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Effect of attention demand on upper trapezius muscle activity – A moderated mediation model☆

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ABSTRACT

Manufacturing continues to become more automated. Consequently, production operators are monitoring automated processes for prolonged durations. The sustained attention required for monitoring work has been was found to be stressful for humans. This study hypothesises that sustained attention is a psychosocial stressor that increases upper trapezius muscle activity via a psychophysiological pathway in a series of simulated industrial tasks. A moderated mediation model was tested and accepted with the parasympathetic nervous system acting as a mediator contingent on certain levels of end-tidal CO_2. The study outcomes confirmed that sustained attention acts as a psychosocial stressor which increases upper trapezius muscle activity by inhibiting the action of the parasympathetic system and increasing hyperventilation.

1. Introduction

1.1. Background

Global competition and growing consumer markets have stimulated the continued advancement of production facilities. One approach to improving manufacturing efficiencies is to increase levels of automation and robotics (Probst et al., 2013), with an estimate that about 1.3 million new industrial robots will be installed in factories around the world between 2015 and 2018 (IFR, 2016). This growth in automation has led to increased mental workload requirements for operators in the form of monitoring or sustained attention (Hancock, 2013; Young et al., 2015).

Along with evidence that mental demand due to sustained attention is stressful for humans (Warm et al., 2008b), mental demand has also been linked to increased muscular activity (Larsman et al. 2011, 2013). High levels of mental demands have been found to increase the risk of developing Work Related Musculoskeletal Disorders (WRMSDs) (Elovainio and Sinervo, 1997; Sjøgaard et al., 2000; Laursen et al., 2002; Smith et al., 2004). WRMSDs refer to a broad range of inflammatory and degenerative conditions that affect the body's muscles, tendons, ligaments, joints and blood vessels (Punnett and Wegman, 2004). Across the 27 EU Member States, WRMSDs represent the most common work related health disorders.

1.2. Links between psychosocial stressors and muscular activity

Psychosocial stressors can be defined as demanding conditions that tax or exceed the resources of an organism (Lazarus, 1966). Studies support links between psychosocial risks and increases in muscular activity (Eijckelhof et al., 2013; Larsman et al., 2013; Shahidi et al., 2013; Taib et al., 2016) and while several progressive models have been developed to explain the mechanisms linking them (Bongers et al., 1993; Sauter and Swanson, 1996; Faucett, 2005), no model is universally acceptable.

Psychosocial stressors can contribute to the aetiology of WRMSDs but can also trigger their development by inducing physiological changes such as increases in muscular tension (Melin and Lundberg, 1997; Lundberg et al., 2002) which is an early sign in the development of WRMSDs (Wahlström et al., 2004; Sandsjö et al., 2006; Hamberg-van Reenen et al., 2008). One theory suggests that sustained low level muscle tension, especially of Type 1 (Cinderella hypothesis (Hägg, 1991),) motor units in response to a stressor may lead to low-level increases in muscle activity (Veiersted et al., 1993; Westgaard et al., 1996). Prolonged stress may compromise tissue quality and the ability of tissues to recover due to hormonal imbalances (Visser and van Dieën, 2006). To date,

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studies showing an increase in musculoskeletal complaints related to sustained attention work in manufacturing have not been carried out. This study investigates sustained attention as a workplace psychosocial stressor, which contributes to increased muscular activity and we develop a psychophysiological model to explain how this might occur.

1.3. Monitoring & sustained attention

Sustained attention has become an integral part of manufacturing operators' job content. It refers to the ability to maintain focus of attention and to remain alert to stimuli over prolonged periods of time (Molloy and Parasuraman, 1996). Sustained attention is also known as vigilance and a large volume of research has been published that vigilance performance starts to deteriorate after 12–15 min (Temple et al., 2000; Helton et al., 2005). There are two theoretical approaches that attempt to explain sustained attention. The first, which includes the mindlessness model are underload theories and look at sustained attention as a monotonous task that leads to mind wandering. (Robertson et al., 1997; Manly et al., 1999; Thomson et al., 2015). The second theoretical approach, based on overload theories views sustained attention as an onerous cognitive activity. Attentional resource theory posits that sustained attention tasks deplete our limited pool of information processing resources (Fisk and Schneider, 1981; Fisk and Scerbo, 1987; Wickens, 1987). This theory considers vigilance as being a source of extensive mental workload and asserts that as tasks become more demanding, greater resources are required to perform them adequately. Studies using the mental workload scales, the NASA Task Load Index (NASA-TLX) (Hart and Staveland, 1988) and the Multiple Resources Questionnaire (Boles and Adair, 2001) have demonstrated that vigilance tasks are highly mentally demanding (Warm et al., 1996; Finomore et al. 2008, 2009, 2013). Stress hormones or catecholamine levels have been shown to increase during sustained attention tasks (Frankenhaeuser, 1976; Lundberg and Frankenhaeuser, 1980; Lundberg, 2005) and neuroimaging has also shown that monitoring work elevates stress levels (Warm et al., 2008b).

