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An assessment of unmanned aircraft system pilot discomfort and fatigue

By

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An assessment of unmanned aircraft system pilot discomfort and fatigue

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The rapid growth of unmanned aircraft system (UAS) use in both the military and civil sectors has uncovered an array of challenges within the field. In terms of human factors and ergonomics, the influence of the unique physical design of the control stations used to pilot the unmanned aircraft on local muscular fatigue and discomfort are of great concern. This study was conducted to assess the influence of two display configurations, Side-by-Side (SS) and Stacked (ST), and two chairs, Ergonomic (EC) and Captain's (CC), on mean and median power frequencies, root mean square amplitude, posture, discomfort, workload, and seat pressure. Sixteen participants [age: 24.75 ± 2.96 years; gender: 4 female/ 12 male; height: 177.56 ± 9.09 cm; weight: 81.37 ± 16.43 kg] completed four, 2-hour simulated UAS flights for all chair/display combinations. Eight participants piloted one, 6-hour simulated UAS flight in the display/chair combination which best minimized discomfort and fatigue in the two-hour flights, EC/SS. During the two-hour flights, muscle activity, discomfort, posture, workload, and seat pressure findings indicated increased muscular fatigue and discomfort over time. Generally, the EC/SS condition appeared to best mitigate muscular fatigue and postures associated with increased risk for the development of musculoskeletal disorders. Six-hour flight data failed to provide additional insights on the influence of extended duration flights on the dependent variables of this study. Finally, linear regression analysis revealed muscle activity can likely be predicted during UAS piloting tasks using the dependent variables in this study; however, the study failed to provide evidence that models built from two-hour data can accurately predict muscle activity out to six hours.

DEDICATION

I dedicate this work to my grandmother, Jeweline “Grams” Ann Burger Parton, a passionate and dedicated individual who gave her all in everything she did. A woman enamored by her Christian faith, her encompassing love and diligence demonstrated how to not only live, but to live fearlessly. Without Grams in my life, none of this would not have been possible.

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CHAPTER I

INTRODUCTION

Overview

Although the idea of an unmanned aircraft has been around since at least 1918 (Sullivan, 2006), only recently have unmanned aircraft systems (UASs) become more readily utilized by the Department of Defense (DOD), which increased its inventory from 50 UASs in 2000 to more than 7,000 in 2010 (Weiss, 2011). However, UASs systems have be found to have a much higher accident rate than manned aircraft averaging about 50 mishaps for every 100,000 flight hours compared to just one mishap per 100,000 flight hours for manned aircraft (Waraich, Mazzuchi, Sarkani, & Rico, 2013). Many of these mishaps could potentially be avoided through implementation of human factors/ergonomics principles in the design of control stations (CS) as 24% of UAS mishaps have been attributed to the absence of human factors/ergonomics (HFE) design considerations (Waraich et al., 2013). The purpose of HFE physical workstation design principles are to enhance user comfort, reduce musculoskeletal injuries, and optimize user performance and productivity. UAS CSs require the integration of task specific elements (controls, multiple screens, etc.) into traditional ergonomically designed workstations. In order to design a UAS CS that both satisfies HFE design principles and provides an effective piloting platform, inefficiencies in the physical designs of currently available control stations must be discovered.

There are a plethora of CS designs available with many of the same general characteristics as a computer workstation (Waraich et al., 2013). Research has shown that there is a suggested 98% similarity between computer workstations and UAS CSs (Waraich et al., 2013).However, there remain no ergonomic standards for the physical layout and design of UAS CSs (Hobbs & Lyall, 2016). Moreover, there is a dearth of literature regarding the influence of physical CS design on user comfort, fatigue, and performance.

Commercial HFE computer workstation standards are derived from the extensive published research on all aspects of computer workstations from the chair to the positioning of individual controls. Further, implementation of these principles established in the HFE computer workstations standards has demonstrated reduced work-related musculoskeletal disorders (Driessen et al., 2010; Esmaeilzadeh, Ozcan, & Capan, 2014; Martimo et al., 2010) and performance improvements (Martimo et al., 2010; Robertson & Huang, 2006; Smith & Bayeh, 2003). Therefore, the application of HFE computer workstation standards will likely positively influence UAS CS operator comfort and performance.

Generally, UAS CS suites or modules are designed similarly to sit-only computer workstations which include a chair, work surface, task specific controls (keyboard, mouse, joystick, etc.), and display(s). Failure to employ ergonomic designs to computer workstation leads to musculoskeletal injury risks (Shikdar & Al-Kindi, 2007). Improper sitting postures have been related to musculoskeletal injury and discomfort of the neck (Cagnie, Danneels, Van Tiggelen, De Loose, & Cambier, 2007), back (O'Sullivan, Mitchell, Bulich, Waller, & Holte, 2006; Williams, Hawley, McKenzie, & van Wijmen, 1991), and upper (Szeto, Straker, & O'Sullivan, 2005) and lower extremities (Williams et al., 1991). Likewise, ergonomically inadequate work table/desk design (Grandjean, Hünting, & Nishiyama, 1984; L. Straker, Pollock, Burgess-Limerick, Skoss, & Coleman, 2008) and control positioning (Asundi, Odell, Luce, & Dennerlein, 2012; C. Cook, Burgess-Limerick, & Papalia, 2004; Karlqvist et al., 1998; Simoneau, Marklin, & Berman, 2003) promote poor posture which may lead to musculoskeletal disorders (Shikdar & Al-Kindi, 2007). Finally, the positioning of displays has been shown to be critical in maintaining user comfort and preventing fatigue of the neck (Straker et al., 2008; Rempel, Willms, Anshel, Jaschinski, & Sheedy, 2007; Chiou, Chou, & Chen, 2012) and eyes (Rempel, Willms, et al., 2007). However, integration of physical ergonomic design principles has proven to reduce musculoskeletal risk factors associated with sit-only workstations (van Niekerk, Louw, & Hillier, 2012). Further, multiple ergonomic workstation standards have been developed which can be readily employed (ADA Standards, 2010, ANSI/HFES 100, 2007, ISO 11064-3, 1999, ISO 11064-4, 2013, ISO 11064-5, 2008, ISO 11064-6, 2005, MIL-STD-1472G, 2012).

Purpose

The purpose of this study was to assess the influence of ergonomically designed CSs and UAS pilot tasks on muscular fatigue of the neck and shoulder, body part discomfort of segments from the entire body, body posture, seat pressure, and mental workload. The CS designs are based on a Federal Aviation Administration (FAA) report (Babski-Reeves, Burch, DeBusk, & Smith, 2017), which surveyed and interviewed UAS pilots to determine common CS designs, and results from a study that compared UAS CSs to ergonomic standards (Waraich et al., 2013). Moreover, all CS components' designs were considered, regardless of the absence of direct impact to the dependent variables of the study, to control for adherence of these components to ergonomic standards.

Research Questions

Study 1 and Study 2

1. When using multiple displays while piloting a UAS from a CS, does display configuration influence muscular fatigue of the neck and shoulder, body discomfort, body posture, or mental workload?
2. When piloting a UAS from a CS, does an ergonomic office chair or a vehicle captain's chair influence muscular fatigue of the neck and shoulder, body discomfort, body posture, seat pressure, or mental workload?
3. When piloting a UAS from a CS, is there a combination of chair type and display orientation that results in significantly lower muscular fatigue of the neck and shoulder, body discomfort, and mental workload and improved body posture?

Study 2

4. Can UAS pilot muscular fatigue be predicted out to six hours from only two hours of data collection?

Scope and Limitations of the Study

Participants

This study was limited to the sample of Mississippi State University students. Further, participants were limited to those between the ages of 18-35 who have a BMI under 30, unless the measurement is obviously skewed by muscle mass, and normal or corrected to normal vision. All participants were inexperience users who had no previous experience piloting an unmanned aircraft system from an office workstation style control station.

Control Station

All experimental trials took place in a laboratory environment minimizing distractions which may be found in the natural environment. Although there are a number of display configurations implemented in control stations, this study only included two monitors in both a vertically stacked orientation and a side-by-side orientation. Flight controls were limited to a mouse and keyboard which are the most common controls for UAS flight from a CS; however, other less commonly utilized controls are implemented in UAS CSs. Finally, participants were not piloting an actual functioning vehicle, likely reducing the stress of crashing the vehicle.

Data Collection

Experimental trials were limited to a maximum of six hours. Although the task may influence muscle activity of the lower extremities and forearms/hands, researchers only collected muscle activity data from the neck and shoulder girdle due to limitations in the number of electromyography wireless transmitters available.

CHAPTER II

LITERATURE REVIEW

Introduction

The following literature review explores scholarly literature concerning the physical design of unmanned aerial system (UAS) CSs. Due to limited research on UAS CS physical design and a previous finding of 98% similarity to traditional office workstations (Waraich et al., 2013), a primary focus is given to scholarly research devoted to workstation physical design elements that would likely be found in both workstation types. Further, ergonomic minimum workstation design guideline recommendations are included in each section (if available) to provide a source of consolidated opinions; however, not all ergonomic workstation design guideline recommendations are in accordance with published literature. A minimal recommendation was chosen based on (1) the assumption that each ergonomic workstation design guideline considered the dimensions of individuals from the 5th to the 95th percentiles (2) the most minimal recommendation recorded.

Unmanned Aircraft System Control Station

In the United States, unmanned aircraft were initially largely developed as target drones and missiles for the military (Keane & Carr, 2013) with little need for human piloting efforts. As unmanned aircraft became more advanced, UASs were designed to complete complex tasks such as reconnaissance, security, and combat roles requiring tedious monitoring and control by pilots from a control station (Austin, 2010). More recently, UASs have been adopted by the civilian sector to complete tasks such as crop-spraying, traffic monitoring, and power-line inspection, to name a few (Austin, 2010). As of March 2017, the Federal Aviation Administration (FAA) forecasts by 2021 there will be up to 4.5 million units in the UAS small model hobbyist fleet and up to 442,000 units in the UAS commercial fleet (Federal Aviation Administration, 2017). Further, the United States Department of Defense (DOD) had an inventory of over 7,000 UASs in 2010 (Weiss, 2011). Although there are a large number of UASs, there is very limited scholarly literature concerning the physical dimensions of the CSs. When conducting the Airborne Subscale Transport Aircraft Research (AirSTAR) project, NASA implemented ten displays, a manual throttle lever, a joystick, and a chair into stationary and mobile CSs (Bailey, Hostetler, Barnes, Belcastro, & Belcastro, 2005). Sponsored by the Office of the Under Secretary of Defense, the Family of Integrated Rapid Response Equipment (FIRRE) Command and Control Station (C2) integrated three displays, keyboard, trackball, joystick, and adjustable chair into a mobile CS (Laird et al., 2006). Further information on the physical design of UAS CSs in scholarly literature is limited. One more specific UAS CS physical design study was performed which suggests up to four displays may not significantly affect piloting a UAS, while eight displays likely negatively affects a piloting (Dixon, Wickens, & Chang, 2005); however, this broad finding only highlights the scarcity of literature on the physical design of CSs and the necessity to study UAS CSs.

In 2013, it was found UAS CSs and office workstations are up to 98% similar and ergonomic workstation guidelines would likely serve similar purposes in the UAS control station (Waraich et al., 2013). Controls found to be similar between general office workstations and UAS CSs include displays, keyboard, and mouse. Survey and interview results from a report by the Federal Aviation Administration (Babski-Reeves et al., 2017) demonstrate similar findings with displays, keyboard, and mouse as commonly found control devices in UAS CSs. Moreover, the report found most UAS CSs to be similar to seated office workstations incorporating a chair and a desk-like work surface. However, multiple display orientation and chair type varied depending on the UAS and pilot with chairs typically either an office-like chair or vehicle-like captain's chair and displays either oriented side-by-side, stacked, or a combination of both side-by-side and stacked.

UAS control station components

Based on the available literature of the physical layout of UAS CSs, the components and physical design of the workstation were defined. The key components of the workstation were determined to include a chair, desk-like work surface, visual display(s), keyboard, and mouse. In the following sections, findings from peer-reviewed, published literature are detailed to provide an understanding of the influence of each component's design and positioning. Ultimately, each section provides rationale for the selection of an ergonomic design for the components which minimizes discomfort and fatigue.

Chair

The chair is an extension of the workstation which requires dimensions that allow the user to maintain comfort, decrease musculoskeletal disorders, and efficiently utilize the features of the workstation. In order to minimize discomfort in the seated workplace, the human body must maintain a neutral posture (Genaidy & Karwowski, 1993), especially at the spine. The spine is most neutral when aligned vertically which creates lordotic and cervical lordosis (Harrison, Harrison, Croft, Harrison, & Troyanovich, 1999). Any deviation from this vertical alignment causes increased myoelectric activity around the spinal region leading to augmented load on the vertebral disc (Nachemson & Elfstrom, 1970). An effectively designed chair minimizes deviations in spinal alignment while providing adequate support to the extremities (B. J. G. Andersson & Ortengren, 1974; Swearingen, Wheelwright, & Garner, 1962). The chair is composed of three major elements, the back/headrest, seat-pan, and armrests.

Backrest/headrest

The incorporation of a backrest in the chair design has demonstrated the ability to reduce lumbar intradiscal pressure (G. B. Andersson, Murphy, Ortengren, & Nachemson, 1979; Keegan, 1953; Szeto et al., 2005; H. Wilke, Neef, Caimi, Hoogland, & Claes, 1999). Reduced muscle activity is associated with a backrest angle of 110°-130° (Harrison et al., 1999; Harrison, Harrison, Croft, Harrison, & Troyanovich, 2000); however, it has been hypothesized visual display workstations should incorporate a 105° backrest angle (Groenesteijn, Vink, de Looze, & Krause, 2009) to reduce the 30° neck flexion associated with visual attention to an anteriorly located object (Harrison et al., 2000), such as a computer monitor. Further, a review of literature suggests back rest inclinations of 110° to be most ideal to reduce intradiscal pressures (Harrison et al., 1999). These findings report similar backrest inclinations when compared to the standard recommendations of 90° to 120° (“ANSI/HFES 100,” 2007).

The back support height should be at least 38.0 cm in height (“MIL-STD-1472G,” 2012) and 36.0 cm in width (“ANSI/HFES 100,” 2007). A lumbar support included in the design of the backrest has been shown to reduce load on the lumbar spine and decrease muscle activity of the lumbar (Makhsous et al., 2009). Moreover, implementation of a lumbar support reduces the pressure around the ischial tuberosities, the areas of greatest pressure (Shields & Cook, 1988). Lumbar supports have been suggested to be most effective with a protrusion from the seatback of 3.0-5.0 cm (Akerblom, 1948; Carcone & Keir, 2007; Harrison et al., 1999) and a height above the compressed seat of 15.0-25.0 cm (“ANSI/HFES 100,” 2007).

Neck pain has been associated with long duration sitting and neck flexion (Ariëns et al., 2001); however, neck pain may be reduced by supporting the head and neck with a headrest along with backrest inclination, as decreased neck and shoulder muscle activity has been associated with the implementation of a headrest and backrest inclination versus sitting with no headrest and a more upright backrest (Monroe, Sommerich, & Mirka, 2001). Workstation ergonomic standards recommend a headrest if the backrest inclination angle surpasses 120° (“ANSI/HFES 100,” 2007).

Seat Pan

The seat pan is the portion of the chair that supports the buttocks and some portion of the femur. Sitting for long durations results in leg edema (Chester, Rys, & Konz, 2002) due to compression of the veins in the thigh and hip areas leading to poor circulation (Shvartz, Gaume, Reiold, Glassford, & White, 1982) and capillary fluid permeation into the interstitial space (Pottier, Durbreuil, & Monod, 1969). Seated lower leg edema may be increased by a seat pan height that does not allow the feet to rest on the floor or a footrest (Yamaguchi, Yoshida, Kamijo, Fujimaki, & Naruse, 2014). Moreover, supporting the foot decreases the load on the sitting area, accounting for approximately 18% of the body weight at a backrest inclination of 105° (Swearingen et al., 1962).

Workstation standards recommend an adjustable seat pan height of 38.0-56.0 cm ("ANSI/HFES 100," 2007) and a footrest when a user is exposed to a seat pan height 46.0 cm or greater for extended durations ("MIL-HDBK-759C," 1995) with a minimum depth of 15.0 cm ("MIL-HDBK-759C," 1995), minimum width of 25.5 cm ("MIL-HDBK-759C," 1995) , and a height up to 22.0 cm ("ANSI/HFES 100," 2007). Seat pan depth must be short enough to allow use of the backrest and avoid pressure to the popliteal region (Chaffin, Andersson, & Martin, 2006). Moreover, the anterior edge of the seat pan should be contoured and softened to further prevent pressure at the popliteal region. Ergonomic standards suggest a minimum seat pan depth of 38.1 cm up to 43.2 cm ("MIL-STD-1472G," 2012). The seat pan width should at least allow for support of the ischial tuberosities (Darcus & Weddell, 1947; Floyd & Roberts, 1958). Ergonomic standards recommend a minimum seat pan width of 40.6 cm ("MIL-STD-1472G," 2012).

