International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Impacts of Postural Stress and Assembling Task Workload Interactions on Individual Performance by Saudis

Abdulrahman M. Basahel[Á*]

[Á]Faculty of Engineering, Department of Industrial Engineering, King Abdulaziz University, Jeddah, Saudi Arabia[Á]

Accepted 15 Sept 2014, Available online 01 Oct 2014, **Vol.4, No.5 (Oct 2014)**

Abstract

Poor working postures and task demands are common factors that affect human performance in a workplace , particularly in the industrial sector (i.e., assembly tasks). These factors can lead to performance deterioration and introduce musculoskeletal disorders (MSDs). The current research study examines the interaction effects of working postures and assembly task demands on human performance and MSDs. Seventy-five male participants (ages 21–26) performed a manual assembly task at four levels of working postures conditions simultaneously at two different levels of assembly task demands. The subjective assessments following the task, Borg-CR10 and NASA-TLX were completed. In addition, rapid upper limb assessment (RULA) was used to assess musculoskeletal disorders due to postural conditions. Heart rate (HR) and mean arterial pressure (MAP) were recorded continuously. The results indicated that the squatting posture condition led to poor performance with high assembly workload. HR and MAP increased considerably when the posture condition changed. The squatting and stooping posture conditions with low- and high-level task workloads had a more harmful impact from physiological stress than the sitting and standing conditions. The NASA-TLX and Borg-CR10 were affected significantly by the assembly task and changes in working postures. The results of the total RULA scores showed that the stooping and squatting conditions were very hazardous to individuals in terms of musculoskeletal disorders, particularly at a high level of assembly workload.

Keywords: *Postures stress, performance, assembly task, RULA method, physiological stress, NASA-TLX, Saudis.*

1. Introduction

One of the most important factors of ergonomics is increasing the level of comfort at a workplace through the provision of good working conditions and improving the level of musculoskeletal health. It has been demonstrated that task factors such as awkward postures, task demands and repetition significantly impacted individual performance (Kee and Lee, 2012). In addition, extreme poor postures and repetitive movements while performing a task are considered the most important task factors that lead to work-related musculoskeletal disorders (WMSDs) in various sectors such as manufacturing, construction (Balasubramanian *et al*, 2009; Kee and Lee, 2012; Lei *et al*., 2005) and healthcare (Ngomo *et al*., 2008). It has been mentioned that each year around 2 million laborers suffer from musculoskeletal disorders; in particular, the number of those suffering is increasing in the developing countries (Abduljabbar, 2008). The WMSDs are considered serious problems in organizations since they lead to low productivity, increased costs of compensation, medical costs and increased human errors (Chung *et al*, 2005). Awkward postures such as bending the back, twisting and stationary standing while performing a task lead to negative effects on a worker's back, shoulders, neck and legs, so these types of poor postures can lead to postural stress as well as poor performance (Trinkoff *et al*, 2003; Lei *et al*, 2005). Bending the back (stooping postures), stationary standing and sitting are extensively common industrial working conditions (Balasubramanian *et al*, 2009). As mentioned in previous research, around 50-70% of the labor force in developing countries is exposed to ergonomic problems in the workplace such as extremely heavy physical workload, unsafe working conditions, manual material handling, poor working postures and lifting heavy objects (Chung *et al*, 2005).

The assessment of the interactions of awkward postures, task factors and both physical and mental demands has received limited attention (Kittusamy and Buchholz, 2004) since most research has been focused on the impact of poor posture conditions and physical and mental demands separately (Vieira and Kumar, 2004). In fact, there are different factors that affect working postures in a workplace, such as workplace layout, workstation design, individual anthropometric characteristics and individual training (Hsiao and Keyserling, 1990; Vieira and Kumar, 2004). It has been reported that there is a significant correlation between musculoskeletal problems of the wrist, shoulder, neck and upper trunk and awkward postures (i.e., poor working postures) (NIOSH, 1997). Awkward posture is the considerable deviation of a joint from the neutral body posture while the individual

*Corresponding author: **Abdulrahman M. Basahel**

performs a task, such as performing a task with different body parts and the back twisted or bent backward or forward (Putz-Anderson, 1988). Numerous researchers have demonstrated a significant relationship between the physical workplace, postures and performance (Drury *et al*, 2008). The results of research that has been conducted on the impact of awkward postures are not uniform (Drury *et al*, 2008). Since some of the researchers found that poor postures result in poor response in memory mental spatial tasks (Yardley *et al*, 2001), performance deteriorated in computer typing tasks (Fountain, 2000). For instance, Lipnicki and Byrne (2005) have mentioned that the awkward postures significantly impact mental anagrams and arithmetic task performance. Other researchers have demonstrated that there are no significant influences on individual memory task performance (e.g., Ehrenfried *et al*, 2003; Dault *et al*, 2001) or visual computer performance tasks (e.g., Lio and Drury, 2000). Nevertheless, the majority of previous research studies have been focused on the impact of postural factors on the comfort and health status of individuals, whereas the influence of postures on performance measures, in particular in terms of time and number of correct responses, is perceived as meriting little attention (Drury and Paquet, 2004). Furthermore, most of the previous studies have measured the impact of postures on non-physical task demands such as reaction tasks, memory tasks, searching and computer tasks (Drury *et al*, 2008). On the other hand, the impact of postural interaction with task demands that include both physical and mental demands (i.e., assembly tasks) on performance is rare (Drury *et al*, 2008). In addition, most of the studies have been carried out to assess the impact of biomechanics and posture stresses in manual materials handling (MMH), whereas the impact of assembly task demands and postures on physiological stress is less studied (Chung *et al*, 2001). Therefore, there is urgent need to assess the impact of postures and multi-task demands (i.e., assembly tasks) on performance, physiological stress and musculoskeletal disorders.

