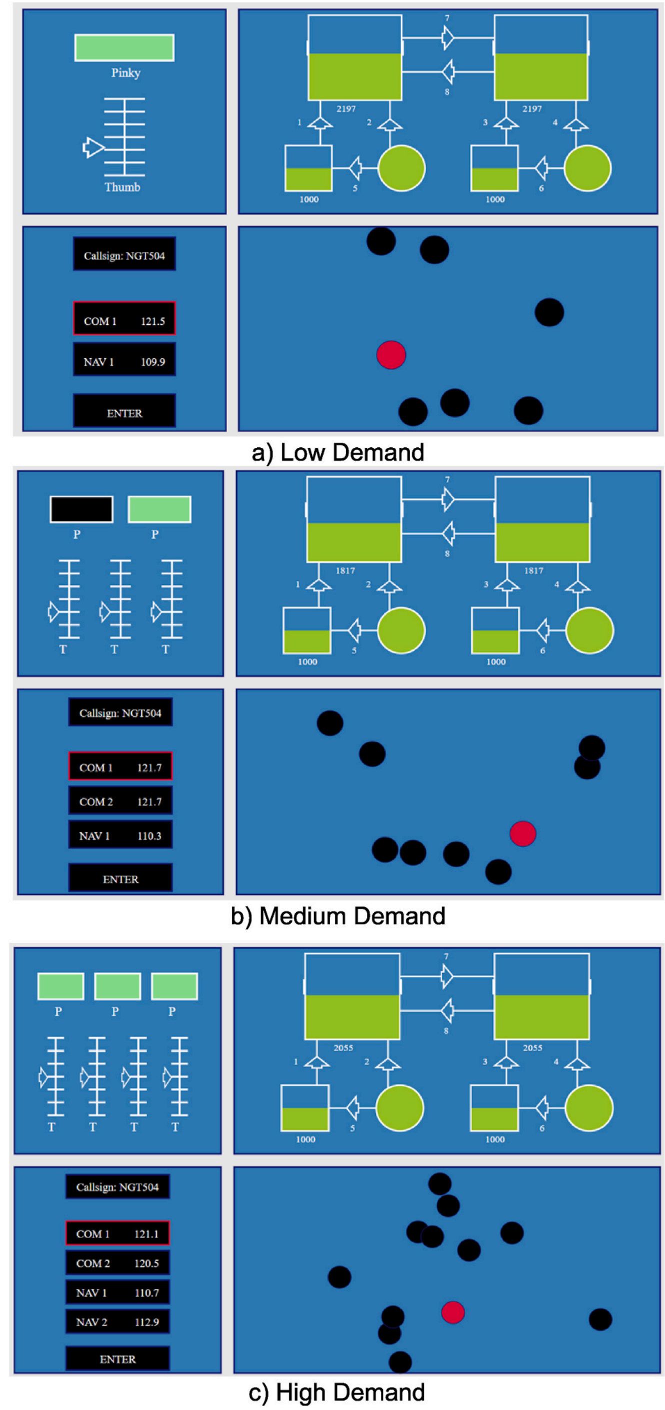

Fig. 2. Examples of the modME task (a) low demand, b) medium demand, and c) high demand). Top left vigilance (press pinky button if changes color, press thumb button if arrow deviates two marks from the middle), top right resource management, bottom left communications (change radio frequency if call sign and com is requested), bottom right, when circle turns green, click on and track dot. Difficulty was also scaled by the frequency of interstimuli.

2.4. Study procedures

Before data collection occurred for each subject, COVID-19 precautions were undertaken. The first precaution was to conduct temperature checks and COVID-19 screening for the subject. The wearing of a mask was enforced for both the subject and researchers during the entire time in the laboratory. An air purifier was located in the room and verified to be active before the research proceeded. Next, the consent process was completed where the subject read the consent form and signed it to establish consent. Subjects then completed a survey to identify potential confounders and exclusion criterion. The VAS was used to assess the baseline discomfort in the specific body regions (Arendt-Nielsen et al., 2011; Ritter et al., 2006; Thong et al., 2018). Then, anthropometric data were collected from each subject.

Prior to data collection, the participant practiced with each of the conditions without a helmet on until each felt comfortable with the conditions. Next, a researcher oriented the XSENSOR pads and system appropriately on the chair and calibrated the system. Live alignment was also completed to verify anchor points through compression on the pad. Pressure mapping data were continuously collected throughout a session at a rate of 30 Hz.