Findings support both rearward (Rasmussen, Tørholm, & de Zee, 2009) and forward (Bendix & Biering-Sørensen, 1983) seat pan inclination. Forward seat pan inclination may cause lumber lordosis and promote a vertically aligned spine up to a forward inclination angle of 10° (Bendix & Biering-Sørensen, 1983); however, lumbar lordosis associated with forward inclination must be maintained by muscle activation (Rasmussen et al., 2009), which increases lumbar disc pressure (B. J. G. Andersson & Ortengren, 1974; H.-J. Wilke, Neef, Hinz, Seidel, & Claes, 2001) compared to passive lumbar lordosis linked with a rearward seat pan inclination, lumbar support, and reclined backrest (G. B. Andersson et al., 1979; Rasmussen et al., 2009). A rearward seat pan inclination angle between 0° and 10° has been proposed as the most appropriate for an ergonomic seated posture (Harrison et al., 1999). A seat pan that allows for dynamic motion of the seat pan in the horizontal plane reduces low back pain due to a reduction in static posture (Van Deursen et al., 1999) which has been found to be a musculoskeletal disorder risk factor (Norman et al., 1998; Sbriccoli et al., 2004; Vergara & Page, 2002; Vieira & Kumar, 2004). Ergonomic standards suggest a user-adjustable seat pan angle over the range of at least 4° including a rearward inclination of 3°; however, these values are based on industry values and not necessarily findings from the literature ("ANSI/HFES 100," 2007).

Armrests

The incorporation of armrests in the chair design promotes a sitting and working posture that minimizes musculoskeletal injury risks (Gerr, Marcus, & Monteilh, 2004). Armrests have been found to support 12.4% of the body weight at a backrest angle of 105° (Swearingen et al., 1962) which may relieve some of the pressure at the ischial tuberosities (Vos, Congleton, Steven Moore, Amendola, & Ringer, 2006). Moreover, forearm support in the seated position reduces the load on the trapezius and erector spinae lumbalis (Aaras, Fostervold, Ro, Thoresen, & Larsen, 1997) and reduces spinal disc pressure (Andersson & Ortengren, 1974). The forearms should be maintained near the height of the elbow, in the anatomically neutral position, to allow for the most effective support of the forearm while performing office desktop tasks such as typing (Aaras et al., 1997; C. Cook et al., 2004; Harvey & Peper, 1997; Kotani, Barrero, Lee, & Dennerlein, 2007; Odell, Barr, Goldberg, Chung, & Rempel, 2007). Ergonomic standards recommend armrests to have a length of at least 25.4 cm (“MIL-STD-1472G,” 2012), width of at least 5.0 (“MIL-STD-1472G,” 2012), an adjustable height of 17.0-27.0 cm above the compressed seat pan (“ANSI/HFES 100,” 2007), and a clearance between armrest of at least 46.0 cm (“ANSI/HFES 100,” 2007).

Material

Dated literature suggests incorporating cushioned (foam) chair materials (Lueder, 1986); however, recent literature suggests the suspension (no hard platform under the material) chair design with net-like material increases comfort compared to cushioned chairs (Vlaović, Domljan, Župčić, & Grbac, 2016). Further, the suspension design reduces pressure between the buttock-thigh region and the seat when compared to cushioned chairs (Makhsous, Lin, Hanawalt, Kruger, & LaMantia, 2012; Yoo, 2015).

Visual Display

Viewing angle

Researchers have long debated the optimal vertical positioning of visual displays as findings have provided mixed results. Previous reviews have classified findings based on a high or low vertical monitor position (Psihogios, Sommerich, Mirka, & Moon, 2001; Leon Straker & Mekhora, 2000). Lower vertical positioning of computer monitors has been associated with increased neck flexion, cervical and thoracic muscle activation (Turville, Psihogios, Ulmer, & Mirka, 1998), and possibly discomfort (Sommerich, Joines, & Psihogios, 2001; Leon Straker & Mekhora, 2000). However, other results showed trapezius and sternocleidomastoid muscle activation to be reduced in low monitor placement (Kumar, 1994), and one finding even shows no difference in trapezius muscle activation between low and high monitor positions (Aaras et al., 1997). Higher vertical positioning of computer monitors has been linked to neck extension (L. Straker, Burgess-Limerick, et al., 2008) and visual stress (Bergqvist & Knave, 1994), whereas low monitor placement has been hypothesized to allow for preferred gaze angles (Burgess-Limerick, Plooy, Fraser, & Ankrum, 1999) and decrease eye dryness due to more eyelid coverage of the eyeball (M. B. G. Villanueva, Sotoyama, Jonai, Takeuchi, & Saito, 1996). More recent research suggests extreme vertical display positions should be avoided, and mid-level display positions minimize musculoskeletal and visual disorder risks (Allie, Purvis, & Kokot, 2005; L. Straker, Skoss, Burnett, & Burgess-Limerick, 2009). Further, this finding is comparable to an ergonomic standard which suggests the center of the display should be positioned 15°-25° below horizontal eye level ("ANSI/HFES 100," 2007).

Viewing Distance

Findings of preferred distance from the eyes to a computer monitor demonstrate values from about 50.0-70.0 cm (Jaschinski, 2002; Rempel, Willms, et al., 2007). However, improved eye comfort has been associated with a 100.0 cm distance (Jaschinski-Kruza, 1988) and participants have demonstrated a greater affinity for a 100.0 cm distance when compared against a 50.0 cm distance (Jaschinski-Kruza, 1988; Jaschinski-Kruza, 1990), suggesting the optimal visual distance likely falls more closely to the 70.0 cm range. The resting focus distance without visual stimulation has been found to be a distance of about 67.0 cm (Owens & Owens, 1984), a comparable value. A minimum viewing distance of 40.0 cm from the nasal bridge to display center is recommended by ergonomic standards ("ANSI/HFES 100," 2007).

Tilt

Some studies allow users to choose a tilt angle of the computer monitor (Sethi, Sandhu, & Imbanathan, 2011; M. B. Villanueva, Jonai, & Saito, 1998). One finding suggests users prefer a backward monitor tilt angle of 5.5° while maintaining an average viewing angle of around -18° as measured from a horizontal reference line and the line from the eye to the center of the display (M. B. Villanueva et al., 1998). However, to the authors' knowledge, there is not an ergonomic standard recommendation for monitor tilt angle

Multiple Display Orientation

Multiple monitor use in the office setting is becoming more popular as prices decrease and software develops, allowing for multitasking and advanced application use (Shin & Hegde, 2010). Dual monitors used in a side-by-side orientation that maintain a horizontal angle of view within 35° in either lateral direction, as recommended by ergonomic standards ("ISO 11064-4," 2013) have been found to have similar preferred viewing distances, viewing angles, monitor tilt angles, monitor heights, keyboard position, visual acuity, and subjective eye and body discomforts as a single monitor of the same dimensions (Shin & Hegde, 2010). It has been demonstrated side-by-side oriented dual monitor use increases head-neck rotation (Nimbarte, Alabdulmohsen, Guffey, & Etherton, 2013); however, it is unclear the effect on musculoskeletal disorders as increased head-neck rotation has been associated with increased (Nimbarte et al., 2013) and decreased (Szeto, Chan, Chan, Lai, & Lau, 2014) musculoskeletal disorder risk. Other findings regarding side-by-side oriented dual monitors have shown increases in right sternocleidomastoid muscle activity (Nimbarte et al., 2013) and reductions in the

50th and 90th percentile amplitudes of the right upper trapezius (Szeto et al., 2014). When using side-by-side oriented dual monitors, users typically align the monitors in a curved pattern (Na, Jeong, & Suk, 2015) which has been found to be preferred to a single flat monitor (Kang & Stasko, 2008). Although modern software and hardware allow for stacked dual monitors, there appears to be a lack of literature regarding this configuration. An ergonomic standard recommends that stacked dual monitors be positioned as low as possible and have similar viewing distances, or the upper displays should incorporate information that does not require long-duration visual attention ("ISO 11064-4," 2013). Further, all adjacent screens, stacked and side-by-side oriented, should be positioned close together with similar viewing distances to frequently viewed displays and an orthogonal line of sight to each display ("ISO 11064-4," 2013).

Seated Workstation Dimensions

Work Surface

The work surface should incorporate a width of at least 61.0 cm and a depth of at least 61.0 cm with a preferred depth of 76.2 cm ("MIL-STD-1472G," 2012). However, if the monitor is supported by the work surface, the surface should allow a viewing distance up to 100.0 cm ("ANSI/HFES 100," 2007). The work surface should allow for a minimum of 3.8 cm of depth for wrist/palm, forearm support ("ANSI/HFES 100," 2007). The inclusion of forearm support has demonstrated lower trapezius and erector spinae lumbalis load (Aaras et al., 1997) and spinal disc pressure (B. J. G. Andersson & Ortengren, 1974).

Work surface height should allow the operator to maintain a vertical work surface distance of less than 15.0 cm (Chengalur, Suzanne, & Bernard, 2004), since elevated reach height is associated with localized muscular fatigue of the shoulder area (Chaffin, 1973; Wiker, Chaffin, & Langolf, 1989). An ergonomic standard recommends a minimal work surface height of 73.5 cm ("MIL-STD-1472G," 2012).

Reach Distance

Increases in vertical (Chaffin, 1973; Wiker et al., 1989) and horizontal reach (Chaffin, 1973) distances have been shown to augment the rate of fatigue of the shoulder (Chaffin, 1973) due to increasing the distance of the hand to the midpoint of the torso causing a larger moment arm and greater load on the joint axis (Nordin & Frankel, 2012). Engaging in office-like tasks requiring reaching to a touch screen compared to reaching to less distant mouse and keyboard has been demonstrated to increase trapezius and neck extensor muscle activity and discomfort in the neck, fingers, and shoulder areas (Shin & Zhu, 2011). Increased shoulder flexion, reaching frequency and duration have been associated with greater discomfort in the shoulder, upper arm, and whole body (Lin, Wang, Drury, & Chen, 2010). Finally, repetitive reaching tasks performed while seated at a desk has been associated with elevated supraspinatus, deltoid, and trapezius muscle activity (Laursen, Jensen, & Sjøgaard, 1998). Attempts at developing ergonomic horizontal reach envelopes for the work surface have been made since at least the mid-1950s (Farley, 1955; Konz & Goel, 1969; Squires, 1956).

Many researchers support the notion of a "normal working area," at or slightly below the height of the elbow, defined by a sweeping motion of the arm about the shoulder with the elbow flexed to about 90° (Das & Grady, 1983; Konz & Goel, 1969; Pheasant, 1986; Squires, 1956). Further, the "zone of convenient reach" was established as the furthest an object could be reached without causing undue physical exertion

(Pheasant, 1986) or the maximum working area of the hands acting synonymously or separately (Barnes, 1980). An ergonomic standard suggests similar work zones with most often used objects located in the "primary" zone, which incorporates all area within reach of the forearm pivoting about the elbow, and less often used objects located slightly further from the body ("ANSI/HFES 100," 2007). These distances have been quantified as 33 – 43 cm from the shoulder for the primary zone and 53 – 64 cm from the shoulder for the secondary zone (Cohen, 1997). In relation to both vertical and horizontal reach, the American National Standards Institute (ANSI) recommends users maintain elbow angles between 70° and 135°, shoulder abduction angles less than 20°, shoulder flexion angles less than 25° ("ANSI/HFES 100," 2007).

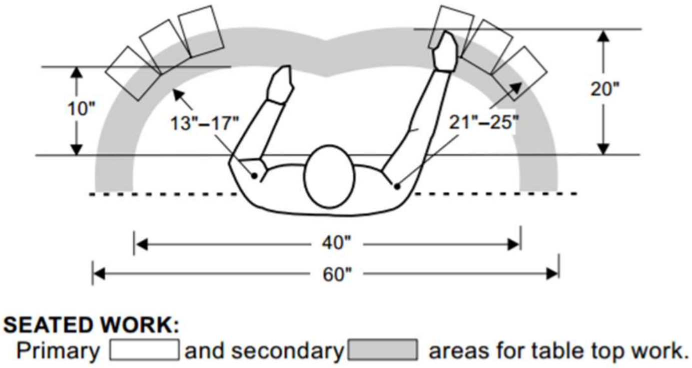


Figure 1 Seated Work Reach Distances

(Cohen, 1997)

Clearances

Ergonomic workstation standards recommend clearances to allow the user to comfortably fit within the workspace. Workstations should allow knee clearance under the work surface with at least 38.1 cm depth, 51.0 cm width, and 63.5 cm height ("MIL-

STD-1472G," 2012) or an adjustable height between 50.0 cm and 64.0 cm ("ANSI/HFES 100," 2007). Continuing, workstations should allow at least 60.0 cm of depth at the level of the foot ("ANSI/HFES 100," 2007).

Controls

Traditional computer workstations require a variable number and type of controls depending on the associated task. UAS CSs were found to incorporate many of the same controls as a traditional computer workstation including the keyboard, mouse (or trackball), and/or joystick which were found in at least 50% of UAS CSs (Waraich et al., 2013). In general, control devices should be positioned no wider than the width of the shoulders as placement outside of this range is associated with shoulder abduction (C. J. Cook & Kothiyal, 1998; Harvey & Peper, 1997), shoulder discomfort (Karlqvist et al., 1998) and elevated anterior, middle (Cook & Kothiyal, 1998) and posterior deltoid (Harvey & Peper, 1997) and trapezius muscle activity (Harvey & Peper, 1997). An ergonomic standard recommends maintain controls within the width of the shoulders ("ANSI/HFES 100," 2007).

Keyboard

Elevated keyboard height above the elbow is associated with greater arm (Sauter & Schleifer, 1991), shoulder (Gerr et al., 2004), and neck discomfort which is in agreement with findings of shoulder fatigue with vertical reach (Chaffin, 1973; Wiker et al., 1989). A distance of greater than 12.5 cm from the "J" key to the front edge of the desk is associated with lower hand or arm musculoskeletal disorder risks (Marcus et al., 2002) likely due to a reduction in ulnar deviation (Kotani et al., 2007), which has been reported to increase carpal tunnel pressures (Keir, Bach, & Rempel, 1998), and shoulder abduction (Kotani et al., 2007) which increases stress to the shoulder (Chaffin, 1973). Moreover, a vertical distance greater than 3.5 cm from the “J” key to the support surface is associated with greater hand or arm musculoskeletal disorder risks likely due in-part to more pronounced wrist extension (Marcus et al., 2002) which has been linked to hand and forearms disorders (Gerr, Monteilh, & Marcus, 2006) including increasing pressure to the carpal tunnel (Keir et al., 1998). Incorporating a negative keyboard slope may decrease wrist extension angles (Rempel, Nathan-Roberts, Chen, & Odell, 2009; Simoneau et al., 2003) and forearm muscle activity (Woods & Babski-Reeves, 2005) compared to positively sloped keyboards. Finally, split keyboards have been found to allow for reduced wrist extension (Honan, Serina, Tal, & Rempel, 1995; Rempel, Barr, Brafman, & Young, 2007) ulnar deviation (Honan et al., 1995; Rempel, Barr, et al., 2007; Rempel et al., 2009), and forearm pronation (Honan et al., 1995; Rempel, Barr, et al., 2007; Smith et al., 1998). An ergonomic standard recommends a keyboard slope to include a positive slope between 0° and 15° and not exceed a height of 3.5 cm (“ANSI/HFES 100,” 2007).

Mouse

Manipulating the mouse while engaging in office work has been associated with exposure to extreme ulnar deviation (greater than 10^o) and wrist extension (greater than 30^o) (Burgess-Limerick et al., 1999) and found to increase the risk for musculoskeletal symptoms for the arm or hand (Jensen et al., 1998). Slanting the hand-mouse surface from left to right (for right hand only) up to 30^o has been shown to position the hand/wrist in a more neutral position while decreasing forearm and shoulder muscle activity (Chen

& Leung, 2007). A further study found a slanted mouse to reduce wrist extensor muscle activity and support a more neutral forearm posture (Houwink, Oude Hengel, Odell, & Dennerlein, 2009). An ergonomic standard recommends a 4.0-7.0 cm width, 7.0-12.0 cm length, and 2.5-4.0 thickness (“HF-STD-001B,” 2016).

Conclusion

UAS utilization is growing and is projecting to continue growing at a high rate. Elevated accident rates have been linked to human factors and ergonomic issues, however, it appears there is a scarcity of scholarly literature analyzing human interaction with the physical design of the CS. CS design and general office workstations have been found to be nearly identical (Waraich et al., 2013), and there is a wealth of information concerning the impact of workstation design on operator comfort, muscle activity, fatigue, and contact pressure. Nonetheless, there has not been a study which analyzes the effect of variations in control station physical design on pilot muscular fatigue and discomfort.