Task demands are considered the main task characteristics that significantly impact human performance. Wickens *et al*. (2002) have defined the task demand as a combination of the available resources of an operating system, task demand and workers' capabilities. Task demand can be classified into two main demands: mental demand (i.e., visual perception, monitoring, calculation, decision-making) and physical demand (i.e., energetic, lifting/holding objects, pushing and material handling, biomechanics) (Mozrall and Drury, 1996). In a dual-task demands situation, the awkward postures could place stress on task performance. Thus, it is necessary to find a balance between the task-load factor and posture factor in order to reduce the stress that is imposed by both factors and to avoid degradation in worker responses (Drury *et al*, 2008). However, according to a number of researchers, the task demands physically and mentally impact human performance significantly (Tomporowski and Ellis, 1986; Tomporowski, 2003), including musculoskeletal health (Visser *et al*, 2004; Laursen *et al*, 2002). According to Landau *et al* (2008), in the assembly tasks in the vehicles and electrical industries, there are a number of risk factors that can impact human performance and worker musculoskeletal health such as awkward postures, task workload stress, highly repetitive hand movements and material handling. The stress of extremely physical task load in assembly jobs, beside the vigilance demand, is still present and significantly influences assembly performance (Karlqvist *et al*, 2003).

It has been mentioned in a number of research studies that the musculoskeletal disorders, such as low back pain, result from over-exertion or improper working postures (Chung *et al*, 2001; Ayoub and Mital, 1989). Assembling is one of the common tasks in the industrial sector that requires both types of demands (Stork and Schubo, 2010). For example, the worker in this type of task needs to lift parts for the assembly process and handle materials and must use his or her mental functions, including monitoring, perception, attention and memory to complete the assembly tasks (Stork and Schubo, 2010). Furthermore, Chung *et al*, (2001) stated that in many industry tasks, such as in automobile assembly factories, the laborers are imposed upon to take poor working postures in a limited environment, and that leads to placing stress on their musculoskeletal systems and performance as well as the assembly task workloads. As a result of that, this type of task is considered as one of the most WMSD-inducing tasks in the industrial sector (Chung *et al*, 2001). Many studies have demonstrated that a high level of task demands (i.e., physical and mental demands) leads to increased levels of physiological arousal; that means increased levels of physiological stress occur as a result of that performance (Basahel *et al*, 2012; Audiffren et al, 2009). Based on the above mentioned studies, it would seem that the contribution of task workloads with posture factors to task performance is significant and constitutes a gap in the literature.

In fact, the economic development activities in Saudi Arabia were increased in particular in the industry sector, the attention of the Saudi people to manpower health and safety in the workplace is poor (Noweir, 1994). The major part of the manufacturing industry in developing countries is manual tasks because the workers still need to perform their tasks with awkward postures and manual handling of different loads (Chung *et al*, 2001). In addition, many of the workers in Saudi Arabia in industry sectors are exposed to an inadequate working posture and physically demanding jobs since most of the industry factories in Saudi Arabia depend on manual work rather than on automatic systems. Furthermore, there is inefficient consideration regarding the importance of ergonomics principles such as workplace design, tool and equipment design, anthropometric factors, types of ergonomics hazards (i.e., awkward postures, high job physical workload) in Saudi society (Abduljabbar, 2008). Studies that have investigated the impact of poor working postures and task demands on individual performance and musculoskeletal disorders (MSDs) in Saudi Arabia are very rare (Abduljabbar, 2008; Al Wazzan *et al*, 2001). As a result of that, the remarkable increase in the economic state of Saudi Arabia in various sectors, as mentioned previously, with neglect of worker health and safety, in particular the ergonomics issues at workplaces, may lead to serious injuries and musculoskeletal problems and poor performance due to the stress from improper working postures and task workloads (i.e., physical and/or mental workloads).

Generally, Kee and Lee (2012) have mentioned that the measurements of postural stresses can be classified into objective and subjective measures. They said that the objective measures include electromyography (EMG), pressure distribution, spinal load and foot swelling. In addition, heart rate (HR) and mean arterial pressure (MAP) have been used to reflect the impact of postural stresses on physiological arousal level and the human cardiovascular system (Balasubramanian *et al*, 2009; Ngomo *et al*, 2008). In contrast, subjective assessment tools include Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA) and Ovako Working Posture Analysis System (OWAS). However, the RULA method has been extensively used to assess the postural stresses and their severity on upper limb parts in sedentary tasks such as in a laboratory situation relative to VDU (Li and Buckle, 1999), truck drivers (Massaccesi *et al*, 2003), rubber tappers (Meksawi *et al*, 2012) and sewing machine operators (Ozturk and Esin, 2011). Massaccesi *et al*. (2003) have found that the RULA method was a suitable assessment tool to measure the postural stress in various postures on upper body parts (e.g., neck and low-back disorders). Moreover, they have demonstrated a significant correlation between RULA scores as an indication of musculoskeletal demands on upper body parts and a body discomfort chart. Furthermore, a number of researchers have stated that the RULA method is a valid subjective assessment tool to reflect the level of MSDs in body parts as well as postural stresses (Chiasson *et al*, 2012; Kee and Lee, 2012; Meksawi *et al*, 2012; Ozturk and Esin, 2011). RULA is a frequently used method to evaluate the ergonomics risk of work-related MSDs due to work posture conditions and forces exerted on the upper arms, lower arms, trunk, neck and legs (Meksawi *et al*, 2012; Pourmahabadian and Azam, 2006).

Meanwhile, a number of authors have extensively used NASA-TLX to evaluate mental and physical workload combinations (Basahel *et al*, 2012; DiDomenico and Nussbaum, 2008; Hart and Staveland, 1988). They stated that the NASA-TLX score was significantly impacted while levels of mental demands and physical demands changed. The NASA-TLX scale has been commonly used to assess mental demand difficulty changes (Hart and Staveland, 1988; Hart, 2006). The validity and reliability of the TLX has been supported by numerous experimental results (Hart and Staveland, 1988; Rubio *et al*, 2004). Consequently, the TLX score was conducted to measure the mental workload and overall workload (physical and mental demands) and to reflect the participants' perceived overall workload.