To start the study, subjects completed the first of the three conditions. Each condition lasted 1 h. For Low/Medium/High, there was an average interstimulus time for monitoring: 82.5s/20s/11s, tracking: 82.5s/60s/27.5s, communications: 90s/67.5s/45s, and resource management: 270s/45s/20s. Frequency of events were tuned with the intent to have a clear delineation between task difficulty. The complexity was confirmed by the Baud rate, which is a measure of difficulty from Phillips et al., (2007). Note that this study was not about the design of cognitive workload, but more focused on the systemic effects from workload (i.e., movements/discomfort). The order of the cognitive workloads was randomized (counterbalanced across all of the subjects) with all 60 subjects being randomly assigned one of the counter-balanced sequences. Participants were assigned as they enrolled in study (gender was not taken into account). After each cognitive workload was completed, the subject completed the assessment for NASA-TLX and VAS discomfort. All participants used the cyclic in their right hand and number pad with the left hand, regardless of their preferred handedness. These were used to control tasks in the simulation. There was a 20-min break period where the participant was out of the seat and encouraged to move around to mitigate fatigue from seating. Extensive piloting determined that the 20-min break was sufficient to protect from fatigue. The subject repeated this sequence for the other two conditions. The sensors were then removed and the subject was released.

2.5. Statistical analysis

SAS statistical software (SAS, Inc. Cary, NC) was used to run repeated-measures, within subject analysis of variance (ANOVA) for each of the dependent variable. A significance level of 0.05 was utilized. Post-hoc studentized Tukey t-tests to determine whether significant effects exist for $SD_{M\text{-}L}$, $SD_{A\text{-}P}$, SD_{RES}, number of occurrences of change in COP_{RES}, discomfort level ratings, and work demands based on NASA-TLX.

3. Results

Statistical analyses revealed significant differences in cognitive workloads (at $p < 0.05$), including NASA-TLX's mental level ($p = 0.0001$, $F = 23.67$), temporal level ($p = 0.0001$, $F = 14.53$), effort level ($p = 0.0001$, $F = 14.75$), and total ($p = 0.0001$, $F = 21.59$). Additionally, significant differences were found in discomfort rating of the upper back ($p = 0.05$, $F = 3.37$) and neck ($p = 0.03$, $F = 3.75$). While no significant trends were found for the remaining micromovement outcomes and discomfort, some trends appear to be present.

As expected, the TLX mental level increased by 28% from low to medium cognitive workloads and 21% from medium to high cognitive workloads. An increasing trend was also seen for TLX temporal, effort, and frustration levels (26%, 23%, and 16% for low to medium, 23%, 14%, and 15% for medium to high, respectively) (see Fig. 3). No trends were seen for TLX physical demands and performance. As a result, the TLX total score trended to increase with increased cognitive workloads with an 18% increase from low to medium cognitive workloads and 15% from medium to high cognitive workloads (see Fig. 4).

Many of the body regions showed an increasing trend in discomfort with increased cognitive workloads but only neck and upper back, were significant (see Fig. 5). Several body regions had virtually no discomfort for any of the cognitive workloads (abdomen, chest, elbow, and knee), which can be indicative of the seated posture which did not place significant stress on these body areas. Overall, many of the subjects did not have discomfort in many of the specific body areas and pain was relatively low.

The standard deviation of $COP_{A\text{-}P}$ and $COP_{M\text{-}L}$ was similar for all cognitive workloads, around 0.45 cm ($p = 0.79$, $F = 0.24$) and 0.32 cm ($p = 0.29$, $F = 1.25$), respectively (Fig. 6). The COP_{RES} also was found to have no difference between the cognitive workloads ($p = 0.76$, $F = 0.27$) (Fig. 6). The number of micromovements was greatest for the medium cognitive demand conditions (around 270), followed by high cognitive workloads (around 235) and low cognitive workloads (around 187) (although not significant at $p = 0.25$, $F = 1.37$) (see Fig. 7).

Although not a factor of interest in current study, gender was significant for multiple outcome variables including $SD_{M\text{-}L}$ ($p = 0.0003$, $F = 13.94$), TLX physical level ($p = 0.0001$, $F = 53.91$), TLX temporal level ($p = 0.0001$, $F = 18.85$), TLX effort level ($p = 0.0001$, $F = 30.56$), TLX frustration level ($p = 0.0001$, $F = 20.78$), and TLX Total ($p = 0.0001$, $F = 8.34$) as well as discomfort for abdomen ($p = 0.0001$, $F = 19.57$), buttock ($p = 0.04$, $F = 4.3$), shoulder ($p = 0.0001$, $F = 22.0$), upper arm ($p = 0.0001$, $F = 21.98$), and wrist/hand ($p = 0.0001$, $F = 18.13$). No significant gender-cognitive demand interactions were found ($p > 0.10$). Males were found to have greater $SD_{M\text{-}L}$ (0.42 cm vs.0.26 cm), TLX physical level (5.91 vs. 3.46), and discomfort for buttock (0.62 vs. 0.39) and wrist/hand (0.78 vs. 0.40). Females had greater TLX temporal level (9.91 vs. 7.29), TLX effort level (11.33 vs. 8.54), TLX frustration level (4.03 vs. 2.69), TLX Total (49.13 vs. 43.92) as well as discomfort in the abdomen (0.17 vs. 0.00), shoulders (0.61 vs. 0.32), and upper arm (0.33 vs. 0.12).