CHAPTER III

METHODS

Experimental Design

Study 1 and 2

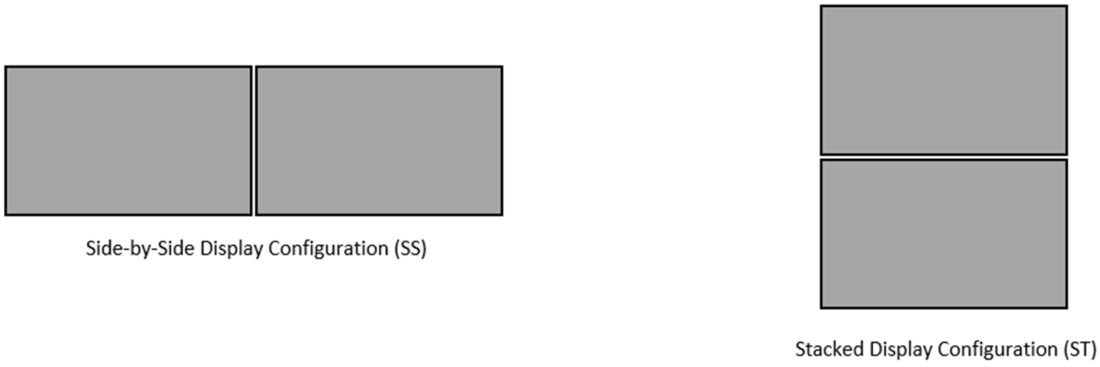
Two studies were completed: 1) to identify workstation design parameters that minimize operator fatigue during simulated UAS piloting tasks and 2) to validate a fatigue prediction models based on workstation design parameters. The first study followed a 2 x 2 within subjects design to study the effects of display orientation (2 levels: side-by-side and stacked) and chair type (2 levels: ergonomics office char and captain's chair) on neck and shoulder girdle muscle activity, body discomfort, mental workload, posture, and seat pressure. The workstation that reduced the risk for the development of musculoskeletal disorders based on muscle activity, body discomfort, mental workload, posture, and seat pressure was used in Study 2 to analyze the influence of an extended duration on these factors. Study 1 exposed participants to 2-hour experimental trials while Study 2 exposed participants to 6-hour experimental trials. Exposure to experimental conditions was balanced using a Latin Square design to control for order effects.

Independent Variables

A total of four workstation combinations were incorporated in this study including, 1) ergonomic office chair and side-by-side display orientation (EC/SS), 2) captain's chair and side-by-side display orientation (CC/SS), 3) ergonomic office chair and stacked display orientation (EC/ST), and 4) captain's chair and stacked display configuration (CC/ST).

Display Orientation

According to an unpublished Federal Aviation Administration report (Babski-Reeves et al., 2017), UAS pilots are exposed to several multi-display designs. This study incorporated some of the most common display configurations including, side-by-side configuration (SS) and stacked configuration (ST) (Figure 2). The primary flight information including a moving map tracking the aircraft was positioned on the right screen of the SS and the bottom screen of the ST. Secondary information was positioned on the remaining screen and included altitude, attitude, and velocity. Likewise, operator chairs vary greatly with different UAS control stations. Two chairs were utilized in this study including ergonomic office chair (EC) and a vehicle captain's chair (CC).



Side-by-Side Display Configuration (SS)

Stacked Display Configuration (ST)

Figure 2 Side-by-Side (SS) and Stacked (ST) Display Configurations

Chairs

An ergonomic office chair and vehicle captain's chair were included in the study and were intended to be representative of a wide range of seating options currently being used in UAS CSs. The EC, a Balt Butterfly Ergonomic Executive Office Chair (MooreCo, Inc., Temple, Texas), incorporates a suspension design, net-like material, a lumbar support, armrests, and a headrest (Figure 3). The CC, a rear seat from a 2001 Ford Windstar, incorporates fabric covered foam, armrests, and a headrest (Figure 4).

Figure 3 Ergonomic Office Chair

Figure 4 Captain’s Chair

Table 1 Chair compliance to workstation standard/literature recommendations (cm).

Chair Component	Workstation standard/literature Recommendation	Ergonomic Chair	Captain's Chair
Seat Pan Depth	38.1 – 43.2 cm	☑	☑
Seat Pan Width	≥ 40.6 cm	☑	☑
Seat Pan Front Edge	Contoured	☑	☑
Seat Pan Inclination	Adjustable at least 4° including a rearward inclination of 3°	☑*	☐
Seat Pan Vertical Height Above Floor	Adjustable height 38.0 – 56.0 cm	☑*	☑*
Backrest Height	≥ 38.0 cm	☑	☑
Backrest Width	≥ 36.0 cm	☑	☑
Backrest Angle	90°-120°	☑	☑
Lumbar Support Height above compressed seat pan	15.0 – 25.0 cm above compressed seat pan	☑	☐
Lumbar support protrusion from seatback	3.0 – 5.0 cm	☑	☐
Headrest	If backrest inclination angle surpasses 120°	☑	☑
Armrest length	≥ 25.4 cm	☑	☑
Armrest Width	≥ 5.0 cm	☑	☑
Width between Armrests	≥ 46.0 cm	☑	☑
Armrest Height Above Seat Pan	Adjustable 17.0 – 27.0 cm above compressed seat pan	☑*	☑*
Material	Net-like material incorporated in a suspension design	☑	☐
Foot Rest	Available	☑	☑

A check mark indicates chair compliance to workstation standard/literature recommendations while an empty box represents non-compliance. * indicates the component's dimension falls within the recommended range but does not meet the adjustability requirements.

Workstation Combinations

All workstations incorporated the following features: 1) height adjustable work surface (64 cm to 99 cm), 2) two 19" computer monitors, 3) keyboard (height of 3.2 cm from work surface to "J" key), and 4) mouse. The workstation configurations were properly adjusted according to workstation literature and ergonomic workstation standards including, 1) maintaining the seat height to allow the feet to rest on the floor or foot rest (Yamaguchi et al., 2014), 2) maintaining the viewing distance between 50 – 100 cm ("ANSI/HFES 100," 2007), 3) adjusting the keyboard so that the "J" key is at least 12.5 cm from the work surface front edge (Marcus et al., 2002), 4) adjusting the height of the work surface to the height of the elbows ("ANSI/HFES 100," 2007), and 5) containing the keyboard and mouse to within the width of the shoulders ("ANSI/HFES 100," 2007). Participants were allowed to tilt the computer monitors to a preferred viewing angle.

CS configurations which incorporated a SS display orientation were adjusted so that the participant was centered between the screens. CS configurations incorporating a ST display orientation were adjusted so that the top of the bottom display is on the same horizontal plane as the eyes. When using the EC, the arm rests were adjusted to the height of the elbows.

Phases of Flight

UAS flights were partitioned into three major phases including, takeoff, pattern flying, and landing. Prior to flight, a flight path was created that included waypoints or coordinates to which the aircraft tracked to. With the help of a certified UAS pilot, participant responsibilities during each phase of flight were designed to mimic the actions of actual UAS pilots. The takeoff phase was approximately two minutes in duration and started with the participant initiating motion of the aircraft down the runway and ended when the UAS reaches the flight altitude of the pre-programmed flight. During takeoff phase, the participant continuously called out the aircrafts velocity. Verbalizing the aircraft's velocity was intended to mimic an actual UAS pilot's responsibility to relay this information to an external pilot who could alter the aircraft's flight path if the velocity and altitude vary from the flight plan. The pattern flying phase was approximately two hours in duration. The participant tracked the aircraft on the screen, ensuring the aircraft remained on the correct flight path and maintaining correct velocity and altitude. At every waypoint, the participants typed the altitude and velocity into an itemized worksheet to assure the participant was constantly engaged in the task. At the end of the pattern flying phase, the participant clicked on the appropriate buttons to engage landing. The landing phase began when the participant initiated landing and ended when the aircraft's velocity reached 0 knots. The duration of the landing phase was approximately two minutes. As in the takeoff phase, the participant continuously called out the aircraft's velocity.

Dependent Variables

The dependent variables in Study 1 and Study 2 included muscle activity, seat pressure, posture, body discomfort, and mental workload. All data collection parameters were designed for Study 1. During Study 2, the pattern flying phase was increased to approximately six hours. The data collection intervals remained the same.

EMG

Muscle activity of four bi-lateral muscles (eight muscles total), including the anterior deltoid (AD), upper trapezius (UT), biceps brachii, and splenius capitis (SC), were collected using a wireless electromyography (EMG) system (Noraxon DTS wireless EMG, USA). Dual pre-gelled, bipolar EMG electrodes were placed on the muscle belly of each of the muscles, with a ground electrode placed on the superficial medial clavicle. The muscle bellies were located following these procedures:

1. Anterior Deltoid - three fingerbreadths below the anterior margin of the acromion (Perotto, 2011).
2. Upper Trapezius - 2 cm lateral to the midpoint between C7 and acromion (Jensen et al., 1998).
3. Biceps Brachii - approximately midway between the axillary fold and the midpoint of the cubital fossa (Evetovich, Nauman, Conley, & Todd, 2003), at the bulk of the muscle in the mid-arm (Perotto, 2011).
4. Splenius Capitis - at the C2-C3 level midway between the uppermost parts of the trapezius and sternocleidomastoid muscles (Lindstrøm, Schomacher, Farina, Rechter, & Falla, 2011).

Prior to the application of the electrodes, appropriate skin preparation procedures for the electrode site including removing hair, cleaning of the skin with alcohol and cotton swabs, and abrasion with fine sand paper were completed. Dual electrodes were then placed on the belly of each muscle. The electrodes were fixed to wireless transmitters via leads (wires). The wireless transmitters were adhered to the participant’s skin with double sided tape. Participants rested for five minutes to allow the electrode application area to reach a stable electrical condition. Signal impedance was tested by measuring the resistance between the electrode pair and compared to the recommended resistance ranges using a standard multimeter. All impedance measures were required to be less than 10 kOhms. If necessary, the skin was prepared again.

Once the electrodes were properly attached, participants performed three trials of five second maximum voluntary isometric contractions (MVIC) for each of the muscles in the mid-range of the joint. The following activities were performed for each muscle:

1. Anterior Deltoid - Shoulder flexion with elbow extended while participant holds a rope fixed at the ground.
2. Upper Trapezius - Shoulder shrug while holding a rope in both hands attached to the ground.
3. Biceps Brachii- Biceps curl with hand supine and elbow bent to approximately 90° while holding onto a rope.
4. Spenius Capitis- Neck extension against a strap across the posterior of the head held by the hands of the participant while seated.

Electromyographic data was collected for the full duration of each trial. Any disturbances to normal operating procedures, such as bathroom breaks, were noted and the associated data was discarded. EMG data was collected at a sampling rate of 1000 Hz. EMG data was used to assess the following variables, mean and median frequency (MnPF and MdPF) and root mean squared muscle (RMS) amplitude activity. To obtain MnPF and MdPF, unfiltered data was processed using the Noraxon MyoResearch 3.0 Frequency Fatigue Report. The software calculated a total power spectrum in 1000 ms steps from which MnPF and MdPF were derived. RMS muscle activity was obtained by bandpass filtering the data to 20-400 Hz (Carlo J. De Luca, Donald Gilmore, Kuznetsov, & Roy, 2010) followed by full wave rectification. The filtered data was then analyzed using the Noraxon MyoResearch 3.0 Smoothing RMS (Figure 5) at a duration of 50 ms and normalized to peak amplitude (Figure 6). Post-trial analysis included separating the data by phases of flight.

$$output\_value_n = \sqrt{\frac{\sum_{i=n-w}^{n+w} input\_value^2_{index(i)}}{2w+1}}$$

where: n is the output index
w is radius of the window
$index(i) = i$ if $first\_index \leq i \leq last\_index$
$index(i) = first\_index$ if $i < first\_index$
$index(i) = last\_index$ if $i > first\ index$

Figure 5 Root Mean Square Equation Implemented in Noraxon MyoResearch 3.0. (*MyoMuscle User Guide v3.8 Report Descriptions*, 2015)

$$= \frac{Mean\ RMS \qquad tude(Tr\ \ a\ )}{Max\ RMS \qquad tude(MVIC)} \times 100$$

Figure 6 Equation to normalize root mean square as a percentage of maximum voluntary contraction peak amplitude.

Pressure Maps

Two FSA 4.0 (Manitoba, Canada) pressure mats were used to quantify seat pressure in mmHg. One pressure mat was centered on the seat pan and the other centered on the backrest. Pressure was measured throughout the trial at 5 Hz (Kim & Chang, 2013). Pressure sensors associated with the ischial tuberosities and mid-thighs were analyzed for mean pressure. Total support area was analyzed for mean pressure. All mean pressure variables were calculated through FSA 4.0 software which sums the values of all pressure sensors sensing pressure and divides the sum of the pressures by the total number of pressure sensors sensing pressure. Post-trial analysis included separating the data by phases of flight and calculating mean average and maximum seat pan (SP_A and SP_M) and seat back (SB_A and SB_M) pressures.

RULA

Participant posture was assessed using the Rapid Upper Limb Assessment (RULA). Investigators video recorded participants for the full duration of each trail. A video camera was positioned so that a full body side profile was captured and both arms were clearly identifiable. Post-trial analysis of the video included assessing still images of participant posture once during the midpoint of takeoff and landing phases and every 15 minutes during the pattern flying phase. Researchers chose to capture posture every 15 minutes to mitigate the risk of eliminating postural alterations. Further, researchers noted extreme postural alterations which occurred between capture points. Using the RULA scoring tables and guidelines, investigators scored each phase of flight for each participant and used the total score ($RULA_T$) numbers in data analysis.

Body Discomfort

Participants were asked to evaluate their level of discomfort at select time periods throughout the trial using a body discomfort map (Corlett & Bishop, 1976). A paper based body discomfort map was presented to the participants. The body discomfort map included an image of the body segmented into numbered body parts and a numerical scale to ranking each body part. Ranking of discomfort followed a 6-point Likert-scale (Sullman & Byers, 2000) with the following associations, 0-No Discomfort, 1-Very Minor Discomfort, 2-Minor Discomfort, 3-Moderate Discomfort, 4-Severe Discomfort, and 5-Extreme Discomfort. Participants were responsible for circling a level of discomfort for each body part. The participants completed a body discomfort map immediately after both takeoff and landing phases and every 30 minutes during the pattern flying phase. Researchers limited the collection of body discomfort to every 30 minutes, instead of every 15 minutes, to reduce muscle activity and postural changes associated with physically answering the body discomfort map.

NASA TLX

Participants were asked to evaluate their mental workload at select time points throughout the trial. A NASA Task Load Index (TLX) (Hart & Staveland, 1988) was delivered to each participant on a sheet of paper. The NASA TLX consists of six questions that evaluate mental demand, physical demand, temporal demand, performance, effort, and frustration. Participants were asked to mark a 10 mm long scale divided into 21 equal parts. The left endpoint of the scale will be marked as “Low” and the right endpoint of the scale “High”. The participants completed a NASA TLX immediately after both takeoff and landing phases and every thirty minutes during the pattern flying phase. A total overall unweighted score (NASA TLX_T) was used in data analysis.

Procedures

Informed Consent/Familiarization

Participants were provided a detailed verbal description of the experiment including any potential risks. Following, researchers were encouraged participants to ask questions and assure the participant fully understands the experiment. Upon agreeing to participate, participants signed an informed consent document approved by the Mississippi State University Institutional Review Board. Next, participants completed a demographic questionnaire and researchers collected basic anthropometrics. Then, participants were familiarized with the mock control station and the UAS flight simulation software. These steps required approximately 30 – 45 minutes.

Test Sessions

In a laboratory setting, participants piloted a UAS using simulation software across four mock CSs. In Study 1, the piloting task lasted 2 hours across four testing days during which the participant was exposed to each CS design. Each testing day was separated by a minimum of 24 hours to minimize carryover and fatigue effects. Additionally, trials occurred at roughly the same time of day to minimize circadian rhythm effects. At the completion of Study 1, all data was processed and analyzed to determine which CS allowed for the least discomfort and fatigue. This control station was the only CS design used in Study 2. In Study 2, participants completed one test session for a 6-hour period. Test sessions were separated by at least 24 hours to minimize fatigue.

Before the start of each trial, EMG transmitters and electrodes were attached to the participant's skin. Following, resting muscle activity and MVCs for each muscle were collected. These procedures required approximately 30 minutes.

Participants sat for the entire duration of each test session. In Study 1, participants were allowed to utilize the restroom if necessary; however, no participants left the chair to use the restroom or for any other reasons during testing. In Study 2, participants were required to walk to the restroom after two and four hours to maintain consistent breaks between participants. Participants engaged in the activities associated with each phase of flight as noted in the section "Phases of Flight" above. Further, participants completed body discomfort maps and NASA TLXs at the predetermined periods outlined in the "Dependent Variables" section above. Finally, at the completion of each test session, researchers removed all EMG equipment and electrodes from the participant, and he or she was free to leave.