While most sustained attention studies focus on the vigilance decrement or deterioration in attentional ability over time, the focus of this study is on the potential impact of sustained attention as a psychosocial stressor on muscular activity. Attention demand was chosen as the measure for this study in line with attentional resource theorists view that the demand imposed by the attention task increases with task complexity (Johnson and Proctor, 2004). Increased task complexity coincides with increased utilisation of attentional resources (Tripp and Warm, 2006; Warm et al., 2008a).

1.4. Physiological measures of psychosocial stress

1.4.1. Upper trapezius muscle activity

Upper trapezius muscular activity is representative of muscular activity in the upper extremities in general (Visser and van Dieën, 2006), and this particular muscle also shows increased activity upon exposure to psychosocial stressors. In relation to computer work, increases in shoulder muscle activity have been linked to mental demands (Waersted et al., 1991; Sjøgaard et al., 2000; Wijsman et al., 2013). Waersted and Westgaard (1996) found that the upper trapezius muscle was sensitive to changes in attention and this muscle is a good indicator of emotional stress (Cacioppo and Tassinary, 1990).

One explanation for the influence of psychosocial stress on WRMSDs is that hyperventilation (overbreathing) due to stress imposes a biomechanical load on the neck/shoulder region. This is a direct result of the shift from abdominal to chest breathing and upper trapezius muscles are more active during chest breathing (Criswell, 2010).

1.4.2. High frequency heart rate variability as a mediating variable

Heart Rate Variability (HRV) is described as variations between consecutive heartbeats and changes in the autonomic nervous system (ANS) can be detected by measuring HRV. When the ANS branches, the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) are in static imbalance individuals become susceptible to disease. High frequency HRV (HRV-HF), controlled by the vagus nerve represents primarily parasympathetic influences (Bozhokin and Shchenkova, 2008) and activity has been found to decrease under conditions of acute time pressure, emotional strain or increased anxiety (Nickel and Nachreiner, 2003; Fairclough and Houston, 2004; Jönsson, 2007). Several studies have found that HRV indices of PNS nervous activity are sensitive indicators of mental stress (Wilson, 2002; Cinaz et al., 2013). Psychosocial stress has been associated with lowered HRV-HF (Togo and Takahashi, 2009) and lower HRV power was observed during an attention task when compared to baseline (Moses et al., 2007). In this study, PNS activity measured by HRV-HF is the mediating variable, which explains an indirect or mediated relationship between attention demand and upper trapezius muscle activity.

1.4.3. End-tidal CO_2 as a moderating variable

Respiration has a crucial role in the maintenance of the neuromusculoskeletal system. Breathing mechanics are influenced by many factors, one of them being psychosocial stress (Chaitow et al., 2002). The hyperventilation theory links stress to musculoskeletal disorders through a breathing mechanism known as hyperventilation (Schleifer et al., 2002). Under stressful conditions, the SNS induces a rise in respiration rate and volume, breathing moves from abdominal to thoracic breathing and hyperventilation occurs (Naifeh, 1994). Hyperventilation refers to breathing that exceeds the metabolic requirements for oxygen (Gravenstein et al., 1995; West, 2012). It can be measured by detecting a decrease in the concentration of end-tidal CO_2 ($PetCO_2$) at the end of an exhaled breath (LaValle and Perry, 1995). Hyperventilation causes a drop in arterial CO_2 resulting in respiratory alkalosis ($pH > 7.45$) and hypocapnia. This disruption in acid-base equilibrium will in turn trigger a neuronal excitation causing increased muscle tension and spasms with adverse effects for muscle tissue. Mental stress can be detected by a decrease in $PetCO_2$ (Schleifer and Ley, 1994; Ley and Yelich, 1998; Schleifer et al. 2003, 2008). Individuals with lowered $PetCO_2$ due to hyperventilation have compromised attention (Van Diest et al., 2000; Matthews et al., 2010), but little is known of the scenario where $PetCO_2$ levels change as a result of sustained attention. $PetCO_2$ is included in the study as a potential moderator between HRV-HF and upper trapezius muscle activity. In other words, when $PetCO_2$ reaches a certain level (<35 mmHg), conditions are potentially created where the influence of HFV-HF on upper trapezius muscle activity is optimised.

1.5. Attention demand

Attention demand was measured using a subscale of the situational awareness to response test (SART) questionnaire. This is a self-rating subjective measure of situational awareness (SA) which was developed by Taylor (1990). The questions within the attention subscales are relevant to operators monitoring automated processes. Attentional demand refers to the demand placed on attentional resources and encompasses the instability, variability and complexity of the situation. Participants are asked to rate each test dimension on a Likert scale of 1–7.