4. Discussion

In many cases, the trends were found not to be statistically significant (at $\alpha = 0.05$). It was apparent that how individuals responded during the cognitive workloads varied among subjects. Fig. 8 provides a summary of how the number of micromovements per each cognitive workload changed across the subjects. The medium cognitive workload resulted in the highest micromovements for 25 of the 60 subjects while low and high cognitive workloads were highest in 11 and 21 subjects, respectively. Two subjects had issues with the pressure map for the high cognitive workload so they only have two conditions. The high cognitive workload had the second most micromovements for 20 subjects with low and medium having 24 and 16, respectively. Finally, low cognitive workloads had the lowest number of micromovements for 24 subjects while medium and high demands had 19 and 17, respectively. In all, it appeared that the cognitive workloads impacted people differently with respect to micromovements. One potential interpersonal factor that may have some impact on the how cognitive workloads influences micromovements may be personality. Others have shown personality to significantly impact response to cognitive demand tasks and stress (Marras et al., 2000; Davis et al., 2002). These studies showed that certain personality traits impacted how a person responded with different types of cognitive workloads. Future analyses will investigate the impact of personality in a similar testing environment.

One additional factor that may have had impact into the subject specific variability was gender as males and females had different responses with respect to cognitive demand perceptions,

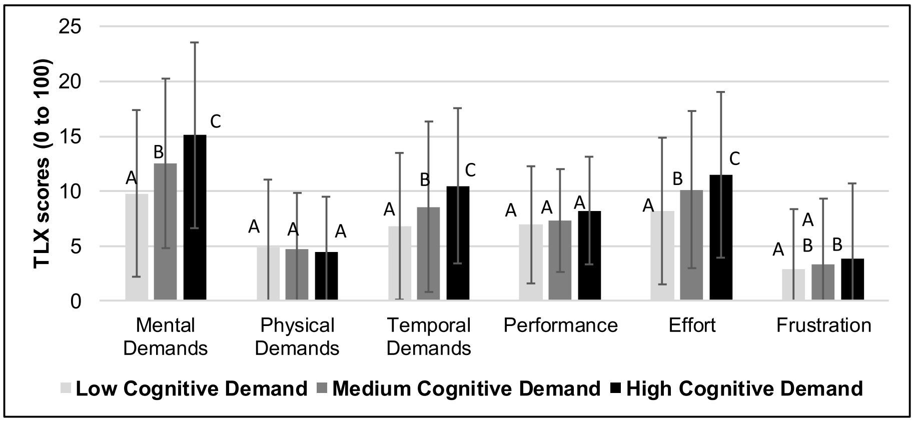

Fig. 3. Average Ratings for the Six Dimensions of the NASA-TLX Assessment (Cognitive workloads, Physical Demands, Temporal Demands, Performance, Effort, and Frustration) as a Function of the Cognitive Demand Conditions (Low, Medium, and High). Error bars represent standard deviations. Different alpha characters indicate post-hoc significant difference.

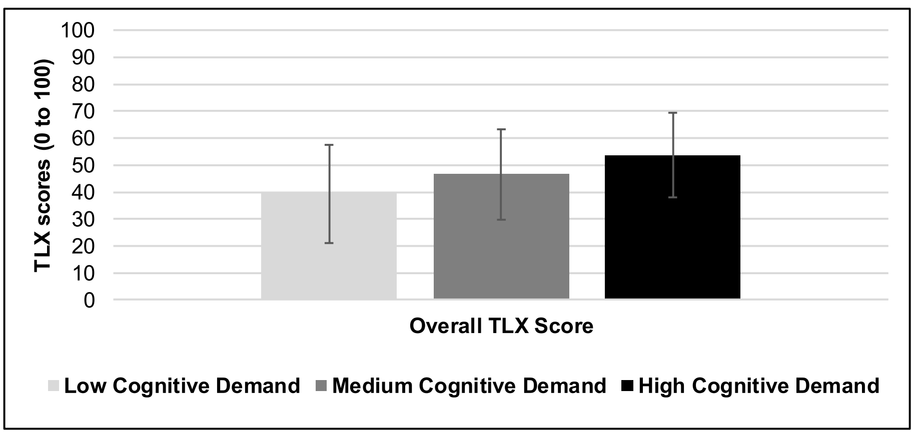

Fig. 4. Average Ratings for the Overall NASA-TLX Score as a Function of the Cognitive Demand Conditions (Low, Medium, and High). Error bars represent standard deviations. Different alpha characters indicate post-hoc significant difference.