Category ratio (Borg-CR10) and rating of perceived exertion (Borg-RPE) scales are sensitive to physical activity, but they are not influenced by mental demand complexity levels (DiDomenico and Nussbaum, 2008), though both scales reflect the perceived exertion caused by physical exercise. The scale follows the physiologically linear increase in aerobic energy loads caused by increased physical demands (Borg, 1998). The main feature of the CR10 scale is its reflection of the pain attribute that affects sensory perceptions due to high-intensity exercise. The result depends upon the subject's feelings of pain that occur due to the increase in physical demand. However, the validations of both scales was satisfied in a number of research studies, and they have shown that the fluctuation in physical demand levels leads to significant changes in Borg scales CR-10 and RPE (Borg, 1990; Borg 1998; DiDomenico and Nussbaum, 2011).

The correlations between physiological parameters such as HR ($r = 0.91$), blood lactate and systolic blood pressure ($r = 0.78$) and the CR10 scale are significant and linear (Borg, 1998). The CR-10 scale has been used broadly in different laboratories' research in order to measure and evaluate high levels of physical workload and musculoskeletal pain due to activity (e.g., Mehta and Agnew, 2011). The overall demands (i.e., physical and mental demands) have been shown to considerably impact the cardiovascular system, and this has been proven by Fredericks *et al*. (2005). They concluded that high complexity of mental demand and high cycling levels are associated with high systolic blood pressure as well as increased heart rate. Therefore, heart rate and blood pressure seem suitable measures to reflect changes in physiological stress and the cardiovascular system due to changes in overall workload.

This paper aimed to investigate the impacts of four postural conditions in combination with two levels of assembly task workloads on cognitive performance in order to determine whether some types of human postures and assembly task demands can affect assembly task performance in a laboratory experiment. In addition, the purpose of this study is to evaluate the level of musculoskeletal disorders and ergonomic risk levels related to the upper and lower body parts in assembly tasks under different types of work postures and workloads. Furthermore, the current study used different methods such as heart rate and blood pressure to reflect the impact of types of postures and levels of assembly workloads on physiological arousal levels. The RULA method was used to examine the prevalence of MSDs introduced by assembly tasks under various types of work postures and different levels of demands whereas the CR-10 scale was used to assess the level of physical demands. The NASA-TLX scale was used to reflect the level of mental demands as well as overall demand.

2. Methods

2.1 Experimental Design

The current study is a 4×2 factorial design to address whether work posture conditions factors (sitting, standing, stooping, and squatting) interact with two assembly task workload conditions (low and high) to impact an individual assembly performance. In addition, the study was conducted to determine the level of MSDs in assembly tasks under various types of work postures and levels of workloads. Repeated measures analysis was used for the within-subjects factor (four levels of work posture interactions with two levels of assembly task workloads).

Assembly task: The current experiment included an assembly task carried out on a wooden plate, and its two uprights have small wooden plates with 12 bolts for each upright plate and each bolt has a nut and a washer (hand tool dexterity test, model 32521, Lafayette Instrument, U.S.) for a total of 24 bolts. The device has the following dimensions: 0.76×0.40×0.40 m. In the low assembly task workload, the subjects were asked to assemble and fix 18 bolts (with 18 nuts and 18 washers for a total of 54 parts) within the allotted time of six minutes. On the other hand, the high assembly task workload required assembling 36 bolts (with 36 nuts and 36 washers for a total of 108 parts) within the allotted time of 12 minutes. These assembly task workloads were validated and approved by a pilot study. In addition, the subjects were asked to use two types of hand tools (a 10-inch crescent wrench and a screwdriver; weight less than 2 kg) to fix the bolts to the wooden plate. The subjects performed these two levels of the assembly task in four work postures: sitting, standing, stooping, and squatting. In the sitting work posture, an adjustable table and chair were fitted to the dimensions of the subject and the same adjustable table was used in the standing work posture as a level work surface. In contrast, in the stooping posture, the subject needed to bend his trunk forward to complete the assembly task (Fig. 1).

2.2 Outcome Measures

There were three main dependents for the outcome measures: first, performance (number of assembled parts); second, physiological parameters including heart rate (HR) and mean arterial pressure (MAP) in order to reflect the postural stress and assembly task workload; and third, the subjective assessment tools including: NASA-TLX used to measure the level of overall workload, the Borg-CR10 used to reflect the level of physical workload and The RULA method was used to assess the level of MSDs while the subjects were performing the assembly tasks in different four postures.

2.3 RULA method

The RULA method (McAtamney and Corlett, 1993) was used to assess the level of ergonomics and MSDs while the subjects performed the assembly task under four different types of working postures (standing, sitting, stooping, and squatting) with two levels of assembly task workloads (low and high). Several scores were obtained with this method to assess the posture risk for different body parts. In this experiment, the scores ranged from 1 to 6 and were used to assess upper arms, neck, and back. The lower arm and wrist scores ranged from 1 to 4, and the leg scores ranged from 1 to 2 (Meksawi *et al*., 2012). For the muscle use and force parts, the scores ranged from 1 to 2 since the weight of the tools that were used was constant (less than 2 kg). The most natural or best posture is referred to by a score of 1 and the higher scores indicate worse postures. The RULA grand score was obtained by adding scores A and B to determine scores C and D, respectively (Fig. 2). The combination of scores C and D results in a grand score that ranges from 1 to 7. This score reflects the musculoskeletal demand associated with the participant's work posture. A total score of 1 to 2 refers to low MSD loading and acceptable posture and a grand score of 3 to 4 indicates a further investigation is required and the individual may need to change his or her work posture. In contrast, a grand score of 5 to 6 indicates that a prompt investigation should be done and that a change in work posture is needed. Finally, immediate action regarding work posture is indicated by a grand score of 7.