All participants were monetarily compensated at a rate of $5/hr. All compensation was provided to participants at the end of their participation. Participants that withdrew early had their compensation prorated for each 30 minute period they complete.

Participants

Sixteen (Study 1: 16; Study 2: 8) healthy adults with no history of musculoskeletal, neurological, cardiovascular, or abnormal vision (unless corrected with lenses) were included in the study (Table 2). Participants were required to have a body mass index (BMI) score less than 30 so as to reduce the likelihood of excessive subcutaneous fat interference with the collection of muscle activity. However, researchers used discretion when participants exceeded a BMI score of 30 due to excessive muscle mass. Participants had no prior experience piloting a UAS from a workstation-like control station; however, participants with experience piloting small UASs using a handheld radio control (RC) controller were allowed to participate. To determine sample size, G-Power statistical software was utilized with a desired power of 0.8, a desired effect size of .25, and at an alpha level of 0.05.

Table 2 Participant Descriptive Statistics.

	Average	Standard Deviation
Age (yrs)	24.75	2.96
Gender	12 Male 4 Female	
Dominant Hand	All Right	
Height (cm)	177.56	9.09
Weight (kg)	81.37	16.43

Data Analysis

Study 1:

Prior to statistical analysis, data from right and left sides of the body were averaged. The dependent variables from Study 1 were analyzed using a 2 by 2 [2 (ST x SS) x 2 (EC x CC)] within subjects, full-factorial Repeated Measures Analysis of Variance (RM ANOVA) independently. Post-hoc pairwise comparisons were performed using a Bonferroni Correction if interaction/main effect significance was found. All statistical analyses were performed using IMB SPSS Statistics for Windows, Version 24.0 (IBM Corporation, Armonk, NY) at an alpha level of 0.05.

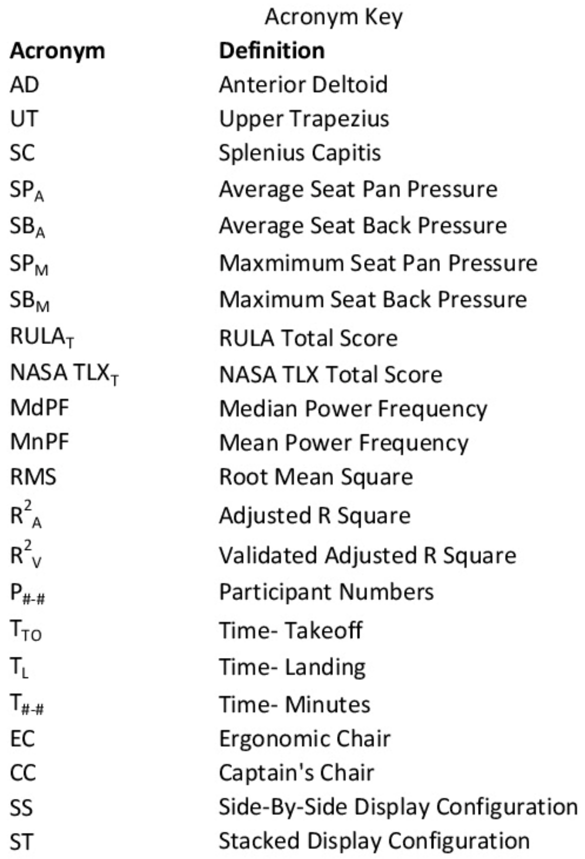
Study 2:

The independent variables (time, chair, display orientation, seat pressure, and RULA scores) from 12 participants in Study 1 were used to create stepwise linear regression models to estimate the muscle activity (median frequency and RMS amplitude) for six hours. Inclusion of independent variables in the regression equations were assessed at an alpha level of 0.05. Regression models were considered acceptable if they encompassed an adjusted R^2 (R^2_A) value of approximately 0.3 - 0.5. Although traditional statistics recommend an adjusted R^2 value of about 0.9 or greater for an acceptable level of goodness of fit, large variability found in human data necessitates a reduction in the qualification value. In order to validate the equations, the independent variables' data from the first four participants, the last four participants, and four randomly chosen participants were entered into the equations constructed from the independent variables' data from the remaining 12 participants. The models were assessed for goodness of fit using validated adjusted R^2 (R^2_V) and residual analysis. The best equations were used to predict muscle activity for six-hours using the six-hour muscle activity data as the dependent variable. Then, these models were assessed for goodness of fit using adjusted R^2 and residual analysis. Additionally, models were created for the six-hour data to predict median frequency and RMS amplitude over the six hours. Again, these models were validated using similar methods to the two-hour models' validation except six participants' data were used to create the models and two participants' data were used to validate the models. Finally, the two-hour and six-hour models were compared for commonalities in factors and numerical constants. All statistical analyses were performed using IMB SPSS Statistics for Windows, Version 24.0 (IBM Corporation, Armonk, NY).

CHAPTER IV

RESULTS

Table 3 Acronym Key.



Acronym Key

Acronym	**Definition**
AD	Anterior Deltoid
UT	Upper Trapezius
SC	Splenius Capitis
SP_A	Average Seat Pan Pressure
SB_A	Average Seat Back Pressure
SP_M	Maxmimum Seat Pan Pressure
SB_M	Maximum Seat Back Pressure
$RULA_T$	RULA Total Score
NASA TLX_T	NASA TLX Total Score
MdPF	Median Power Frequency
MnPF	Mean Power Frequency
RMS	Root Mean Square
R^2_A	Adjusted R Square
R^2_V	Validated Adjusted R Square
$P_{\#-\#}$	Participant Numbers
T_{TO}	Time- Takeoff
T_L	Time- Landing
$T_{\#-\#}$	Time- Minutes
EC	Ergonomic Chair
CC	Captain's Chair
SS	Side-By-Side Display Configuration
ST	Stacked Display Configuration

Table 4 Descriptive Statistics: Study 1 (2-hour Trials).

Descriptive Statistics: Study 1 (2-hour Trials)

Means

	MdPF				MnPF				RMS				NASA TLX$_T$	RULA$_T$
Time	AD	Biceps	UT	SC	AD	Biceps	UT	SC	AD	Biceps	UT	SC		
T_{TO}	54.725	93.337	51.476	48.386	100.622	134.590	90.729	89.736	1.238	0.870	0.933	7.885	71.466	2.470
$T_{0\text{-}30}$	56.186	94.833	52.389	47.987	104.396	135.599	93.252	88.863	1.478	1.025	1.061	7.732	36.455	2.490
$T_{30\text{-}60}$	56.486	91.068	53.829	48.446	104.434	131.591	92.854	88.078	1.594	1.153	1.192	8.287	40.928	2.625
$T_{60\text{-}90}$	56.669	89.943	54.550	47.730	103.941	130.337	92.578	87.062	1.688	1.248	1.374	9.259	40.995	2.617
$T_{90\text{-}120}$	57.546	89.687	56.432	49.656	105.118	129.766	93.242	88.649	1.719	1.260	1.484	8.730	41.097	2.569
T_L	56.640	97.677	57.723	50.053	109.997	140.246	98.392	92.504	0.857	0.938	0.932	7.152	64.693	2.605

	Seat Pressure				Discomfort										
Time	SP$_A$	SB$_A$	SP$_M$	SB$_M$	Ankle/Feet	Arm/Hand	Calf	Eye	Knee	Low Back	Neck/Head	Shoulder	Upper Back	Buttocks	Thigh
T_{TO}	8.432	2.609	48.049	27.280	0.016	0.164	0.031	0.195	0.023	0.125	0.305	0.102	0.102	0.016	0.016
$T_{0\text{-}30}$	9.655	3.221	51.388	33.805	0.094	0.063	0.031	0.406	0.063	0.320	0.609	0.164	0.227	0.133	0.031
$T_{30\text{-}60}$	10.902	3.421	60.149	38.616	0.172	0.055	0.047	0.617	0.078	0.430	0.852	0.266	0.375	0.242	0.047
$T_{60\text{-}90}$	12.285	3.696	68.445	42.288	0.188	0.063	0.070	0.734	0.086	0.539	1.016	0.297	0.469	0.320	0.070
$T_{90\text{-}120}$	13.006	3.413	73.187	39.157	0.266	0.125	0.125	0.844	0.125	0.703	1.000	0.383	0.477	0.508	0.086
T_L	13.826	3.590	81.745	36.368	0.273	0.133	0.117	0.984	0.148	0.703	1.016	0.320	0.516	0.516	0.125

Generally, the findings of Study 1 demonstrate most dependent variables increased as a product of time. This trend is most notable in RMS, Seat Pressure, and Discomfort. Although, less notable, similar trends were found in NASA TLX and RULA.

Table 5 Descriptive Statistics: Study 2 (6-hour Trials)

Descriptive Statistics: Study 2 (6-hour Trials)

Means

		MdPF				MnPF					RMS			
Time	AD	Biceps	UT	SC	AD	Biceps	UT	SC	AD	Biceps	UT	SC	NASA TLX_T	$RULA_T$
T_{TO}	44.206	72.569	38.294	38.919	92.313	126.875	80.256	87.975	1.240	0.813	0.986	5.614	39.604	2.125
$T_{0\text{-}30}$	46.044	70.844	41.869	41.606	91.794	121.069	83.069	85.425	1.532	1.273	1.236	6.829	21.146	2.250
$T_{30\text{-}60}$	47.119	69.656	41.919	46.344	90.694	116.538	80.013	86.475	1.844	1.434	1.426	8.098	19.333	2.250
$T_{60\text{-}90}$	45.919	66.788	44.406	44.400	91.088	113.944	81.575	83.738	1.773	1.626	1.562	8.328	24.708	2.313
$T_{90\text{-}120}$	46.831	66.794	45.444	43.219	90.913	113.181	83.069	82.056	1.798	1.826	1.547	8.193	24.313	2.625
$T_{120\text{-}150}$	47.831	71.163	46.256	43.975	94.206	115.469	84.638	83.675	1.809	1.652	1.468	8.215	23.833	2.375
$T_{150\text{-}180}$	47.350	72.150	48.120	46.275	93.469	116.694	83.662	87.556	1.943	1.816	1.724	9.203	30.604	2.500
$T_{180\text{-}210}$	45.881	72.375	47.042	43.881	92.719	117.556	83.604	86.188	1.795	1.531	1.376	8.102	22.563	2.625
$T_{210\text{-}240}$	48.994	73.644	51.521	44.988	94.031	116.138	85.573	83.675	1.867	1.825	1.573	8.656	25.896	2.625
$T_{240\text{-}270}$	53.119	76.438	48.831	44.944	97.663	119.650	86.063	87.719	1.623	1.598	1.365	7.608	22.583	2.375
$T_{270\text{-}300}$	54.750	74.525	50.875	44.100	96.988	115.550	86.675	84.319	1.903	1.794	1.580	8.225	24.188	2.813
$T_{300\text{-}330}$	53.906	75.675	50.606	44.925	99.738	118.156	87.825	82.631	1.529	1.538	1.331	8.384	26.958	2.750
$T_{330\text{-}360}$	56.456	78.975	51.131	46.738	100.488	119.506	86.138	85.294	1.825	1.675	1.763	9.358	25.813	2.688
T_L	57.275	91.725	48.419	48.588	103.906	132.600	88.313	92.338	1.109	1.057	1.246	7.109	40.250	2.500

		Seat Pressure								Discomfort					
Time	SP_A	SB_A	SP_M	SB_M	Ankle/Feet	Arm/Hand	Calf	Eye	Knee	Low Back	Neck/Head	Shoulder	Upper Back	Buttocks	Thigh
T_{TO}	8.335	2.294	58.533	45.313	0.000	0.000	0.000	0.000	0.000	0.000	0.188	0.000	0.063	0.000	0.000
$T_{0\text{-}30}$	9.581	3.083	68.357	59.643	0.000	0.000	0.000	0.125	0.125	0.000	0.250	0.000	0.063	0.000	0.000
$T_{30\text{-}60}$	10.620	3.252	72.089	64.111	0.125	0.000	0.125	0.250	0.250	0.125	0.313	0.063	0.063	0.250	0.125
$T_{60\text{-}90}$	11.125	3.006	73.046	50.201	0.125	0.000	0.125	0.250	0.250	0.375	0.188	0.063	0.188	0.250	0.250
$T_{90\text{-}120}$	12.294	2.828	91.458	38.879	0.125	0.000	0.125	0.500	0.250	0.625	0.188	0.250	0.313	0.500	0.250
$T_{120\text{-}150}$	10.683	2.538	83.493	34.803	0.125	0.000	0.125	0.500	0.250	0.750	0.188	0.250	0.188	0.500	0.250
$T_{150\text{-}180}$	11.777	2.666	86.218	34.940	0.125	0.000	0.125	0.500	0.250	0.750	0.188	0.125	0.313	0.625	0.500
$T_{180\text{-}210}$	13.032	2.999	87.964	47.376	0.125	0.000	0.125	0.625	0.250	0.875	0.313	0.250	0.438	0.750	0.500
$T_{210\text{-}240}$	14.455	2.182	96.759	26.867	0.125	0.000	0.125	0.375	0.250	1.000	0.313	0.375	0.313	0.875	0.500
$T_{240\text{-}270}$	11.367	2.421	79.318	43.150	0.250	0.125	0.250	0.375	0.250	0.875	0.438	0.375	0.438	1.000	0.500
$T_{270\text{-}300}$	11.775	2.052	82.830	31.530	0.125	0.125	0.125	0.625	0.500	0.875	0.438	0.500	0.563	1.125	0.625
$T_{300\text{-}330}$	12.929	2.209	97.901	37.917	0.125	0.125	0.250	0.750	0.563	1.000	0.438	0.375	0.563	1.250	0.875
$T_{330\text{-}360}$	13.284	1.809	86.522	35.348	0.125	0.125	0.250	0.750	0.625	1.125	0.438	0.500	0.688	1.250	0.750
T_L	14.403	1.569	89.516	31.197	0.125	0.125	0.250	0.875	0.500	1.250	0.438	0.500	0.688	1.250	0.750

Generally, the findings of Study 2 demonstrate most dependent variables increased as a product of time. However, this trend does not appear to be consistent. Rather, the mean values appear to oscillate at some time points with an overall increasing trend.

Study 1

Table 6 Study 1 (2-hour Trials) ANOVA results.

ANOVA Results- Study 1 (2-hour Trials)

	P-Values						
Variable	Display	Chair	Time	Display*Chair	Display*Time	Chair*Time	Display*Chair*Time
MdPF							
AD	0.569	**0.004**	0.462	0.798	0.484	0.698	0.148
Biceps	0.246	0.412	**0.013**	0.743	0.344	0.612	0.907
UT	0.682	0.314	**0.002**	**0.005**	0.514	0.536	0.769
SC	0.401	**0.042**	0.48	**0.023**	0.106	0.955	0.122
MnPF							
Anterior Deltoid	0.719	0.199	**0.021**	0.532	0.731	0.586	0.946
Biceps	0.777	0.141	**0.021**	0.584	0.554	0.384	0.916
Upper Trapezius	0.442	0.285	0.06	**0.005**	0.905	0.434	0.996
Splenius Capitis	0.716	0.055	0.242	0.25	0.483	0.297	0.567
RMS							
Anterior Deltoid	0.755	0.173	**0**	0.102	0.419	0.134	0.694
Biceps	0.779	0.107	**0.006**	0.194	0.546	0.403	0.194
Upper Trapezius	0.816	0.869	**0**	0.675	0.518	0.53	0.304
Splenius Capitis	0.779	0.725	**0.007**	**0.007**	0.297	0.129	0.084
Seat Pressure							
SP_A	0.517	**0.002**	**0**	0.58	0.718	0.239	0.667
SB_A	0.315	**0**	**0**	0.487	0.255	**0**	0.446
SP_M	0.307	**0.001**	**0**	0.345	0.11	**0.038**	0.426
SB_M	0.418	**0.002**	**0**	0.27	0.526	**0.007**	0.185
Discomfort							
Eye	0.567	0.054	**0.003**	0.857	0.334	0.264	0.99
Neck/ Head	0.608	0.381	**0**	0.487	0.074	0.177	0.719
Shoulder	0.532	0.87	**0.009**	0.303	0.529	0.508	0.93
Upper Back	0.676	0.837	**0.002**	0.593	0.168	0.83	0.373
Arm/Hand	0.385	0.523	0.302	0.964	0.837	0.588	0.864
Low Back	0.819	0.667	**0.001**	0.467	0.317	0.828	0.41
Buttock	0.039	0.019	**0.004**	0.093	0.189	0.078	0.749
Thigh	0.383	0.15	0.195	0.718	0.956	0.47	0.335
Knee	0.227	0.295	0.141	0.186	0.501	0.22	0.243
Calf	0.093	0.301	0.151	0.148	0.58	0.953	0.502
Ankle/ Feet	0.696	0.353	0.073	0.884	0.168	0.314	0.458
$RULA_T$	**0.015**	**0**	0.227	0.599	0.18	0.411	0.39
NASA TLX_T	0.692	0.416	**0.009**	0.244	0.243	0.081	0.798

Median Power Frequency (MdPF)

Statistical analysis revealed the AD MdPF was significantly affected by chair (p = .004, F (1,15) = 11.336, η_p^2 = .430), with the CC resulting in higher MdPFs than the EC (60.990 vs 51.760) (Table 6). Biceps MdPF was significantly affected by time (p = 0.013, F (2.479, 37.187) = 4.480, η_p^2 = .230); though post hoc analysis could not identify any differences between the time periods. UT MdPF was also significantly affected by time (p = .002, F (2.303, 34.540) = 6.651, η_p^2 = .307), with $T_{90\text{-}120}$ (56.432) having higher MdPFs than T_{TO} (51.476), $T_{0\text{-}30}$ (52.389), $T_{30\text{-}60}$ (53.829), and $T_{60\text{-}90}$ (54.550). Further, there was a significant Display*Chair interaction effect (p = .005, F (1,15) = 11.064, η_p^2 = .424), where higher UT MdPFs were found for the CC/ST (61.846) versus EC/ST (48.264), and CC/ST (61.846) versus CC/SS (50.380) (See Figure 7). SC MdPF was significantly affected by chair (p = .042, F (1,15) = 4.930, η_p^2 = .247) and the Display*Chair interaction (p = .023, F (1,15) = 6.455, η_p^2 = .301) where greater values were found for CC/ST (54.592) versus EC/ST (44.991).