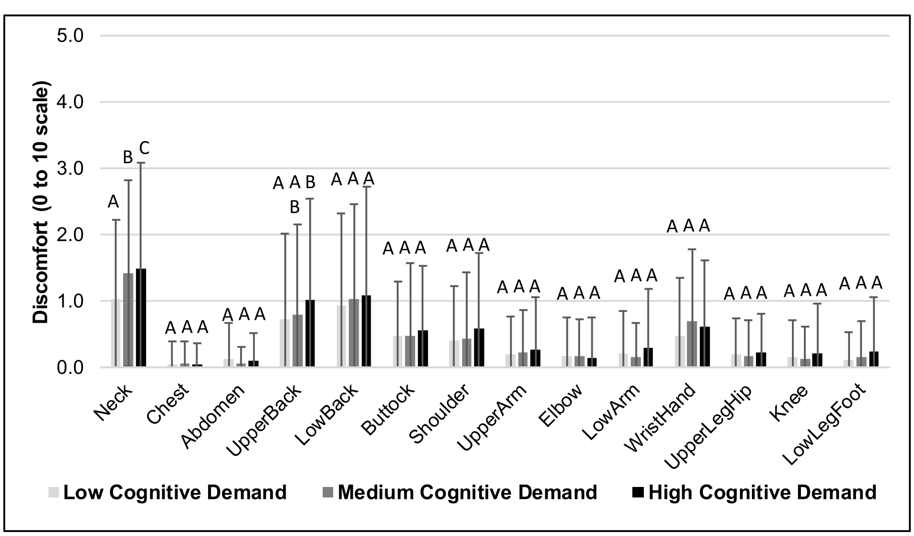

Fig. 5. Average Ratings for the Discomfort in the Body Parts (Neck, Abdomen, Upper Back, Lower Back, Buttock, Shoulder, Upper Arm, Hand and Wrist, and Upper Leg and Hip) as a Function of the Cognitive Demand Conditions (Low, Medium, and High). Error bars represent standard deviations. Different alpha characters indicate post-hoc significant difference.

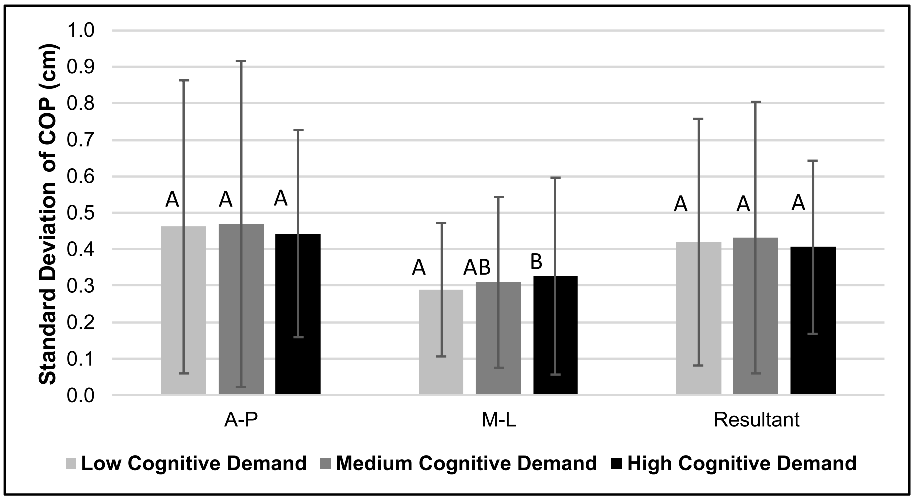

Fig. 6. Average Standard Deviation of the Components and Resultant of Center of Pressure (COP) as a Function of the Cognitive Demand Conditions (Low, Medium, and High). Error bars represent standard deviations. Different alpha characters indicate post-hoc significant difference.