The RULA score was assessed by two independent evaluators to satisfy the inter-rater reliability. SPSS software was used to evaluate the reliability, and the analysis showed that the kappa was 0.94, 0.82, 0.69, 0.90, and 0.84 for arm, wrist, neck, and leg scores, respectively. So the analysis showed that the acceptable inter-reliability was satisfied.

Fig. 1 Working postures and the assembly tasks used during the experiment: top left corner-sitting posture; top right corner- standing posture; bottom left corner- stooping posture and bottom right corner- squatting posture.

2.4 Participants

Participants were 75 young male (ages 21–26) students in the KAU College of Engineering. In addition, all the students were selected randomly from academic records. All students completed an informed consent. The participants' characteristics are illustrated in Table 1. All participants were in good health and had no self-reported history of lower-limb muscle, tendon and ligament, or knee joint injuries within the previous 12 months.

Table 1 All participants' characteristics for age, height, and body mass, Mean ± SD (range) (N=75).

Body mass (Kg)	Height(cm)	Age (years)	
79.6±12.4 (68-95)	171.2±5.6 (166-182)	23.8±4.2 (21-26)	Male

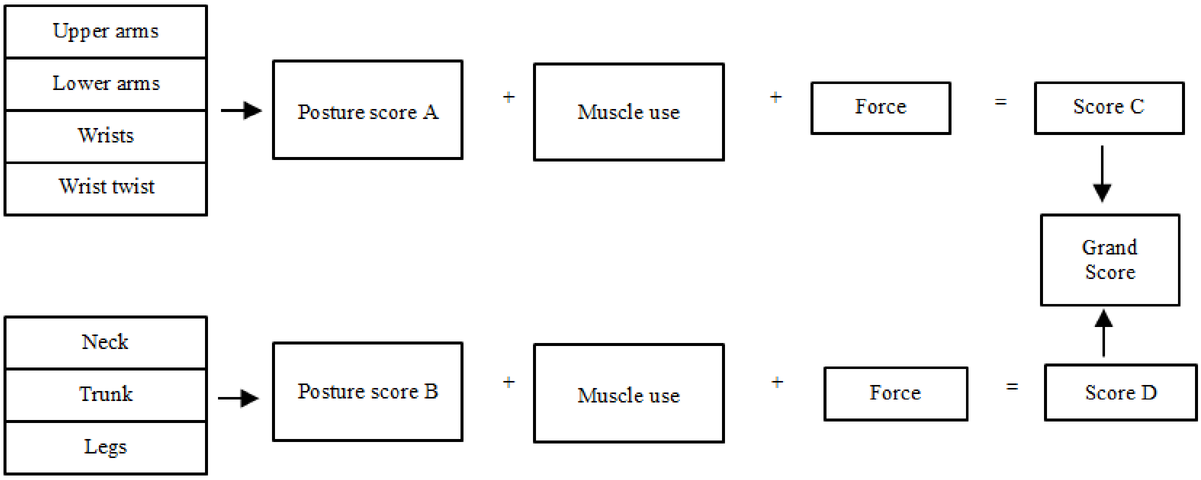

Fig. 2 The rapid upper limb assessment scoring (RULA) adapted from McAtamney and Corlett (1993)

2.5 Materials and Experimental Protocol

At the beginning, the participants were given a brief introduction to the experiment in order to familiarize them with the steps. Also, the participants were provided with instructions and advice on how to perform the assembly task under two levels of workloads using the four types of work postures (standing, sitting, stooping, and squatting). Then, the participants were asked to affix the chest electrodes for the heart-rate monitor (Polar CS600, Polar Electro Inc., Kempele, Finland) to their chests and for the Digital A&D Hand-Held Medical monitor (UA 767, U.S.) on the left hand. The hand-held monitor was used to measure blood pressure at the end of each minute for each participant during the assigned task in a room kept at 24ºC. Before starting, the participants' HR and BP at rest were measured, along with their height and weight. Then the HR and BP were recorded continuously during the test. The MAP was calculated by the following equation (Ngomo *et al*., 2008):

$$MAP = D+1/3(S-D) \quad (1)$$

Equation (1) (N) was used to calculate the mean arterial pressure in mmHg, where D is diastolic blood pressure and S is a systolic blood pressure.

Then, the participants were asked to complete eight different conditions for four work postures (standing, sitting, stooping, and squatting) with two levels of assembly task workloads. The conditions were selected randomly in order to counterbalance the fatigue effects. The participants were asked to continue wearing the chest electrodes for the HR monitor so that the researchers could continue measuring HR, and BP was measured in each trial. The allotted time for the low assembly task workload was six minutes, and the time for the high assembly task workload was 12 minutes. The participants had approximately five minutes to rest between each trial (until HR reached resting level). Immediately after completing each trial, the participants were asked to complete the NASA-TLX scale and the Borg-CR10 scale. The RULA was completed during each trial as the participant performed the tasks.

3. Results

3.1 Performance

Tow-way repeated measures ANOVA technique showed that the work posture factor ($F(3,74) = 604.51$, $p<0.01$) and assembly task workload ($F(1,74) = 541.21$, $p<0.01$) have a significant impact on participants' performance in assembly task ($p<0.01$). The interaction effect of work posture factor and assembly task workloads on number of assembled parts was also significant ($F(3,74) = 32.16$, $p<0.05$). When the difficulty levels of assembly workload were increased, percentage of assembly parts decreased as illustrated in Fig. 3.

The findings presented that the worst assembly performance was observed under the squatting posture and the high assembly workload ($p<0.05$). In contrast, the best performance was observed when sitting and standing versus the low assembly task workload. However, the Tukey post-hoc analysis shows that there was a significant difference between participants' performance when stooping and squatting versus the low and high assembly workloads ($p<0.05$) (Fig. 3). In addition, it becomes clear from the analysis that there were significant differences between the percentage of assembled parts with low and high assembly workloads under all conditions of work posture ($p<0.05$). The difference between sitting and standing posture conditions was not significant under low and high assembly workloads ($p=0.12$) and ($p=0.085$), respectively.