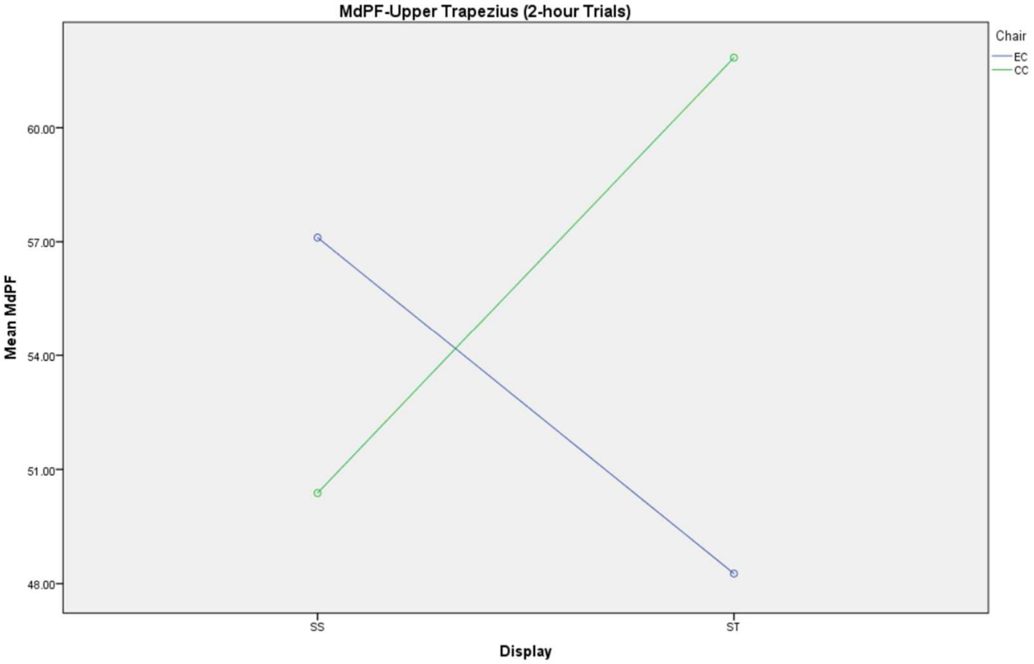


Figure 7 Study 1: Median Power Frequency Upper Trapezius Display*Chair Graph

Mean Power Frequency (MnPF)

AD MnPF was significantly affected by time (p = .021, F (1.658,24.873) = 4.909, η_p^2 = .247), with greater MnPFs for T_L (109.997) versus T_{TO} (100.622), T_{30-60} (104.434), T_{60-90} (103.941), and T_{90-120} (105.118). Biceps MnPF was significantly affected by time (p = .021, F(2.467, 37.010) = 3.959, η_p^2 = .209); though post hoc analysis could not identify differences in the time periods. UT MnPF resulted in a Display*Chair interaction significance (p = .005, F (1,15) = 10.750, η_p^2 = .417), with greater MnPF for CC/ST (101.306) vs CC/SS (89.159) and CC/ST (101.306) vs EC/ST (88.044). SC MnPF was not significantly affected by any of the independent variables.

Root Mean Square (RMS)

AD (p = .000, F (1.77, 29.650) = 17.641, η_p^2 = .559), Biceps RMS (p = .006, F (1.624,24.356) = 7.003, η_p^2 = .318), UT (p = .000, F (1.970,29.557) = 10.526, η_p^2 = . 412),and SC (p = .007, F (2.466,36.987) = 5.198, η_p^2 = .257) RMS values were significantly affected by time. For the AD, T_L (.857) resulted in lower RMS values than T_{0-30} (1.478), T_{30-60} (1.594), T_{60-90} (1.688) and T_{90-120} (1.719). For the Biceps greater RMS values were associated with T_{90-120} (1.260) compared to T_{TO} (.870) and T_{0-30} (1.025). UT RMS was significantly greater in T_{60-90} (1.374) and T_{90-120} (1.484) compared to T_{TO} (.933), T_{0-30} (1.061), T_{30-60} (1.192), and T_L (.932); and T_{30-60} (1.192) resulted in higher RMS values than T_{0-30} (1.061) (See Figure 8). For SC, T_L (7.152) resulted in lower RMS values than T_{30-60} (8.287) and T_{60-90} (9.259). There was also a significant Display*Chair interaction effect for SC RMS (p = .007, F (1,15) = 9.929, η_p^2 = .398) with greater RMS values for EC/ST (9.231) vs EC/SS (6.756) and CC/SS (9.309) vs EC/SS (6.756) (See Figure 9).

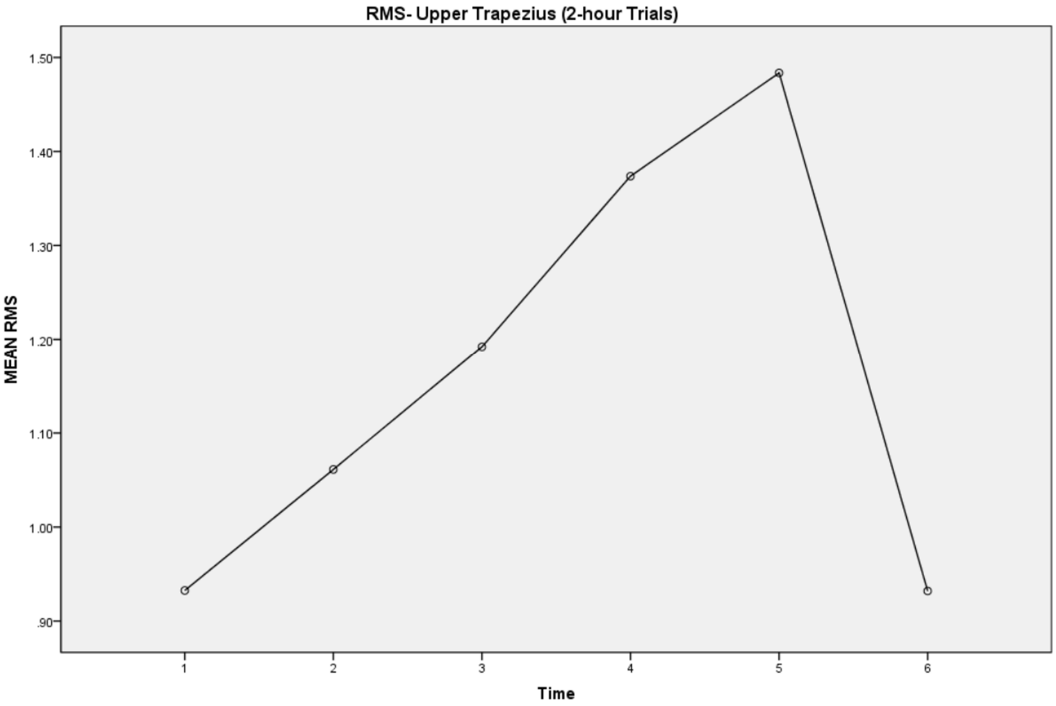


Figure 8 Study 1: Root Mean Square- Upper Trapezius Time Graph

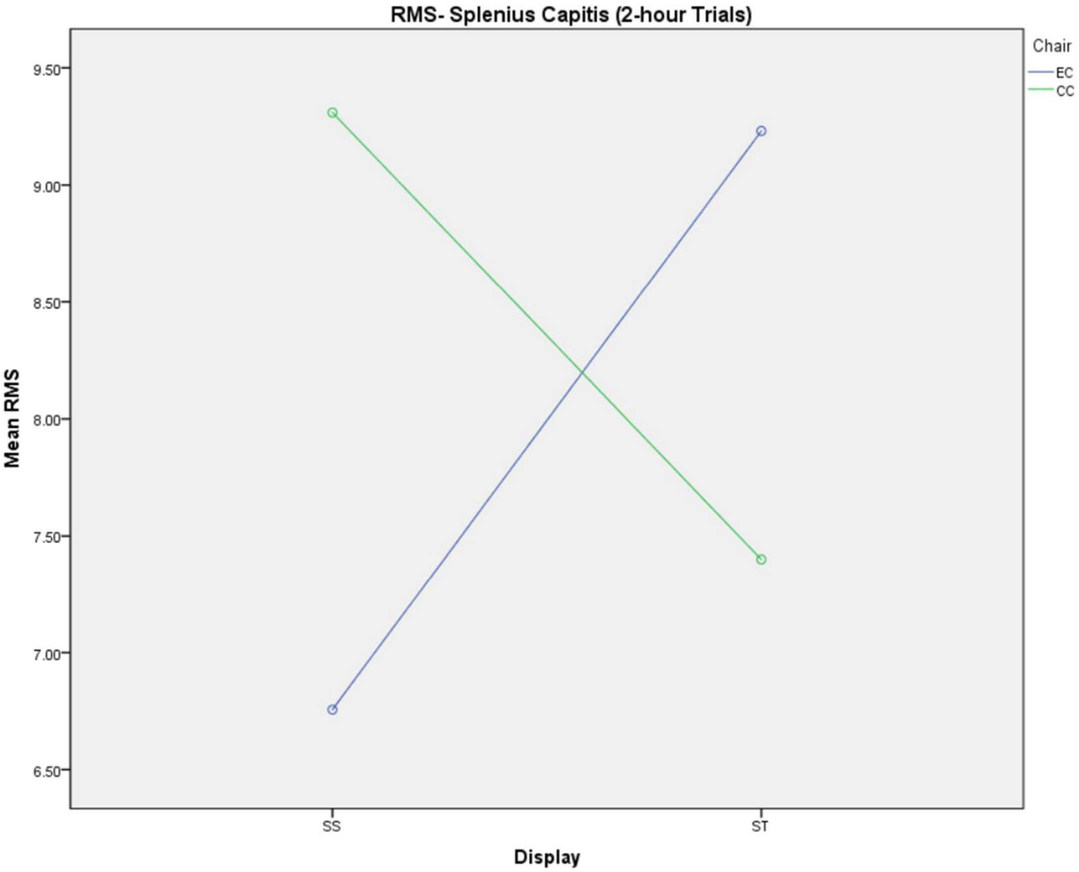


Figure 9 Study 1: Root Mean Square- Splenius Capitis Display*Chair Graph

Average Seat Pan (SP_A) and Seat Back (SB_A) Pressure

Statistical analysis revealed that SP_A was significantly affected by Chair (p = .002, F (1,15) = 14.523, η_p^2 = .492) with greater SP_A values for the EC (12.569) vs CC (10.133). Additionally, SP_A was significantly affected by Time (p = .000, F (1.308, 19.625) = 33.747, η_p^2 = .692) with greater SP_A values for $T_{90\text{-}120}$ (13.006) and T_L (13.826) compared to T_{To} (8.432), $T_{0\text{-}30}$ (9.655), $T_{30\text{-}60}$ (10.902), and $T_{60\text{-}90}$ (12.285). Moreover, greater SP_A values were found for $T_{30\text{-}60}$ (10.902) and $T_{60\text{-}90}$ (12.285) compared to T_{TO} (8.432 and $T_{0\text{-}30}$ (9.655). SB_A was significantly affected by Chair (p = .000, F (1,15) = 120.810, η_p^2 =

.890), Time (p = .000, F (1.845,27.673) = 17.406, η_p^2 = .537), and Chair*Time (p = .000, F (1.766,26.483) = 14.981, η_p^2 = .500) (See Figure 10). The Chair*Time interaction revealed greater SB_A for CC vs EC at T_{TO} (CC = 3.457 vs EC = 1.761), T_{0-30} (CC = 4.080 vs EC = 2.363), T_{30-60} (CC = 4.473 vs EC = 2.370), T_{60-90} (CC = 4.879 vs EC = 2.512), T_{90-120} (CC = 4.782 vs EC = 2.044), and T_L (CC = 5.417 vs EC = 1.764). Moreover, for EC alone, lower SB_A values were found for T_{TO} (1.761) vs T_{0-30} (2.363), T_{30-60} (2.370), and T_{60-90} (2.512) while, for CC alone, lower SB_A values were found for T_{TO} (3.457) vs T_{0-30} (4.080) and for T_{TO} (3.457) and T_{0-30} (4.080) vs T_{30-60} (4.473), T_{60-90} (4.879), T_{90-120} (4.782), and T_L (5.417).