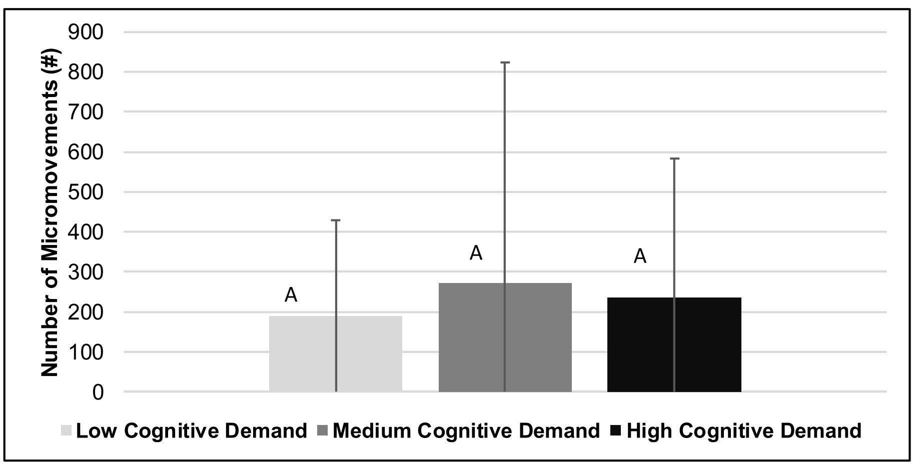

Fig. 7. Average Number of Micromovements due to Whole Body Motion as a Function of the Cognitive Demand Conditions (Low, Medium, and High). Error bars represent standard deviations. Different alpha characters indicate post-hoc significant difference.

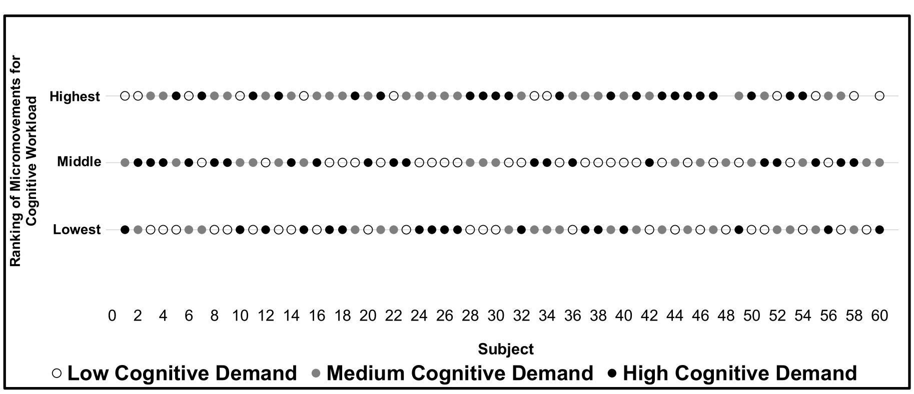

Fig. 8. Ranking by Subject of the Number of Micromovements for the Cognitive workloads (Low (1), Medium (2), High (3)).

micromovements, and discomfort. Males appeared to been taxed more physically that resulted in more discomfort in buttocks and hand/wrists. As a result, males had more variability in the COP in the anterior-posterior direction, potentially indicating more shifting front to back in the seat. For females, effort levels and frustration were higher along with discomfort in the shoulders, abdomen, and upper arm. Again, these perceptions of effort and discomfort may have resulted in some of the large variability in micromovements and deviation in COP across the female subjects. This points to a complex system that is responding to the different cognitive demands.

Further, fatigue in the body musculature may also be a factor in the subject-to-subject variability as there was a trend of increasing micromovements with the order of the conditions completed (independent of level of demands). The last condition completed had the largest $SD_{RES} = 0.47$ cm as well as the largest number of micromovements (299) while the first condition completed had $SD_{RES} = 0.38$ cm and 180 micromovements respectively. The second cognitive workload resulted in $SD_{RES} = 0.41$ cm, and number of micromovements (216) which were lower or in the middle of the other two conditions. Both of these factors (personality and fatigue) could contribute to the large variability among the subjects that led to the lack of statistical significance in the micromovement outcomes. Future work will need to explore these factors more which will require more subjects for personality and additional monitoring of fatigue outcomes (e.g. muscle oxygenation, electromyographical spectral shifts).

The trends in micromovements provide some evidence that the pilots may use small body changes to adjust to the long periods of physical static demands and resulting discomfort that accompany pilots when flying helicopters. Multiple studies reported that a majority of participants produced micromovements in response to discomfort from static postures (Gallagher and Callaghan, 2015; Arippa et al., 2022, O'Sullivan et al., 2012). Baker and associates (2018) also reported more micromovements as the dual demands increased. In all, the current study provided some evidence that people may change their body through micromovements in response to dual demands but appears that the relationship is complex.