3.2 Physiological Parameters

Fig.4 and Fig.5 show that the HR and MAP were sensitive to assembly workload as posture conditions changed. The highest observation of HR (124.2 beats/min) and MAP (119.9 mmHg) were associated with squatting posture under high assembly workload condition. The lowest observations were observed during sitting and standing under low workload. The repeated measures ANOVA technique showed that the HR and MAP of the participants were affected significantly under different work posture conditions (HR: $F(3,74) = 2032.51$, $p<0.01$; MAP: $F(3,74)$

= 987.84, $p<0.01$) and different assembly workload levels (HR: $F(3,74) = 782.27$, $p<0.01$; MAP; $F(3,74) = 634.1$, $p<0.01$). The interaction effect of work posture factor and assembly task workloads on HR ($F(3,74) = 41.34$, $p<0.05$) and MAP ($F(3,74) = 29.87$, $p<0.05$) was also significant.
However, Tukey post-hoc analysis indicated a significant difference between HR under both levels of assembly workloads ($p<0.05$). Also, the analysis showed a significant difference between HR with stooping and squatting postures under low and high assembly workloads conditions ($p<0.05$) (Fig. 4). Moreover, the HR and MAP with sitting and standing postures were significantly different from those with stooping and squatting posture conditions under low and high assembly workloads ($p<0.01$) (Fig. 4 and Fig. 5). In contrast, the analysis illustrated that the differences between HR while sitting and standing (p = 0.182), and under low and high assembly workloads (p =0.24) were not significant. Similarly, Fig. 5 shows that the differences between MAP while sitting and standing (p = 0.358), and under low and high assembly workloads (p =0.271) were not significant.

3.3. Subjective Assessment Tools

NASA-TLX: The subjective assembly workload of the task was measured by NASA-TLX. Overall workload ratings on the TLX were calculated by averaging all the dimensions of the NASA-TLX ratings: mental demand (MD), physical demand (PD), temporal demand (TD), performance (P), effort (EF), and frustration (FR). The averages of all the dimensions of the NASA-TLX ratings were calculated to obtain the overall workload ratings on the TLX. The assembly workload factor has a highly significantly influence on the NASA-TLX scores ($F(1,74) = 2087.11$, $p<0.01$). In addition, the work posture conditions significantly impacted the ratings ($F(3,74) = 2415.58$, $p<0.01$). However, the effects of the assembly workload × work posture conditions interaction on NASA-TLX were significant ($F(3,74) = 73.91$, $p<0.05$). Moreover, when the assembly task workload increased, the TLX score increased significantly (Fig. 6).

Tukey post-hoc analysis indicated that there was a significant difference between TLX scores with sitting and standing postures under the high assembly workload condition ($p<0.05$), yet there was no significant difference under the low assembly workload (p=0.131) (Fig. 6). Furthermore, significant differences were found between TLX scores in the squatting and stooping postures versus sitting and standing postures under all assembly workloads ($p<0.05$). There was no significant differences between the squatting and stooping postures at low and high assembly workload at (p=0.274) and (p=0.308), respectively.

Borg-CR10: The Borg CR10 scale was used to evaluate the perceived physical assembly task workload as well as the posture stress. The scores significantly increased when the assembly workload increased. The repeated measures ANOVA analysis indicated that the effect of working posture conditions ($F(3,74) = 1972.38$, $p<0.01$) and physical assembly workload ($F(1,74) = 847.05$, $p<0.01$) on the Borg-CR10 was significant (Fig.7). Also, there was a significant impact on CR10 by working posture conditions in combination with physical assembly workload interactions ($p<0.05$).

According to Tukey post-hoc analysis, Fig.7 shows that there were significant differences between the CR10 scores with squatting and stooping posture conditions versus sitting and standing posture conditions under both low and high assembly workloads ($p<0.05$ in all cases).

RULA assessment tool: As illustrated in Fig 2, the upper arm, lower arm, wrist, and wrist twist scores resulted in a posture A score, and the neck, trunk, and leg scores resulted in a posture B score. The highest grand score was obtained in the stooping posture condition with high assembly workload, whereas the lowest score appeared under the sitting posture condition with low assembly workload. However, as illustrated in Table 2, the t-test analysis showed that there was a significant difference between the stooping posture versus the sitting and standing conditions under the low and high assembly workloads ($p<0.05$). Similarly, the grand score for the squatting posture condition was significantly different from the sitting and standing conditions with low and high assembly workloads ($p<0.05$). Furthermore, the difference between the grand scores of the stooping posture condition under low and high assembly workloads, 5.12 (± 0.54) and 6.94 (± 0.29), respectively, was significant ($p<0.05$) (see Table 2). Also, the grand score of the squatting posture under low and high assembly workloads, 5.23 (± 0.16) and 6.81 (± 0.97), respectively, was significant ($p<0.05$). Moreover, there was a significant difference between the sitting posture under low and high assembly workloads ($p<0.05$). In addition, the difference between the grand score with standing posture versus low and high assembly workloads was significant ($p<0.05$). In contrast, the difference between the grand score with standing posture and sitting postures under low assembly workloads was significant (p= 0.12). Likewise, the difference between the scores of standing and sitting postures under a high workload was non-significant (p= 0.082). The differences between grand scores of squatting and stooping postures under low and assembly workload was non-significant (p= 0.131) and (p= 0.18), respectively (see Table 2).