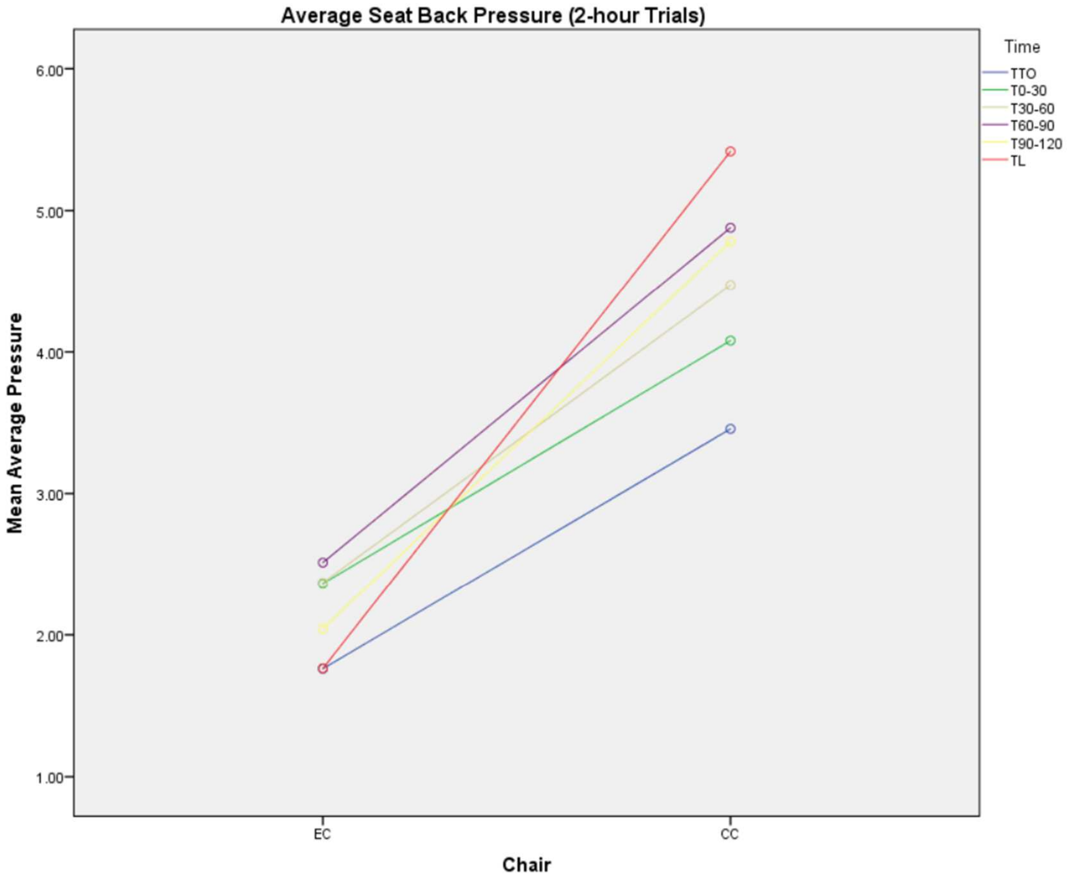


Figure 10 Study 1: Average Seat Back Pressure Chair*Time Graph

Maximum Seat Pan (SP_M) and Seat Back (SB_M) Pressure

Statistical analysis revealed SP_M was significantly affected by Chair (p = .001, F (1,15) = 17.271, .535), Time (p = .000, F (2.462,36.927) = 30.980, η_p^2 = .674), and the Chair*Time interaction (p = .038, F (2.056, 30.836) = 3.618, η_p^2 = .194) (See Figure 11). The Chair*Time interaction revealed greater SP_M values for EC vs CC at T_{TO} (EC = 59.046 vs CC = 37.051), $T_{0\text{-}30}$ (EC = 58.730 vs CC = 44.046), $T_{30\text{-}60}$ (EC = 65.940 vs CC =54.359), $T_{60\text{-}90}$ (EC = 76.784 vs CC =60.105), $T_{90\text{-}120}$ (EC = 81.213 vs CC =65.161), and T_L (EC = 99.775 vs CC = 63.714). Moreover, for the EC alone, greater SP_M was found for T_L (99.775) vs T_{TO} (59.046), T_{0-30} (58.730), T_{30-60} (65.940), T_{60-90} (76.784), and T_{90-120} (81.213), and T_{90-120} (81.213) resulted in greater SP_M vs T_{0-30} (58.730) and T_{30-60} (65.940). For the CC alone, lesser SP_M was found for T_{TO} (37.051) vs T_{0-30} (44.046) and for T_{TO} (37.051) and T_{0-30} (44.046) vs to T_{30-60} (54.359), T_{60-90} (60.105), T_{90-120} (65.161), and T_L (63.714). SB_M was significantly affected by Chair (p = .002, F (1,15) = 13.813, η_p^2 = .479), Time significance (p = .000, F (3.484,52.261) = 11.562, η_p^2 =.435), and the Chair*Time interaction significance (p = .007, F (5,75) =3.499, η_p^2 =.189). For the Chair*Time interaction, greater SB_M values were found for CC vs EC at T_{60-90} (CC = 49.977 vs EC = 34.600), T_{90-120} (CC = 47.866 vs EC = 30.448), and T_L (CC = 47.133 vs EC = 25.603). Moreover, for the EC alone, greater SB_M values were found for T_{60-90} (34.600) vs T_L (25.603) while, for the CC alone, lower SB_M values were found for T_{TO} (29.139) vs T_{30-60} (42.470), T_{60-90} (49.997), T_{90-120} (47.866), and T_L (47.133) and for T_{0-30} (35.770) vs T_{60-90} (49.977).

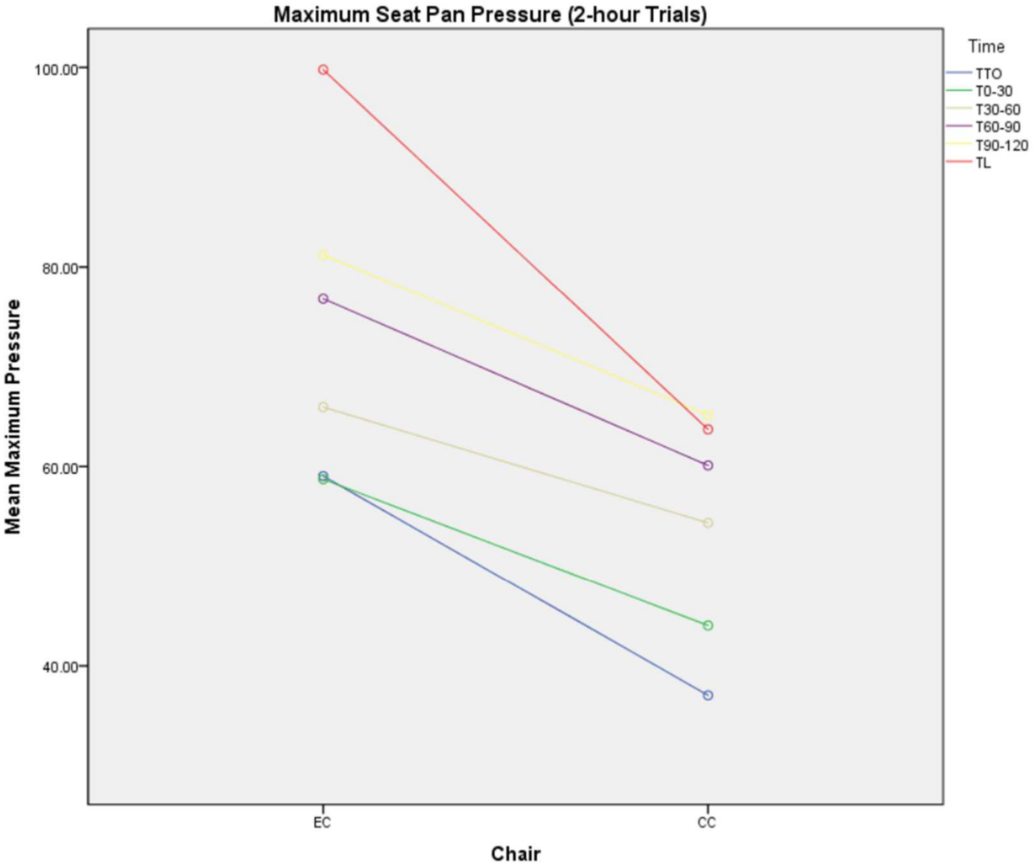


Figure 11 Study 1: Maximum Seat Pan Pressure Chair*Time Graph

Rapid Upper Limb Assessment -Total Scores ($RULA_T$)

Statistical analysis revealed $RULA_T$ was significantly affected by Display (p = .015, F (1,15) = 7.517, η_p^2 = .334) and Chair (p = .000, F (1,15) = 58.031, η_p^2 = .795). Greater $RULA_T$ scores were found for the SS configuration (2.621) vs the ST configuration (2.484), and greater $RULA_T$ were found for the CC (2.881) vs the EC (2.224).

Body Discomfort

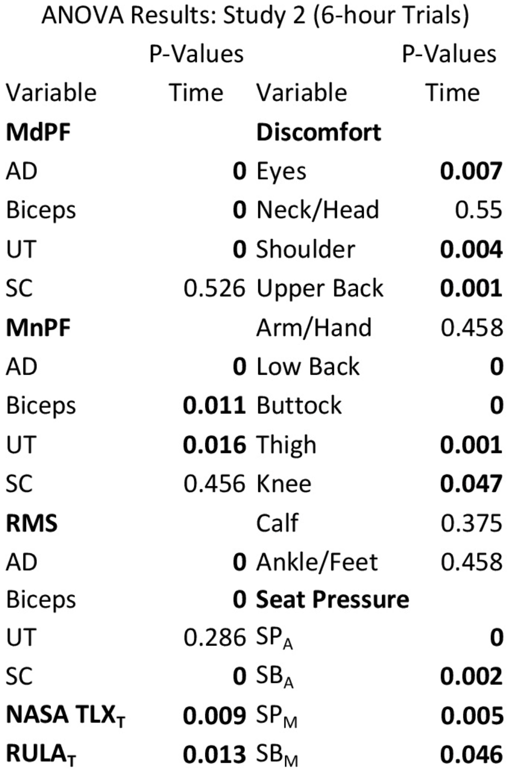
Statistical analysis revealed Eye (p = .003, F (1.851,27.762) = 7.792, η_p^2 = .342), Neck and Head (p = .000, F (2.033, 30.494) = 17.124, η_p^2 = .533), Shoulder (p = .009, F (2.172, 32.574) = 5.274, η_p^2 = .260), Upper Back (p = .002, F (2.513,37.688) = 6.651, η_p^2 = .307), Lower Back (p = .001, F (1.683,25.245) = 9.929, η_p^2 = .398), and Buttocks (p = .004, F (1.296,19.433) = 9.344, η_p^2 = .384) discomfort were significantly affected by Time. For the Eye, lower ratings were found for T_{TO} (.195) vs T_L (.984). For the Neck and Head, lower ratings were found for T_{TO} (.305) vs T_{0-30} (.609) and T_{30-60} (.852) and for T_{TO} (.305) and T_{0-30} (.609) vs T_{60-90} (1.016), T_{90-120} (1.000), and T_L (1.016). For the Shoulder, no pairwise differences were detected. For the Upper Back, lower ratings were found for T_{TO} (.102) vs T_L (.516). For the Lower Back, lower ratings were found for T_{TO} (.125) and T_{30-60} (.430) vs T_{90-120} (.703) and T_L (.703). For the Buttocks, no pairwise differences were detected.

NASA Task Load Index– Total Scores (NASA TLX$_T$)

Statistical analysis revealed that NASA TLX$_T$ scores were significantly affected by Time (p = .009, F (1.236, 18.537) = 7.749, η_p^2 = .341) with lower ratings for T_{0-30} (36.455) vs T_{30-60} (40.928) and T_{90-120} (41.097).

Study 2: Repeated Measures ANOVAs

Table 7 Study 2 (6-hour Trials) ANOVA results.



ANOVA Results: Study 2 (6-hour Trials)

	P-Values		P-Values
Variable	Time	Variable	Time
MdPF		**Discomfort**	
AD	**0**	Eyes	**0.007**
Biceps	**0**	Neck/Head	0.55
UT	**0**	Shoulder	**0.004**
SC	0.526	Upper Back	**0.001**
MnPF		Arm/Hand	0.458
AD	**0**	Low Back	**0**
Biceps	**0.011**	Buttock	**0**
UT	**0.016**	Thigh	**0.001**
SC	0.456	Knee	**0.047**
RMS		Calf	0.375
AD	**0**	Ankle/Feet	0.458
Biceps	**0**	**Seat Pressure**	
UT	0.286	SP_A	**0**
SC	**0**	SB_A	**0.002**
NASA TLX_T	**0.009**	SP_M	**0.005**
$RULA_T$	**0.013**	SB_M	**0.046**

Median Frequency (MdPF)

Statistical analysis revealed AD (p = .000, F (13,91) = 4.893, η_p^2 = .411), Biceps (p = .000, F (13,91) = 5.665, η_p^2 = .447), and UT (p = .000, F (13,91) = 4.450, η_p^2 = .389) MdPFs were significantly affected by Time (Table 7); however, no pairwise differences were found for any of the muscles. Statistical analysis revealed no significance for SC MdPF data.

Mean Frequency (MnPF)

Statistical analysis revealed AD (p = .000, F (13,91) = 3.630, η_p^2 = .341), Biceps (p = .011, F (13,91) = 2.317, η_p^2 = .249), and UT (p = .016, F (13,91) = 2.182, η_p^2 = .238)

MnPFs were significantly affected by Time; though no pairwise differences were found for any muscle. Statistical analysis revealed no significance for SC' MnPF data.

Root Mean Square (RMS)

Statistical analysis revealed AD ($p = .000$, $F(13,91) = 5.504$, $\eta_p^2 = .440$), Biceps ($p = .000$, $F(13,91) = 3.421$, $\eta_p^2 = .328$), and SC ($p = .000$, $F(13,91) = 3.931$, $\eta_p^2 = .360$) RMS values were significantly affected by Time. No pairwise significance was found for the AD or Biceps. For SC, greater RMS was found for $T_{90\text{-}120}$ (8.193) vs T_L (7.109). Statistical analysis revealed no significance for UT RMS data.

Average Seat Pressure

Statistical analysis revealed SP_A ($p = .000$, $F(13,91) = 4.402$, $\eta_p^2 = .386$) and SB_A ($p = .000$, $F(13,91) = 2.864$, $\eta_p^2 = .290$) were significantly affected by Time; however, no pairwise differences were found for either measure.

Maximum Seat Pressure

Statistical analysis revealed SP_M ($p = .005$, $F(13,91) = 2.542$, $\eta_p^2 = .266$) and SB_M ($p = .046$, $F(13,91) = 1.859$, $\eta_p^2 = .210$) were significantly affected by Time; however, no pairwise differences were found for either measure.

Rapid Upper Limb Assessment- Total Scores ($RULA_T$)

Statistical analysis revealed R ($p = .013$, $F(26,182) = 1.807$, $\eta_p^2 = .205$) was significantly affected by Time; however, no pairwise differences were found.

Body Discomfort

Statistical analysis revealed Eye (p = .007, F (13,91) = 2.439, η_p^2 = .258), Shoulder (p = .004, F (13,91) = 2.594, η_p^2 = .270), Upper Back (p = .001, F (13,91) = 3.198, η_p^2 = .314), Low Back (p = .000, F (13,91) = 4.440, η_p^2 = .388), Buttocks (p = .000, F (13,91) = 5.545, η_p^2 = .442), Thigh (p = .001, F (13,91) = 3.086, η_p^2 = .306), and Knee (p = .047, F (13,91) = 1.850, η_p^2 = .209) discomfort ratings were significantly affected by Time. No pairwise differences were detected for any of these body parts. Statistical analysis revealed no significance for Neck and Head, Arm and Hand, Calf, or Ankle and Feet Discomfort data.

NASA Task Load Index- Total Scores (NASA TLX_T)

Statistical analysis revealed NASA TLX_T ratings were significantly affected by Time (p = .009, F (13,91) = 2.373, η_p^2 = .253); though no pairwise differences were detected.

Study 2: Prediction Equations

Median Frequency (MdPF)

Two-Hour Prediction Equations

Regression analysis found acceptable prediction equations based on the participant data used, but for all models and muscles, model performance was very poor (Table 8). For the AD, adjusted R^2 (R^2_A) values for the modeling building data ranged from .578 (P_{1-16}) to .650 (P_{5-16}). Validated adjusted R^2 (R^2_V) values ranged from -.580 (P_{3-14}) to .192 (P_{5-16}). For the Biceps, R^2_A ranged from .057 (P_{1-12}) to .217 (P_{5-16}) and R^2_V ranged from -2.649 (P_{5-16}) to -.807 (P_{3-14}). For the UT, R^2_A ranged from .381 (P_{5-16}) to .591 (P_{1-12}) and R^2_V ranged from -3.301 (P_{1-12}) to -.340 (P_{3-14}). For the SC, R^2_A ranged from .268 (P_{1-16}) to .427 (P_{5-16}) and R^2_V ranged from -1.871 (P_{1-12}) to -.146 (P_{5-16}).

Table 8 Median Frequency (2-hour Trials) prediction equations.

Median Frequency- 2-hour Trials																					
				Discomfort											Seat Pressure				$RULA_T$	$NASA\ TLX_T$	Time
Prediction Equation	R^2_A	R^2_V	Constant	Ankle/Feet	Arm/Hand	Calf	Eye	Knee	Low Back	Neck/Head	Shoulder	Upper Back	Buttock	Thigh	SP_A	SB_A	SP_M	SB_M			
AD P1-16	0.578		45.092				-4.657	-4.540		-15.969						4.298				-0.034	3.374
AD P1-12	0.591	-0.328	34.810	18.882	-35.054				3.388	-12.945			-11.900			6.730					3.770
AD P5-16	0.650	0.192	45.657				-7.734			-15.958						8.695		-0.382			3.710
AD P3-14	0.595	-0.580	28.194				-7.288			-12.194						7.399	0.245			-0.044	
Biceps P1-16	0.197		86.432	20.128		-18.681				10.312											
Biceps P1-12	0.057	-0.330	99.477			-14.156															
Biceps P5-16	0.217	-2.649	33.467							16.684									21.212		
Biceps P3-14	0.203	-0.807	99.213	25.621		-25.174															
UT P1-16	0.457		22.951	26.497			-13.691					8.486			2.933	5.551	-0.140				-14.199
UT P1-12	0.591	-3.301	12.783				-9.820			-11.151		11.968			2.754	5.206		0.213			
UT P5-16	0.381	-1.268	36.689	22.251							-10.472	17.871		-26.049	1.117						
UT P3-14	0.445	-0.340	15.658	29.973			-19.457								2.750	6.754					
SC P1-16	0.268		46.564				-5.015		3.811			-7.124	5.358								
SC P1-12	0.340	-1.871	47.891				6.969					-6.633	10.916								
SC P5-16	0.427	-0.146	43.019		-19.881					5.819			3.438				-0.074	0.205			
SC P3-14	0.310	-1.743	55.079					-11.869	4.075							4.392			-7.116		

Generally, median frequency prediction equations resulted in adequate adjusted R^2s and inadequate validated adjusted R^2s. Some trends can be seen such as Neck/Head Discomfort and Average Seat Back Pressure for the Anterior Deltoid and Average Seat Pan and Back pressure, Eye Discomfort for the Upper Trapezius.