Cognitive workload and performance tend to follow a J-curve where performance is best in medium demand conditions and worse when demands are low or high (Young et al., 2015). The micromovement responses may also be a result of this complex relationship with workload. At low workload, their movements could be lowered due to general disengagement and boredom resulting in less musculoskeletal tension, less discomfort, and less need for micromovements. At the medium workload level, participants are more likely optimizing with active engagement that contributes to muscular tension and discomfort, which results in highest micromovements. In the highest workload level, the participants may be super stressed, resulting in active muscular tension and discomfort. In this overloaded state, they may tense their entire body, reducing the capability respond (e.g. forgot or can't) through micromovements leading to more discomfort. The NASA-TLX indicated that the cognitive workloads increased with the expected cognitive demands of the conditions. While the explanation provides a theoretical pathway that links workload to micromovements to discomfort, this research provides only initial evidence of the complex system.

The physical load of a helmet on an aviator, particularly in the neck and upper back, was found to be high due to high levels of muscle co-contraction (Knight and Baber, 2004). It was evident that the conditions resulted in elevated perceived physical demands as indicated by NASA-TLX physical demand index, particularly for male who had significantly more than females (5.9 vs 3.5). These loads can further be increased due to the inclusion of cognitive demand tasks with physical demands (Davis et al., 2002). The combination of cognitive workloads (simulated helicopter control) and physical demands (wearing of heavy helmet) appears to impact adversely the pilots through multiple mechanisms but on a more individual basis. Other researchers (Mclean et al., 2001; Leyman et al., 2004; Au and Keir, 2007; Wang et al., 2011; Roman-Liu et al., 2013; Biondi et al., 2021; Bloemsaat et al., 2005) have reported increased muscle activation as dual demands increased. According to one study by Le and Marras, discomfort levels were highest during performing tasks that were standing while sitting tasks produced the lowest discomfort levels (Le and Marras, 2016). Thus, these results cannot be extrapolated to prolonged standing-based tasks and future work should consider these differences in task and posture.

The dual demands of wearing a helmet and simulated helicopter flying may directly impact the discomfort in the neck, upper back, and shoulder at the end of each cognitive workload condition. Part of the discomfort may result from prolonged non-neutral static postures of the neck with increased muscle activation to support the load of the helmet, in addition to cognitive demand levels (Anghel et al., 2007; Baker et al., 2018, Gallagher and Callaghan, 2015). A study by Le and associates also found that head-supported mass, non-neutral head posture, and cognitive and visual stress were part of a complex relationship influencing muscle activation patterns of the neck (Le et al., 2021). A deeper dive into the relationship between dual demands and discomfort needs to be further investigated.

Another factor that may contribute to discomfort is blood oxygenation to different body regions. For example, a study by Le and associates found that during seating, taller subjects with lower blood oxygenation in the hamstrings tended to report discomfort in the buttock region (Le et al., 2014). Therefore, evaluating blood oxygenation based on height might provide further data on discomfort levels.

The subjective assessment of the cognitive workloads through the NASA-TLX revealed that the cognitive workloads and effort were found to have a significant increasing trend from low to medium to high cognitive workloads, which resulted in a significant increasing trend in the overall TLX score. Thus, the selected cognitive workloads provided the targeted demands on the subjects, at least based on perception.

There are several limitations to consider when interpreting the results of the study. First, there was a lack of significance due to the large variability among the micromovement outcomes, particularly between subjects. While this may not be an inherent limitation, the large unaccounted variability does influence the conclusions drawn. More subjects may allow for better understanding of factors such as personality and individual fatigue responses. Other factors that are inherent to the subjects such as anthropometry may also impact the variability and micromovement responses, cognitive capacity, and physiological response. Second, the study was conducted under static simulated aviation conditions in a mock H-60 cockpit. The demands on a helicopter pilot are likely to be different from the simulation as the cockpit area was missing several features to be found in an operational aircraft (e.g., collective control, mobile rudder pedals). Moving the rudder pedals and collective control would produce more variability due to additional movements, which would likely influence the results. Further, the use of a keypad on the thigh to simulate a pilot's knee-board information pad/tablet reduced potential confounding factors associated with Fitts law, otherwise, the participants would have moved their extremities to execute the task, resulting in body changes that would look like an actual movement. This was particularly clear in a previous study, in which, texting was compared to other distractions that did not involve gross movements (Le et al., 2015). Texting required more gross movements due to postural changes, which showed up in the center of pressure data. Hence, everything was designed to keep input devices as close to the person as possible to mitigate gross movements that would confound micromovement data. Further, while the simulated cognitive demand tasks achieved the targeted demands, some of the physical demands may be higher in a real-world cockpit. Third, micromovements were measured by gross movements that translated to pressure on the seat mat. Additional data were collected about the movements and postures of the body using motion capture that will allow for further delineation of the micromovements. Future work will need to investigate how micromovements in the different body parts (e.g. neck, back, upper extremities, etc.) influences the pressure under the torso at the seat.