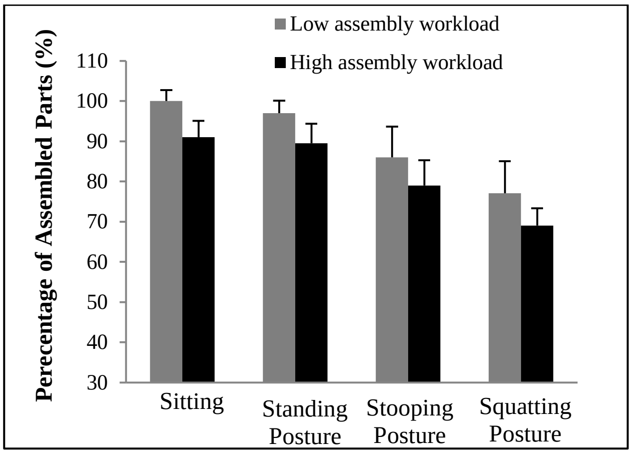

Fig. 3 Mean percentage of assembled parts and standard error bars for the four posture conditions with both assembly workloads (low and high workloads).

Table 2 Mean (± SD) of RULA scoring for four posture conditions associated with a low assembly workload

	Low assembly workload			High assembly workload		
Posture Conditions	Score C	Score D	Grand score	Score C	Score D	Grand score
Sitting	2.37 (± 1.08)	2.11 (± 0.80)	2.78 (± 0.82)	3.97 (± 0.29)	3.84 (± 0.48)	4.07(± 0.46)
Standing	2.74 (± 0.78)	2.21 (± 0.34)	2.96 (± 0.40)	4.03 (± 0.63)	4.11 (± 0.28)	4.15 (± 0.91)
Stooping	4.98 (± 0.37)	4.04 (± 0.67)	5.12 (± 0.54)	6.24 (± 0.41)	6.86 (± 1.04)	6.94 (± 0.29)
Squatting	4.91 (± 0.61)	4.76 (± 1.10)	5.23 (± 0.16)	6.18 (± 0.61)	6.72 (± 0.71)	6.81 (± 0.97)

Mean score C (posture score A+ muscle use score + force score), score D (posture score B+ muscle use score + force score), and the grand score were calculated for four posture conditions versus low and high assembly workloads (N=75).

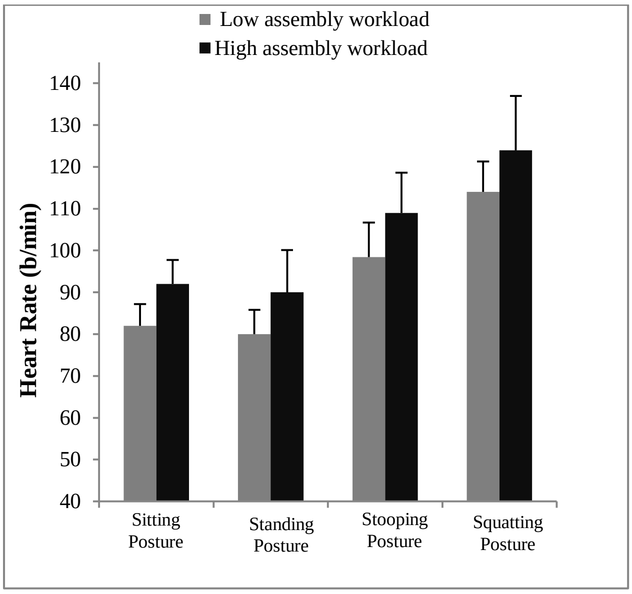

Fig. 4 The mean of HR and standard error bars for the four posture conditions' interactions with the assembly workloads (low and high workloads)

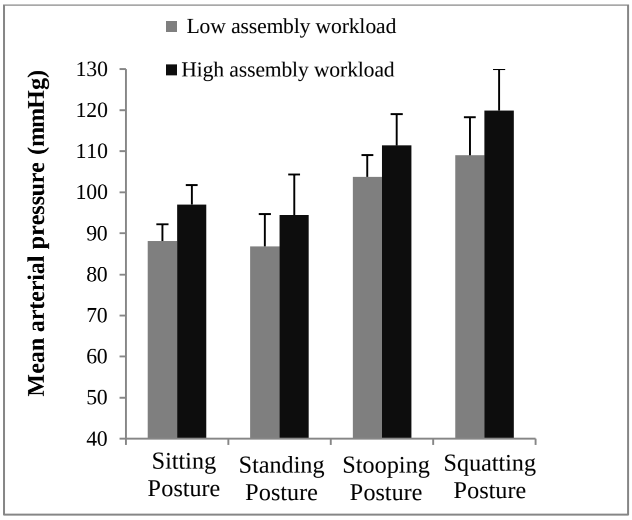

Fig. 5 The mean of MAP and standard error bars for the four posture conditions with both assembly workloads (low and high workloads)

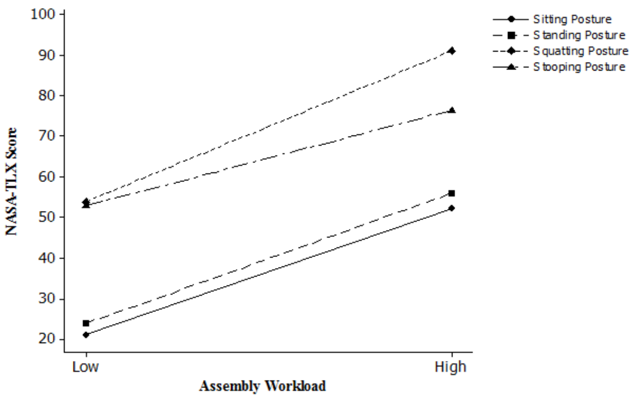

Fig. 6 Mean of NASA-TLX score for the assembly task against four posture conditions' interactions with assembly workloads (low and high workloads).

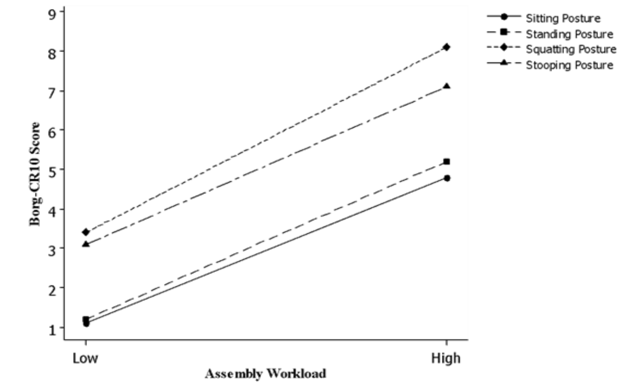

Fig. 7 Mean of Borg-CR10 scores for the assembly task against four posture conditions' interactions with assembly workloads (low and high workloads).