Six-Hour Prediction Equations

Model performance was improved when using 6-hour data (Table 9). For the AD, R^2_A ranged from .725 (P_{1-8}) to .824 (P_{1-6}) and R^2_V ranged from -4.418 (P_{3-8}) to -2.006 (P_{1-6}). For the Biceps, R^2_A ranged from .284 (P_{1-6}) to .494 (P_{3-8}) and R^2_V ranged from -7.730 (P_{1-6}) to -.807 (P2-7). For the UT, R^2_A ranged from .685 (P_{3-8}) to .838 (P_{1-6}) and R^2_V ranged from -13.416 (P_{3-8}) to -.010 (P_{2-7}). For the SC, R^2_A ranged from .548 (P_{2-7}) to .565 (P_{1-8}) and R^2_V ranged from -.712 (P_{3-8}) to .280 (P_{1-6}).

Table 9 Median Frequency (2-hour Trials) prediction equations.

Median Frequency- 6-hour Trials																					
				Discomfort											Seat Pressure				$RULA_T$	NASA TLX_T	Time
Prediction Equation	R^2_A	R^2_V	Constant	Ankle/Feet	Arm/Hand	Calf	Eye	Knee	Low Back	Neck/Head	Shoulder	Upper Back	Buttock	Thigh	SP_A	SB_A	SP_M	SB_M			
AD P1-8	0.725		59.919			-6.403			5.588	-13.430	15.806		-2.920			-1.354	-0.199			0.119	0.739
AD P1-6	0.824	-2.006	59.460			-11.826			2.529	-16.865	14.616					-1.575	-0.133			0.104	0.881
AD P3-8	0.785	-4.418	60.648			-10.642			5.042	-16.752	17.526	7.015					-0.247			0.113	0.602
AD P2-7	0.796	-3.505	62.671			-11.546			2.603	-13.197	12.267					-2.072	-0.148				0.995
Biceps P1-8	0.450		85.947						2.852		7.388	10.755							-7.945		
Biceps P1-6	0.284	-7.730	70.456								8.656										0.795
Biceps P3-8	0.494	-0.921	87.598					7.812		-9.847		14.363					-0.087		-7.424		0.594
Biceps P2-7	0.428	-0.807	86.506									10.766							-6.637	-0.163	0.954
UT P1-8	0.704		40.968				5.078		-5.784	-13.767	6.841		7.993		-1.208	-0.923	0.255				
UT P1-6	0.838	-3.727	38.869				7.326			-19.966	12.340				-1.463		0.261				
UT P3-8	0.685	-13.416	34.383				4.402		-7.075		4.310		4.225				0.144				0.622
UT P2-7	0.721	-0.010	42.034						-5.929				6.139		-1.996	-1.303	0.359				0.641
SC P1-8	0.565		58.983	4.975					-2.861						-1.499	-1.850	0.107			-0.206	0.789
SC P1-6	0.558	0.280	61.198												-2.306	-1.284	0.159			-0.192	0.659
SC P3-8	0.558	-0.712	59.110				5.907		-5.020	-7.866					-1.053					-0.208	1.058
SC P2-7	0.548	0.265	57.569			4.996			-3.085						-2.165		0.102			-0.131	1.191

Generally, median frequency prediction equations resulted in adequate adjusted R^2s and inadequate validated adjusted R^2s. Some trends can be seen such as Discomforts, Maximum Seat Pan Pressure, and Time for the Anterior Deltoid, Seat Pressures, and Discomforts for the Upper Trapezius, and Seat Pressures, NASA TLX, and Time for the Splenius Capitis.

Using Two Hour Prediction Equations for Six-hour data--MdPF

No single 2-hour model performed better than another for predicting MdPF, therefore, the model built using all participants was selected to determine if 2-hour data could predict MdPF for a 6-hour test session. For all muscles, the 6 hour predicted data had adjusted R2 values ranging from -2.231 (AD Model) to -.655 (SC model) (Table 10). All models resulted in highly dispersed residuals and a consistent over-prediction of MdPF values. Therefore, 2-hour models are not sufficient to predict MdPF over a 6-hour period for any of the muscles studied. Given the similarities in the findings between MdPF and MnPF, regression equations were not formulated for MnPF.

Table 10 Median Frequency- 2-hour Trial’s Prediction Equations for 6-hour Data.

Median Frequency- 2-hour Trials' Prediction Equations for 6-hour Data																					
				Discomfort											Seat Pressure				$RULA_T$	NASA TLX_T	Time
Prediction Equation	R^2_A	R^2_V	Constant	Ankle/Feet	Arm/Hand	Calf	Eye	Knee	Low Back	Neck/Head	Shoulder	Upper Back	Buttock	Thigh	SP_A	SB_A	SP_M	SB_M			
AD P1-16	0.578	-2.231	45.092				-4.657	-4.540		-15.969						4.298				-0.034	3.374
Biceps P1-16	0.197	-1.099	86.432	20.128		-18.681				10.312											
UT P1-16	0.457	-1.639	22.951	26.497			-13.691					8.486			2.933	5.551	-0.140				-14.199
SC P1-16	0.268	-0.655	46.564				-5.015		3.811			-7.124	5.358								

Generally, median frequency prediction equations resulted in adequate adjusted R^2s and inadequate validated adjusted R^2s. There do not appear to be consistent trends in variables between prediction equations.

Root Mean Square (RMS)

Two-Hour Prediction Equations

Regression analysis found acceptable prediction equations based on the participant data used, but for all models and muscles, model performance was very poor (Table 11) For the AD, R^2_A values for the modeling building data ranged from .059 ($P_{1\text{-}12}$) to .291 ($P_{3\text{-}14}$). R^2_V values ranged from -5.247 ($P_{5\text{-}16}$) to .099 ($P_{1\text{-}12}$). For the Biceps, R^2_A ranged from .168 ($P_{5\text{-}16}$) to .246 ($P_{3\text{-}14}$) and R^2_V ranged from -2.609 ($P_{5\text{-}16}$) to -.247 (P1-12). For the UT, R^2_A ranged from .238 ($P_{1\text{-}12}$) to .388 ($P_{5\text{-}16}$) and R^2_V ranged from -4.511 ($P_{5\text{-}16}$) to -.181 ($P_{1\text{-}12}$). For the SC, R^2_A ranged from .561 ($P_{1\text{-}16}$) to .690 ($P_{1\text{-}12}$) and R^2_V ranged from -14.511 ($P_{3\text{-}14}$) to -9.870 ($P_{5\text{-}16}$).

Table 11 Root Mean Square (2-hour Trials).

Root Mean Square- 2-hour Trials																					
				Discomfort											Seat Pressure				$RULA_T$	NASA TLX_T	Time
Prediction Equation	R^2_A	R^2_V	Constant	Ankle/Feet	Arm/Hand	Calf	Eye	Knee	Low Back	Neck/Head	Shoulder	Upper Back	Buttock	Thigh	SP_A	SB_A	SP_M	SB_M			
AD P1-16	0.083		1.372						-0.206												
AD P1-12	0.059	0.099	1.355						-0.183												
AD P5-16	0.262	-5.247	0.985	-0.682					-0.303			0.593						0.017			
AD P3-14	0.291	-2.063	0.979	-0.580					-0.334			0.613						0.014			
Biceps P1-16	0.223		0.950								0.481	-0.304				-0.126					0.069
Biceps P1-12	0.214	-0.247	1.149								0.563	-0.238				-0.138					
Biceps P5-16	0.168	-2.609	0.648																	0.002	0.085
Biceps P3-14	0.246	-0.922	0.894						-0.163		0.635										
UT P1-16	0.282		0.942								0.296			-0.715						0.004	
UT P1-12	0.238	-0.181	0.922											-0.467						0.004	
UT P5-16	0.388	-4.511	0.756									-0.579								0.006	0.085
UT P3-14	0.337	-0.929	1.043									-0.512			-0.043					0.005	0.139
SC P1-16	0.561		6.155						-1.210		4.179			-6.028	-0.522		0.067			0.037	
SC P1-12	0.690	-12.053	9.597						-1.813		3.052	-3.650	-2.606		-0.688					0.051	1.907
SC P5-16	0.590	-9.870	4.922		-5.617						6.957			-7.725						0.042	
SC P3-14	0.639	-14.511	5.870		-7.630				-1.942		9.556			-5.758						0.033	

Generally, root mean square prediction equations resulted in adequate adjusted R^2s and inadequate validated adjusted R^2s. Some trends can be seen such as Low Back Discomfort for the Anterior Deltoid, NASA TLX for the Upper Trapezius, and Shoulder Discomfort and NASA TLX for the Splenius Capitis.

Six-Hour Prediction Equations

Model performance was improved when using 6-hour data (Table 12). For the AD, R^2_A ranged from .274 (P_{1-8}) to .515 (P_{2-7}) and R^2_V ranged from -1.764 (P_{3-8}) to -.133 (P_{1-6}). For the Biceps, R^2_A ranged from .578 (P_{2-7}) to .665 (P_{3-8}) and R^2_V ranged from -8.435 (P_{3-8}) to .115 (P_{1-6}). For the UT, R^2_A ranged from .363 (P_{3-8}) to .436 (P_{1-8}) and R^2_V ranged from -3.078 (P_{3-8}) to .199 (P_{1-6}). For the SC, R^2_A ranged from .672 (P_{1-8} & P_{2-7}) to .747 (P_{1-6}) and R^2_V ranged from -19.101 (P_{1-6}) to -8.494 (P_{2-7}).

Table 12 Root Mean Square (6-hour Trials).

Root Mean Square- 6-hour Trials																					
				Discomfort											Seat Pressure				RULA$_T$	NASA TLX$_T$	Time
Prediction Equation	R^2_A	R^2_V	Constant	Ankle/Feet	Arm/Hand	Calf	Eye	Knee	Low Back	Neck/Head	Shoulder	Upper Back	Buttock	Thigh	SP$_A$	SB$_A$	SP$_M$	SB$_M$			
AD P1-8	0.274		2.608					0.328							-0.046				-0.192		
AD P1-6	0.374	-1.764	2.342	0.659						-0.311					-0.046						
AD P3-8	0.280	-0.133	2.280					0.217											-0.199	-0.006	
AD P2-7	0.515	-0.775	2.150	0.495			0.231			-0.587					-0.043						
Biceps P1-8	0.612		1.607		-0.707				-0.323	-0.913	1.195					-0.262			0.475	-0.014	
Biceps P1-6	0.584	0.115	2.076							-0.759	1.520			-0.507		-0.170				-0.009	
Biceps P3-8	0.665	-8.435	1.506		-1.050				-0.308	-0.814	1.529					-0.308			0.523	-0.013	
Biceps P2-7	0.578	0.024	2.477							-0.484	1.444			-0.408	-0.069	-0.129					
UT P1-8	0.436		1.974				0.401		-0.232	-0.630	0.554					-0.204					
UT P1-6	0.403	0.199	2.125				0.426		-0.228							-0.270					
UT P3-8	0.363	-3.078	1.831								0.971					-0.227					
UT P2-7	0.384	-0.009	2.020				0.489						-0.242			-0.278					
SC P1-8	0.672		15.998							-7.650	8.045	3.771	-2.193		-0.346	-1.381					
SC P1-6	0.747	-19.101	13.800				1.920			-11.318	8.100	4.377	-4.322			-1.506					
SC P3-8	0.728	-13.412	12.184		-9.344					-4.165	11.634	4.383	-2.296			-1.662					
SC P2-7	0.672	-8.494	14.469							-6.114	9.424		-2.875			-1.822					

Generally, root mean square prediction equations resulted in adequate adjusted R^2s and inadequate validated adjusted R^2s. Some trends can be seen for Discomforts and Seat Pressures for all equations.

Two Hour Prediction Equations with Six-Hour Data as Dependent Variable

No single 2-hour model performed better than another for predicting RMS, therefore, the model built using all participants was selected to determine if 2-hour data could predict RMS for a 6-hour test session. For all muscles, the 6 hour predicted data had adjusted R^2 values ranging from -.824 (AD Model) to .097 (Biceps model) (Table 13). All models resulted in highly dispersed residuals and a consistent under-prediction of RMS values. Therefore, 2-hour models are not sufficient to predict RMS over a 6-hour period for any of the muscles studied.

Table 13 Root Mean Square- 2-hour Trials' Prediction Equations for 6-hour Data.

Root Mean Square- 2-hour Trials' Prediction Equations for 6-hour Data																					
				Discomfort											Seat Pressure				$RULA_T$	$NASA\ TLX_T$	Time
Prediction Equation	R^2_A	R^2_V	Constant	Ankle/Feet	Arm/Hand	Calf	Eye	Knee	Low Back	Neck/Head	Shoulder	Upper Back	Buttock	Thigh	SP_A	SB_A	SP_M	SB_M			
AD P1-16	0.083	-0.824	1.372						-0.206												
Biceps P1-16	0.223	0.097	0.950								0.481	-0.304				-0.126					0.069
UT P1-16	0.282	-0.712	0.942								0.296			-0.715						0.004	
SC P1-16	0.561	-0.107	6.155						-1.210		4.179			-6.028	-0.522		0.067			0.037	

Generally, root mean square prediction equations resulted in adequate adjusted R^2s and inadequate validated adjusted R^2s. There do not appear to be consistent trends in variables between prediction equations.

CHAPTER V

DISCUSSION AND CONCLUSION

Study 1:

The purpose of this study was to quantify muscle activity, discomfort, posture, seat pressure, and workload at four UAS control station design over a 2-hour and 6-hour period to identify design parameters that reduce fatigue and risk of musculoskeletal injury and improve performance and comfort. It was hypothesized that muscle activity, discomfort, posture, seat pressure, and workload would differ over time and between workstation designs. These hypotheses were largely supported by the study's findings. Generally, mean and median power frequency (MnPF and MdPF) and root mean square (RMS) were found to be highest when participants were exposed to the Captain's Chair and Stacked Display combination. RMS values were found to increase over time; however, RMS amplitude was generally significantly lower for both Takeoff and Landing phases. Seat pressure results showed increased pressure for both seat back and pan over time independent of chair and display configuration. The Ergonomic Chair demonstrated greater seat pan pressure values while greater seat back pressures were associated with the Captain's Chair. Like MnPF, MdPF and RMS, both discomfort and workload increased over time. Finally, postural analysis revealed worse postures were associated with the Side-by-Side Display configuration and the Captain's Chair, separately.

Muscle Activity

Literature has long established fatigue in electromyography signals as a decrease in MnPF, MdPF and MVC and an increase in RMS amplitude over time (C J De Luca, 1984; Madeleine, Farina, Merletti, & Arendt-Nielsen, 2002; Merletti, 1990; Merletti, Lo Conte, & Orizio, 1991). However, these findings are specifically associated with static contractions. More comprehensive studies exploring contractions with varying kinematics and kinetics suggest EMG frequency parameters may be influenced by factors beyond fatigue (Doheny, Lowery, FitzPatrick, & O'Malley, 2008; Phinyomark, Thongpanja, Hu, Phukpattaranont, & Limsakul, 2012; Potvin, 1997). These factors are especially relevant to our study because EMG data was collected for the full duration of the study incorporating dynamic contractions with varying joint angles and force demands.

Our results demonstrate MnPFs and MdPFs were higher in the Captain's Chair and Stacked Display combination. The Captain's Chair's fixed backrest angle of 110° and non-tilting headrest was associated with increased neck flexion as noted by the significantly greater Rapid Upper Limb Assessment (RULA) total scores. Acting as a neck extensor, the force requirements of the upper trapezius likely increased during neck flexion to stabilize the neck and head in a mechanically disadvantageous position. This posture associated with the Captain's Chair likely influenced MnPFs and MdPFS as literature suggests these decrease as joint angles increase (Bazzy, Korten, & Haddad, 1986; Potvin, 1997) and more pronounced frequency shifts have been associated with shorter muscle lengths (Doud & Walsh, 1995; Potvin, 1997). Moreover, findings demonstrate MnPFs and MdPFs tend to shift towards higher frequencies as force requirements increase (Doheny et al., 2008; Gerdle, Eriksson, & Brundin, 1990; Hagberg & Ericson, 1982). Therefore, the increased muscle length and force requirements of the upper trapezius in this posture likely resulted in increased mean and median frequencies. Similarly, the significantly greater median frequency findings for the anterior deltoid when utilizing the Captain's Chair likely resulted from increased force production requirements. The 110° backrest inclination angle likely positioned the shoulder and arm farther from the keyboard and mouse requiring excessive shoulder flexion and elbow extension. Such movements demand more force and likely larger, fast oxidative glycolytic (Type II) and fast glycolytic (Type IIx) muscle fibers which have been associated with shifts to higher frequencies (Kupa, Roy, Kandarian, & De Luca, 1995). Due to the probability of the aforementioned confounding factors influencing the EMG frequency data, it is unreasonable to apply the traditional definition of shifts to lower frequencies as fatigue to this study. These findings suggest MnPF and MdPF may not be appropriate measures of fatigue during dynamic contractions.