There several strengths of the methodology that was used in the current study. First, the study looked at cognitive workload with realistic tasks that provided different levels of cognitive processing. Second, the study investigated the role of cognitive load in combination under a traditional physical load (e.g. wearing a helmet). Third, utilized both subjective and objective measures of mental and physical responses to the cognitive workload conditions. Finally, the study evaluated a relatively large subject pool including 30 males and 30 females.

5. Conclusion

This study provided insight into how static postures with different cognitive workloads impact the body's response during tasks simulating helicopter flight operations. The medium cognitive demand conditions produced the highest number of micromovements while low cognitive demand conditions produced the lowest number of micromovements, similar to the high cognitive demand conditions, but effects were not significant due to high variability between subjects. The medium cognitive demand condition resulted in the highest overall standard deviation of $COP_{A\text{-}P}$ and COP_{RES}, confirming the results of the number of micromovements. There was an increasing trend in discomfort with increasing cognitive workloads for the neck and upper back. Similarly, there were increasing trends with increased cognitive workloads for the NASA-TLX scores of cognitive workloads, temporal demands, effort, and total score. In all, there appears to be a complex relationship between cognitive workloads, static postures, discomfort, and resulting micromovements of the body. While these trends provide an interesting insight into the complexity of the helicopter pilot's environment, most of the trends were not statistically significant. Future work will need to continue to explore these complex interactions between cognitive and physical demands of helicopter pilots.

Author statement

Nathan Frank collected, analyzed, and wrote the paper as part of his thesis.

Emily Mills was involved in the data collection and analyses, and lead the data collection team at NAMRU.

Peter Le was the main researcher that lead the overall project, developed the overall project and obtained funding. He oversaw the data collection and main team efforts.

Kermit Davis was the mentor and advisor for Nathan and oversaw the writing, analysis, and overall thesis development.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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References

Anghel, M., Argeanu, V., Talpo, C., Lungeanu, D., 2007. Músculoskeletal disorders (MSDS) consequences of prolonged static postures. J Exper Med Surg Res 4, 167–172.

Arendt-Nielsen, L., Fernández-de-Las-Peñas, C., Graven-Nielsen, T., 2011. Basic aspects of musculoskeletal pain: from acute to chronic pain. J. Man. Manip. Ther. 19 (4), 186–193.

Arippa, F., Nguyen, A., Pau, M., Harris-Adamson, C., 2022. Postural strategies among office workers during a prolonged sitting bout. Appl. Ergon. 102, 103723.

Au, A.K., Keir, P.J., 2007. Interfering effects of multitasking on muscle activity in the upper extremity. J. Electromyogr. Kinesiol. 17 (5), 578–586.

Baker, R., Coenen, P., Howie, E., Williamson, A., Straker, L., 2018. The short term musculoskeletal and cognitive effects of prolonged sitting during office computer work. Int. J. Environ. Res. Publ. Health 15 (8), 1678.

Biondi, F.N., Cacanindin, A., Douglas, C., Cort, J., 2021. Overloaded and at work: Investigating the effect of cognitive workload on assembly task performance. Hum. Factors 63 (5), 813–820.

Blaha, L.M., Carlsen, L., Halverson, T., Reynolds, B., 2018. Interfacing the modifiable multitasking environment with ACT-R for computational cognitive modeling of complex tasks. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Sage CA: Los Angeles, CA: SAGE Publications 62 (1), 316–320.

Bloemsaat, J.G., Meulenbroek, R.G., Van Galen, G.P., 2005. Differential effects of mental load on proximal and distal arm muscle activity. Exp. Brain Res. 167 (4), 622–634.

Davis, K.G., Marras, W.S., Heaney, C.A., Waters, T.R., Gupta, P., 2002. The impact of mental processing and pacing on spine loading. Spine 27 (23), 2645–2653.

Gallagher, K.M., Callaghan, J.P., 2015. Early static standing is associated with prolonged standing induced low back pain. Hum. Mov. Sci. 44, 111–121.

Galy, E., Paxion, J., Berthelon, C., 2018. Measuring mental workload with the NASA-TLX needs to examine each dimension rather than relying on the global score: an example with driving. Ergonomics 61 (4), 517–527.