4. Discussion

The main goal of the current study was to investigate the impact of various posture conditions interactions with two levels of assembly workloads on individual performance. This was performed for four different work posture conditions (sitting, standing, stooping, and squatting) while the participant performed two levels of assembly workloads (low and high). Also, it was aimed to assess the impact of work posture conditions and assembly workloads on musculoskeletal disorder levels of upper and lower body parts. As mentioned previously there were three primary variables measured in the present study: performance, physiological and subjective measures.

4.1 Performance Measure

The current study showed that the work posture conditions and assembly workload interactions were significantly impacted by the number of assembled parts. The poor performance was associated with the squatting posture versus the high assembly workload. Moreover, the best participant performance occurred under sitting and standing posture conditions with a low assembly workload. Generally, the results of this study found that there was no significant difference between performance with sitting and standing posture conditions with low and high assembly workloads. These results were consistent with previous studies that mentioned there was no significant difference among individuals while performing a baggage threat detection task in sitting and standing posture conditions (Drury *et al*., 2008), computer tasks (Lio and Drury, 2000; Smith *et al*., 1998), simple assembly tasks (Lutz *et al*., 2001), and visual computer memory tasks (Ehrenfried *et al*., 2003). Noteworthy, the current study concluded that the participants' performance of the assembly task in the squatting posture was significantly different and lower than from the stooping posture condition. In addition, it is also remarkable that there was a significant difference between performance while squatting and stooping under low and high assembly workloads. This is in accordance with Straker (2003) who mentioned that the performance of an individual working in a stoop posture is quicker than in a squatting posture condition. This might be because the squat posture condition results in more whole body fatigue than the stoop posture (Straker, 2003). The stoop posture consumes 14.3% less than the maximum oxygen consumption of the squat posture since the squat posture requires greater muscle mass utilization and more fatigue (Hagen at al., 1993). As might be expected, the performance of participants in squatting and stooping postures was significantly poorer than in the standing and sitting postures conditions. These results are similar to Chung *et al*. (2001) who stated that the squatting posture has a greater negative and significant impact on performance and the physiological state of the individual than the standing posture in a simple assembly task. The participants' performance significantly deteriorated when the assembly workload changed from low to high, in agreement with the results of other studies that mentioned the increasing level of physical and mental workloads had a significant effect on individuals' cognitive performance (Audiffren *et al*., 2009; Audiffren *et al*., 2009; Chung *et al*., 2001; Mozrall and Drury, 1996; Tomporowski, 2003).

4.2 Physiological Parameters

From the results of physiological analysis, it is confirmed that the HR and MAP were sensitive to the working posture conditions and assembly workload levels. The interaction impacts of work posture conditions and assembly workloads on HR and MBP were significant. This study demonstrated that the HR and MBP were increased significantly when the posture condition changed from sitting to stooping and squatting postures. In addition, the average HR and MAP in the stooping and squatting postures were significantly higher than the sitting and standing posture conditions under low and high assembly workloads. This finding is not consistent with Chung *et al*. (2001) who found that there was no significant difference in HR with a change in posture condition from standing to squatting for a simple assembly task. The reason for this difference could be due to the variations in the assembly tasks that were used in the two studies. The majority of the assembly tasks used in the current study were manual work and were more complex than those used by Chung *et al*. (2001). Also, the HR value for the squatting posture was higher than the stooping posture condition under low and high assembly workloads. Hagen *et al*. (1993) stated that the HR increased significantly from 172 beats/min to 184 beats/min when the lift task posture was changed from stooping to squatting. The MAP declined significantly when the posture conditions were altered from a squatting to a stooping posture under both levels of assembly workloads. This is consistent with previous experimental studies that concluded that the squatting posture condition consumes a high amount of oxygen and raises the HR and BP (Hagen *et al*., 1993; Straker, 2003). However, the HR and MAP were significantly altered when the assembly task workloads were changed under all types of work postures. Numerous studies confirmed that the HR and MAP are sensitive to task workload, in particular, a task that involves physical and mental workloads since they mentioned that the cardiac stress can be reflected by a change in HR (Audiffren *et al*., 2009; Fredericks *et al*., 2005), and blood pressure (Fredericks *et al*., 2005; Hwang *et al*., 2008).

4.3 Subjective Assessment Tools

NASA-TLX: The current study was used to assess the overall assembly workload. Expectedly, the overall TLX score increased as the assembly workload increased under all types of working postures. This was similar to the numbers in previous authors' findings as they concluded that the overall TLX score was impacted by the task workload (i.e., physical and mental demands) (Audiffren *et al*., 2009; Mozrall and Drury, 1996; Reilly and Smith, 1986; Tomporowski, 2003) and overall task workload (Hart, 2006). For instance, Reilly and Smith (1986) mentioned that the change of physical cycling workload from 25% to 85% of VO2 max reduced the performance in a pursuit rotor task. The overall assembly workloads for stooping and squatting postures under low and high assembly workloads were higher than the TLX scores for sitting and standing posture conditions. This might be because the stressfulness of squatting and stooping posture conditions affects the subscales in the TLX (i.e., performance, frustration, and effort dimensions). These dimensions reflect the amount of effort perceived due to the poor working posture as well as task workload (Newell and Mansfield, 2008). Chung *et al*. (2001) mentioned that the squatting posture is more fatiguing than the standing posture. However, the results of current study found that the squatting posture condition obtained a higher NASA-TLX score than the stooping posture under the high assembly workload. This result was consistent with previous studies in which the squatting posture was observed as lower than the stooping posture rating in a subjective assessment tool such as rating perceived exertion (RPE) (Straker, 2003). In addition, the assembly task that was used in the current study may differ at the high workload level and the participants in a squatting posture needed to utilize a large amount of muscles that may increase the effort of quadriceps muscles along with the arms and back (Chung *et al*., 2001).