The findings in our study suggest biceps' and upper trapezius' RMS amplitude increased over time. These results could be an indication of fatigue as an increase in EMG amplitude over time has been defined as an indicator of local muscular fatigue (Hermans & Spaepen, 1995; Kallenberg, Schulte, Disselhorst-Klug, & Hermens, 2007; Kleine, Schumann, Bradl, Grieshaber, & Scholle, 1999). Nonetheless, an increase in EMG amplitude over time as an indicator of fatigue is largely founded by studies analyzing isometric contractions at specific muscle lengths. As with EMG frequency, EMG amplitude is influenced by factors other than fatigue such as muscle length and force production demands (Doheny et al., 2008; Milner-Brown & Stein, 1975). Several studies have reported increases in EMG amplitude with decreases in muscle length for specific muscles including the biceps femoris (Mohamed, Perry, & Hislop, 2002; Onishi et al., 2002), tibialis anterior (Vander Linden, Kukulka, & Soderberg, 1991), quadriceps femoris (Babault, Pousson, Michaut, & Van Hoecke, 2003), biceps (Linnamo, Strojnik, & Komi, 2006), and soleus and gastrocnemius muscles (Kennedy & Cresswell, 2001). Although, these findings are contradicted by findings of decreases in EMG amplitude with decreased muscle length specifically in the quadriceps (Kubo, Tsunoda, Kanehisa, & Fukunaga, 2004), two-joint hamstrings (Mohamed et al., 2002), and gastrocnemius muscles (Arampatzis et al., 2006). Finally, some studies have found no trends in EMG amplitude with changes in muscle length distinctively in the musculature of the elbow joint (Doheny et al., 2008; Leedham & Dowling, 1995). These inconsistent findings suggest muscle length may influence EMG amplitude, but there are likely other confounding factors not yet realized influencing amplitude. Unlike muscle length, literature has more consistently provided findings supporting the notion that EMG amplitude increases as force demands increase until near maximal force production capabilities are reached (Bilodeau, Schindler-Ivens, Williams, Chandran, & Sharma, 2003; Karlsson & Gerdle, 2001; Milner-Brown & Stein, 1975).

In this study, both changes in muscle length and force demands likely influenced RMS amplitude. However, it is not expected that muscle length and force demands varied in each chair and display combination as a result of time because task demands remained similar throughout the duration of each trial. With this in mind, our findings of increased biceps and upper trapezius amplitude over time are likely an indication of fatigue. These results are consistent with findings in the literature of shoulder girdle musculature fatigue due to prolonged low-force contractions in similar tasks (Kimura, Sato, Ochi, Hosoya, & Sadoyama, 2007; Kleine et al., 1999; Looze, Bosch, & Dieen, 2009; Shin & Zhu, 2011); however, the literature primarily highlights changes in trapezius activity and fails to note changes in biceps activity. In our study, an increase in biceps RMS amplitude could be a result of fatigue induced by repetitive reaching tasks; although, this is unlikely as there was no increase in anterior deltoid RMS amplitude which has been shown to be associated with reaching tasks (Zadry, Dawal, & Taha, 2009). The most probable explanation for the increase in upper trapezius and biceps without an increase in anterior deltoid RMS amplitude is participants exhibited forward head posture increasing the demands of the upper trapezius (Weon et al., 2010). Moreover, the participants were provided armrests which mitigated the need to exhibit shoulder flexion, reducing muscle activity (Berguer & Smith, 2006), while still requiring activation of the biceps to manipulate the keyboard and mouse.

Our finding of lesser splenius capitis RMS amplitude during the Ergonomic Chair and Side-by-Side Display combination provides evidence that more neutral neck postures were adopted by participants in this condition reducing force requirements. Conversely, the Captain’s Chair and Stacked Display likely promoted neck postures requiring increased force production from the splenius capitis to maintain a static posture to view the monitors, independently. Increased splenius capitis RMS amplitude during the Ergonomic Chair with the Stacked Display configuration compared to the Side-by-Side Display configuration is indicative of increased neck extension to monitor the upper screen which is consistent with literature findings of neck extension with monitors positioned high above the preferred gaze angle (L. Straker, Burgess-Limerick, et al., 2008). Higher splenius capitis RMS amplitude while exposed to the Captain's Chair and Side-by-Side Display combination is suggestive of increased neck flexion likely caused by the 110° backrest angle positioning the preferred gaze angle higher than the monitor placement (Turville et al., 1998). Overall, the higher RMS amplitudes demonstrated in the Ergonomic Chair and Stacked Display combination and the Captain's Chair and Side-by-Side combination are indicative of prolonged static postures which are accompanied by increased risk for the development of musculoskeletal disorders (Shikdar & Al-Kindi, 2007).

Seat Pressure

Overall, the findings of this study demonstrate greater seat pan pressures were associated with the Ergonomic Chair while higher seat back pressures were found with the Captain's Chair. Moreover, seat pan and back pressures increased over time, independent of chair or display type. The findings of greater back pressure in the Captain's Chair and higher seat pressure in the Ergonomic Chair are likely a result of postural differences assumed by participants in the respective seats. The fixed 110° backrest angle incorporated in the Captain's Chair appears to have prompted participants to rest a portion of their body weight on the backrest, alleviating seat pan pressures. This finding is consistent with reports of reduced seat pan pressures with the utilization of a backrest (Hobson, 1992; Swearingen et al., 1962; Vos et al., 2006). Further, a review of video recordings from each trial revealed more upright postures when utilizing the Ergonomic Chair suggesting participants failed to offset a comparable proportion of bodyweight onto the backrest as compared to the Captain's Chair. Although the Ergonomic Chair incorporated a dynamic backrest, the backrest required a considerable amount of force to recline which may have influenced postures. The greater seat pan pressure associated with the Ergonomic Chair is potentially problematic as contact pressure, especially over extended durations, has been shown to be related to tissue damage; however, it is not yet understood if there is an exact amount of pressure which increases the risk for tissue damage as measured by pressure maps (Conine, Hershler, Daechsel, Peel, & Pearson, 1994; Swain, 2005; Swain & Bader, 2002). Finally, previously published literature demonstrates the differences in seat pressures could be a result of seat pan and back material type (Lueder, 1986; Makhsous et al., 2012; Vlaović et al., 2016; Yoo, 2015); yet, the finding of greater seat pressures at different parts of the chair, pan or back, suggest it is unlikely seat material dramatically influenced seat pressures. Rather, the seat pressures changes were most likely a result of postural differences donned by participants when exposed to the two chairs.

Subject Measures: Discomfort, RULA, NASA TLX

Generally, participants expressed increased discomfort over time irrespective of the workstation design. This finding is consistent with previously published literature in similar tasks (Bhatnager, Drury, & Schiro, 1985; Fenety & Walker, 2002) and may be concerning as discomfort has been related to the development of musculoskeletal disorders (Werner, Franzblau, Gell, Ulin, & Armstrong, 2005).

Similarly, our results demonstrate increased NASA Task Load Index (TLX) scores over time. Although results simply display total NASA TLX scores, it is likely the physical workload portion of the questionnaire were influenced by discomfort. Additionally, a review of the individual scores suggests participants became more frustrated over time which is corroborated by verbal complaints of boredom by many participants. As with discomfort, complaints of boredom may be an indicator of increased risk for the development of musculoskeletal disorders as boredom and related psychosocial factors have been associated with the development of musculoskeletal disorders (Hauke, Flintrop, Brun, & Rugulies, 2011; Ryan & Hampton, 1988).

Finally, Rapid Upper Limb Assessment (RULA) total scores demonstrated greater values for the Side-by-Side Display and the Captain's Chair, independently. As discussed previously, the greater RULA scores in the Captain's Chair appear to be associated with a forward head posture potentially exacerbated by the non-adjustable 110° backrest angle. A review of the trial videos suggests greater scores for the Side-by-Side Display are likely a result of increased neck flexion in both chair types. This finding suggests the stacked displays may have promoted a more neutral neck posture; however, these results are contradictory to the EMG results which provide evidence for worse postures for the Stacked Display.

Conclusion: Study 1

Generally, the results of this study provide evidence for decreased musculoskeletal disorder risks for the Ergonomic Chair and Side-By-Side Display combination as compared to all other combinations. This notion is supported by the findings of muscle activities and postures more conducive to mitigating the development of musculoskeletal disorders when exposed to the Ergonomic Chair and Side-by-Side Display combination as compared to the other combinations. However, the greater seat pan pressures found in relation to the Ergonomic Chair and more pronounced neck flexion angles associated with the Side-by-Side Display suggests the Ergonomic Chair and Side-by-Side combination could be improved. Future studies should analyze the influence of slightly higher positioned side-by-side configured monitors on shoulder and neck muscle activity, posture, and seat pressure. Moreover, future studies should identify the effect of backrests with differing force demands to reline the backrest on posture and seat pressures.

Study 2:

The objective of this study was twofold: 1) to quantify characteristic muscle activity, discomfort, posture, seat pressure, and workload for six hours at the workstation design from Study 1 which best mitigated the development of musculoskeletal disorders, and 2) to predict muscle activity out to six hours utilizing prediction equations based on discomfort, posture, seat pressure, and workload measures from the two-hour trials from Study 1. As Study 1 revealed, the Ergonomic Chair and Side-by-Side Display combination appeared to reduce muscle activity and postures associated with the development of fatigue as compared to the three other workstation combinations. Therefore, the Ergonomic Chair and Side-by-Side Display combination was utilized for Study 2. It was hypothesized that muscle activity, discomfort, posture, seat pressure, and workload would differ over time and between workstation designs. Additionally, it was hypothesized that the prediction equations formulated from Study 1 data would be capable of predicting muscle activity over six hours. The findings from this study provided some support of the hypotheses.

Part 1

Our findings suggest muscle activity, discomfort, posture, seat pressures, and workload did not significantly differ over time. This finding is interesting because it contradicts the significant Time effects found in the 2-hour trials. Our study may have failed to find Time significance simply due to a small sample size and high variance between participants; though more complex factors may have influenced the results. One such factor likely contributing the significant Time effect in the 2-hour trials and not the 6-hour trials is the other chair and display combinations strongly influenced the overall findings of significant time trends. This may have masked insignificant Time effects for the Ergonomic Chair and Side-by-Side Display, alone; however, this is an assumption that cannot be verified by our statistical analyses. A second factor potentially influencing the findings of no Time significance in the 6-hour trials is the inclusion of mandatory walking breaks at hours two and four. Literature provides evidence that breaks during computer tasks decrease discomfort (Barredo & Mahon, 2007; Nakphet, Chaikumarn, & Janwantanakul, 2014), suggesting the breaks in our study may have reduced discomfort over the 6-hour trial.

Part 2

The findings of our study demonstrate most regression models developed (59 out of 64 models) accounted for at least 20% of the variance, Adjusted $R^2 > .20$. Moreover, over 70% of the models (46 out of 64 models) accounted for at least 30% of the variance, Adjusted $R^2 > .30$, and approximately 47% of models (30 out of 64 models) accounted for at least 50% of the variance, Adjusted $R^2 > .50$. Although the Adjusted R^2 values in our study may seem low, literature suggests lower Adjusted R^2 values are acceptable for regression models based on human subjects research. For example, a research study predicting body discomfort using computer workstation design characteristics and simple posture measures as independent variables resulted in a regression model with an Adjusted $R^2 = .31$ (Sauter & Schleifer, 1991). Greater R^2 values, up to .95, have been reported by studies using highly objective measures such as force and 3D kinematics to predict muscle activity (Laursen et al., 1998; Mogk & Keir, 2006); however, using these highly objective measures still resulted in some R^2 values as low as .23 (Laursen et al., 1998; Xu, McGorry, & Lin, 2014). Finally, a study predicting discomfort using joint angle and angular acceleration at various postures resulted in R^2 values as high as .88 and as low as .005 (Xu et al., 2014). These findings demonstrate a prediction model's ability to account for variance in the data is likely related to the objectivity of the data, with more precise objective data providing greater accountability for variance, R^2.

Considering the largely subjective nature of the independent variables used in our study to predict muscle activity, body discomfort values, RULA total scores, NASA TLX total scores, and seat pressure values adequately predicted MdPF and RMS amplitude over two-hours.

When using partial data sets to develop and validate the most robust regression models for predicting muscle activity, a consistent model was not found for each muscle, and the models were unable to replicate accurate predictions of the model building data. This is likely the result of too few participants' data used to create the models and too few participants' data used to validate the models. The small sample size of each validation model allowed some large variations in the data significantly influence the model's creation and the output of the model. Even though the regression models built with all 16 participants' data from the 2-hour trials were used to predict the median frequency and RMS amplitude out to 6-hours, the two-hour models were unable to adequately predict the median frequencies and RMS amplitudes over six-hours. The two-hour models were likely unable to predict muscle activity out to six hours because the trends in the two-hour data were not found in the six-hour data. The dissimilar trends between the two-hour and six-hour data are further highlighted by models which do not contain common factors or numerical constants. Interestingly, median frequency models consistently over-predicted while RMS amplitude models consistently under-predicted muscle activity. This finding may be uncovering a shift to lower median frequencies and higher RMS amplitudes over the extended six-hour trials which is in agreement with the traditional definitions of fatigue. Unfortunately, this finding is not supported by the results of statistical analysis in our study; however, researchers should specifically consider this finding when conducting research with larger participant samples.

Conclusion: Study 2

The utilization of largely subjective measures to predict objective measures such as median frequency and RMS amplitude has been established as a difficult task (Sauter & Schleifer, 1991; Xu et al., 2014). The findings of this study suggest body discomfort measures, RULA total scores, NASA TLX total scores, and seat pressure values are capable of sufficiently predicting muscle activity. However, the limited sample size of this study did not allow for successful validation of these models. Further, the two-hour models were incapable of effectively predicting muscle activity out to six hours. Again, this finding is likely the result of an inadequate sample size. Nonetheless, the results of this study suggest muscle activity during seated computer tasks can be predicted using largely subjective measures. Future studies should utilize larger sample sizes and more objective measures to define a more robust set of regression models.

Overall contributions and next steps

Overall, the findings of this research suggest prolonged sitting while controlling a UAS from a control station will lead to local muscular fatigue and discomfort. Moreover, the findings suggest the design of the chair and configuration of the displays in a UAS control station will influence pilot muscle activity, seat pressure, and posture. Of the combinations analyzed in this study, the Ergonomic Chair and Side-by-Side Display combination appears to minimize fatigue and discomfort. Our results do not provide evidence that muscle activities related to UAS control station piloting tasks can be accurately predicted for extended duration using largely subjective measures. Although the results of our study provide valuable initial findings, future studies should build upon these findings to enhance understanding of how chair design and display configurations influence human operators. Such studies should analyze more complex display configurations such as those that incorporate more than two displays and displays that allow the operator to click between multiple windows. Further, studies should assess other chair designs such as the specialized chairs designed specifically for UAS control stations. Future studies should incorporate additional objective measures; such as 3D motion capture; to improve the understanding of the workstation designs' effect on posture and to potentially improve the accuracy of prediction models. Finally, the EMG recordings in this study focus on the shoulder girdle and neck; however, other muscles, such as those of the back, should be considered in future studies.

Limitations

Although these research studies accomplished their aims, the studies were suspect to limitations. First, the studies did not incorporate actual UAS pilots or live unmanned aircraft flights. This limited the study to simulated flights in which only one operator was simply responsible for basic flight controls. In actual UAS flights, it is common for multiple personnel to work as a team in commanding the flight. Thus, our study failed to capture the teamwork component found in most UAS flights. Further, the participants did not experience the realistic fear of the plane crashing which likely decreased the workload and related psychosocial factors. Second, software limitations forbid the inclusion of pre-programmed deviations in the flights. Even though participants were told the aircraft could deviate from the programmed path, it is probable the anticipation of a deviation decreased over time. Again, this limitation likely diminished the workload and related psychosocial factors faced by piloting controlling live flights. Moreover, this may have caused a disengagement with the task, potentially affecting both mental and physical demands. Next, the study was limited to a postural analysis tool (RULA) which was not designed to capture slight postural deviations such as those associated with seated computer tasks. A task specific analysis tool should be created to allow for quick and accurate postural deviations in seated computer tasks. Additionally, many of the measures in this study were subjective. Future studies should incorporate objective measures such as 3D motion capture for postural analysis and eye tracking to determine where the pilot focuses. The inclusion of more objective measures may provide more crucial findings or reveal that less cumbersome, subjective measures are adequate. Further, our study particularly focused on the effects of workstation design on the shoulder girdle and neck; however, the postures and discomfort findings suggest future studies should consider both the upper and lower back. Finally, this study was constrained by sample size due to limited participant interest and time constraints. A larger sample size may have emphasized trends in the data which were not readily apparent.

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