Harris, D., Wilson, M., Vine, S., 2020. Development and validation of a simulation workload measure: the simulation task load index (SIM-TLX). Virtual Real. 24 (4), 557–566.

Hart, S.G., Staveland, L.E., 1988. Development of NASA-TLX (task load index): results of empirical and theoretical research. In: Hancock, P.A., Meshkati, N. (Eds.), Human Mental Workload. North Holland Press, Amsterdam.

Knight, J.F., Baber, C., 2004. Neck muscle activity and perceived pain and discomfort due to variations of head load and posture. Aviat Space Environ. Med. 75 (2), 123–131.

Le, P., Marras, W.S., 2016. Evaluating the low biomechanics of three different office workstations: seated, standing, and perching. Appl. Ergon. 56, 170–178.

Le, P., Rose, J., Knapik, G., Marras, W.S., 2014. Objective classification of vehicle seat discomfort. Ergonomics 57 (4), 536–544.

Le, P., Hwang, J., Grawe, S., Li, J., Snyder, A., Lee, C., Marras, W.S., 2015. Biomechanical Patterns of Text-Message Distraction. Ergonomics, pp. 1–11.

Le, P., Weisenbach, C.A., Mills, E.H.L., Monforton, L., Kinney, M.J., 2021. Exploring the Interaction between Head-Supported Mass, Posture, and Visual Stress on Neck Muscle Activation. Human Factors, 00187208211019154.

Leyman, E.L., Mirka, G.A., Kaber, D.B., Sommerich, C.M., 2004. Cervicobrachial muscle response to cognitive load in a dual-task scenario. Ergonomics 47 (6), 625–645.

Marras, W.S., Davis, K.G., Heaney, C.A., Maronitis, A.B., Allread, W.G., 2000. The influence of psychosocial stress, gender, and personality on mechanical loading of the lumbar spine. Spine 25 (23), 3045–3054.

McLean, L., Tingley, M., Scott, R.N., Rickards, J., 2001. Computer terminal work and the benefit of microbreaks. Appl. Ergon. 32 (3), 225–237.

Noyes, J.M., Bruneau, D.P., 2007. A self-analysis of the NASA-TLX workload measure. Ergonomics 50 (4), 514–519.

O'Sullivan, K., O'Keeffe, M., O'Sullivan, L., O'Sullivan, P., Dankaerts, W., 2012. The effect of dynamic sitting on the prevention and management of low back pain and low back discomfort: a systematic review. Ergonomics 55 (8), 898–908.

Ohnhaus, E.E., Adler, R., 1975. Methodological problems in the measurement of pain: a comparison between the verbal rating scale and the visual analogue scale. Pain 1 (4), 379–384. . 1.

Phillips, C.A., Repperger, D.W., Kinsler, R., Bharwani, G., Kender, D., 2007. A quantitative model of the human–machine interaction and multi-task performance: a strategy function and the unity model paradigm. Comput. Biol. Med. 37 (9), 1259–1271.

Ritter, P.L., González, V.M., Laurent, D.D., Lorig, K.R., 2006. Measurement of pain using the visual numeric scale. J. Rheumatol. 33 (3), 574–580.

Roman-Liu, D., Grabarek, I., Bartuzi, P., Choromański, W., 2013. The influence of mental load on muscle tension. Ergonomics 56 (7), 1125–1133.

Schneider, L., Sogemeier, D., Weber, D., Jaitner, T., 2023. Effects of a seat-integrated mobilization system on long-haul truck drivers motion activity, muscle stiffness and discomfort during a 4.5-h simulated driving task. Appl. Ergon. 106, 103889.

Strøm, V., Knardahl, S., Stanghelle, J.K., Røe, C., 2009. Pain induced by a single simulated office-work session: time course and association with muscle blood flux and muscle activity. Eur. J. Pain 13 (8), 843–852.

Thong, I.S., Jensen, M.P., Miró, J., Tan, G., 2018. The validity of pain intensity measures: what do the NRS, VAS, VRS, and FPS-R measure?, 1 Scandinavian Journal of Pain 18 (1), 99–107.

Wang, Y., Szeto, G.P., Chan, C.C., 2011. Effects of physical and mental task demands on cervical and upper limb muscle activity and physiological responses during computer tasks and recovery periods. Eur. J. Appl. Physiol. 111 (11), 2791.

Young, M.S., Brookhuis, K.A., Wickens, C.D., Hancock, P.A., 2015. State of science: mental workload in ergonomics. Ergonomics 58 (1), 1–17.