Borg-CR10: The Borg-CR10 score was used to measure the level of physical workload in the assembly task. Borg-CR10 ratings were sensitive to increases in assembly workload under all types of postures since the CR10 score increased significantly when the assembly workload changed from a low to a high level. These results were similar to those stating that the increasing level of task demands, in particular, physical demand, leads to a rise in CR10 ratings in treadmill and cycling tasks (Borg, 1998), and lifting task (DiDomenico and Nussbaum, 2008). Also, according to Kee and Lee (2012), the CR-10 score was sensitive to changes in body postures such as upper body parts and was considered a valuable subjective measure for posture stresses. The present results showed that there was a significant difference between CR10 scores in a sitting posture condition versus stooping and squatting posture conditions under low and high assembly workloads. Also, the difference between CR-10 scores at sitting and standing posture conditions versus a squatting posture was significant under low and high assembly workloads.

The highest CR-10 rating was observed in the squatting posture versus the high assembly workload. This might be because the participants perceived high effort and a level of discomfort due to the squatting posture (the participants needed to utilize a large number of muscles) and the difficulty level of the high assembly load (high level of manual work and repetitive tasks). These findings align with a previous study that postulated the high score of rate perceived exertion (RPE) was associated with the squatting posture rather than other types of postures since the participant needed to utilize a larger number of muscles and so incurred more cardiovascular stress and more fatiguing (Straker, 2003).

RULA method: According to MSD levels and ergonomics risks in the RULA method, the current results showed that the sitting posture condition under a low assembly workload had the lowest grand RULA score 2.78, which was almost similar to the standing posture under low workload level at 2.96. There was no significant difference between sitting and standing grand scores, which means the posture is acceptable and has low ergonomics risks.

On the other hand, the highest RULA score was associated with squatting and stooping posture conditions under a high assembly workload and these conditions were indicated as an extreme posture and action level 4, which means immediate action is needed. The impacts of stooping and squatting postures as an MSD risk were described by Meksawi *et al*. (2012) and Straker (2003) who indicated that the stoop and squat postures with a high level of task demands lead to reduced strength and functional capability of trunk muscles' coactivity and increased spinal column structural changes that involve shear and compression forces. However, in terms of RULA score, the current results did not find a significant difference between stooping and squatting postures under low and high assembly workloads, which was not consistent with Straker (2003) who mentioned that the stooping posture is more fatiguing and stressful on body regions. This inconsistency might be due to the assembly task used in current study not being used in most of the previous studies. Those studies used the lifting of different weights, whereas the task in the current study depended on the number of assembly parts and tools.

The RULA score for a low assembly workload was significantly lower than for a high assembly and this was supported by Chung *et al*. (2001) who mentioned that increasing levels of physical activities lead to increased stress on body parts as well as poor working postures in automobile assembly line task (squatting and stooping).

4.4 Strengths and limitations of the study

Most of the previous research studies have been conducted on the impact of postural stresses on simple tasks, such as simple reaction time, computer tasks, and memory activities (i.e., non-physical activity tasks) (Drury *et al*., 2008). The current study assessed the impacts of postural stresses and complex assembly task workload factors on individual performance among Saudi participants. Also, this study applied the RULA method to assess the level of MSDs of different postures and recorded physiological parameters to assess the impact of these factors on the physiological state of participants. Previous authors focused on biomechanical methods rather than physiological measures (Chung *et al*., 2001).

According to Abduljabbar (2008) and Al Wazzan *et al*. (2001), studies of the effects of improper working posture and task demands on human musculoskeletal problems and ergonomic risks, as well as on performance, are too limited in Saudi Arabia. Therefore, the results of this study will be useful in helping designers avoid designs that promote improper working postures, especially for work environments with heavy multi-task demands such as assembly tasks, for the purposes of reducing workers' musculoskeletal injuries and company costs and ultimately increasing productivity.

On the other hand, one of the limitations in the current study is that all participants in the experimental study were male students of King Abdulaziz University, between the ages of 21 and 26, and were considered healthy. Therefore, the findings of this study cannot necessarily be generalized to all populations, such as elderly groups and female workers. The methods used in this study mainly focused on objective measures such as performance and physiological parameters, and subjective measures such as TLX-NASA, Borg CR-10, and RULA. Further objective measures such as biomechanics (e.g., compressive forces (CFs) on a lumbar disc) could be useful in establishing to a greater extent the influence of posture stresses and task workloads on individual performance and capabilities.

Conclusion

In this study, a laboratory experiment was conducted in order to examine the effects of different postures and working conditions and two assembly task workload combinations on individual performance and the physiological stresses while performing an assembly task. In addition, the RULA method was used to assess the level of MSD risks while performing the assembly task under various posture conditions and assembly workloads.

The findings showed that the performance was significantly impacted by changes in posture conditions and assembly workload levels. The worst performance was observed under squatting versus a high assembly workload, and the best response was associated with a low assembly workload versus sitting and standing posture conditions. The HR and MAP increased significantly as the assembly workload increased and when the working posture changed from sitting and standing to stooping and squatting. Furthermore, the changing of the assembly workload levels led to an increase in the CR-10 and TLX scores as the posture conditions changed.

The results confirmed that the stooping and squatting posture conditions had a higher risk of MSDs with a high assembly workload than other posture conditions (i.e., sitting and standing). Consequently, in manual tasks such as an assembly task, the working posture and the workload of a task should be considered important issues. In designing such tasks, the squatting and stooping postures should be avoided and the task workload should be maintained at acceptable levels.

Acknowledgement

The author wishes to give thanks to all of the subjects who participated in this study as their participation is considered to be the main part that helped to complete this study.

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