IOSR Journal Of Humanities And Social Science (IOSR-JHSS)
Volume 21, Issue12, Ver. 3 (December. 2016) PP 07-12
e-ISSN: 2279-0837, p-ISSN: 2279-0845.
www.iosrjournals.org

User perceived exertion, work posture and muscle activity while doing engineering drawing using adjustable and fixed table's heights

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Abstract: Manual tasks in many operational settings can force individuals in awkward postures that may cause human discomfort, musculoskeletal fatigue, and disorders. Designers often fail to reasonably take into account human capabilities and body postures. This study shared the designer to choose one of the available drafting tables which characterize of causing fewer work stresses. There were three evaluation methodologies implemented to differentiate between the two types of tables. Electromyogram (EMG) measure, subjective assessment and biomechanical technique were applied to demonstrate the importance of introducing the use of these tools in the design for human beings. Results of the study proved that adjustable table had less biomechanical and muscular stresses when compared to fixed surface table. Also, the adjustable table had more comfort ratings when compared to fixed surface table.

Keywords: *- drafting, biomechanics, sEMG, perceived exertion, drawing table, posture analysis.*

I. INTRODUCTION

Most engineering students spent weekly four hours in drafting classes. The effects of using the inadequate design for the students in terms of capabilities and dimensions could be very harmful to their musculoskeletal systems. Of course, this will be very harmful to operators who use such types of inadequate furniture daily for years. Research by van Wely [1] who studied the relationship between pain site and workplace characteristics for use by individual engineers found a high correlation between posture at work and the complaints received at a medical center. Floyd and Ward [2] found a curved upper spine developed by two operators was an effect of working at the too much low level for their heights. When the mean working height falls in a distance more than elbow height, the percent of fatigued individuals generally increased [3]. Recently, Keester and Sommerich [4] study found that artists experience work-related musculoskeletal discomfort in the neck, shoulders, elbows, hands/wrists, upper back, lower back, and legs/feet, and in many cases report that their discomfort is made worse by work activities even with using simple light tools. The authors suggested new intervention is needed to reduce the exposure to risk factors for reducing experience work-related musculoskeletal discomfort and disorder. For some fields such as Workineh and Yamaura [5] study in such, they developed a computer workstation, which allows users to sit in multiple working positions in order to provide better comfort to people who spend a long time sitting at their workstations. On the other hand, Delleman and Dul [6] adjusted traditional sewing machine workstation at ten different combined adjustments of table height, desk slope, and pedal position in order to evaluate working postures and developing the minimum the load on the musculoskeletal system during users' operation.The early quoted studies show a short term effect (i.e., pain extending beyond the work period) and a long term effect (body distortion) as a result of inadequate postures maintained over long periods of time. The correction of working postures to increase work performance and productivity has been discussed by several researchers. Brideger [7] demonstrated that using sloping furniture reduced trunk flexion significantly. In addition, sloping furniture was perceived more comfortable sensation than the conventional furniture. Damecour et al. [8] investigated two forward-placed supports with different heights during manual activities. Their findings suggested that leaning against a higher-placed trunk support could be beneficial for tasks requiring forward flexion. As a result of the reduced muscle tension, lumbar spine and hip joint loading was reduced when using the forward-placed supports compared to unsupported and desk supported reaching. Antle et al. [9] showed that a sit-standing posture supported by leg results in back and upper limb outcomes that do not differ from those ones in a standing posture. This sit-standing posture leads to more favorable outcomes for lower limb discomfort and vascular outcomes. Rosati et al. [10] investigated the influence of work height, and paint tool design on shoulder muscle activity and exerted forces during wall painting. The authors suggested that the high working height imposed greater muscular demands compared to middle and low heights. This finding suggested that, if possible, avoid working at extreme heights (low or high); this will reduce fatigue onset and subsequently mitigate potential musculoskeletal upper limb injury risks. Shin and Zhu [11] administrated that touchscreen in desktop PC users would need proper armrests to reduce physical risks associated with hand use. Santos, et al. [12] reviewed and analyzed the studies investigating the effect of job rotation and work-rest schemes, as well as, work pace, cycle time and duty cycle, on upper limb muscle fatigue. The authors identified the need for future research, which will eventually lead to the adoption of best industrial work practices based on users' capabilities. Zhua and Shin [13] addressed the essential of proper positioning of forearm support by comparing neck and upper extremity muscle activities at varying heights of forearm support in keyboard setting. The authors suggested that forearm support can help computer users lessen physical stress in computer task, but only when the supports are positioned at resting elbow height. The description of the individual body posture and the assessment of the stresses imposed on the human body are the two basic aspects of working postures analysis. Khalil and Ramadan [14] a developed biomechanical assessment tool to evaluate body posture. This technique considers the angles adopted by the major links of the body in relation to the horizontal directions. This methodology does tell us about the articulations stresses and torques. However, it does not tell us anything about the effect of posture on body discomfort. To evaluate this effect we must look for subjective measures to assess the pain levels perceived as a result of the postures being experienced. The aim of this study was to quantify the stresses imposed on the drafting class' students while using both drafting tables used in the University.

II. METHODOLOGY

2.1. Participants

Eight healthy males from the university population took part in this study. None has recently a history of musculoskeletal injury or back pain symptom and no physical difficulty in conducting typical drafting tasks in a seated posture for four continuous hours similar to the University drafting class time. Mean (±SD) age of 20.6±1.9 years, the height of 175±7.4 cm, and body mass of 74.3±10.2 kg, respectively. King Saud University Ethics Committee approved the methodology, and all participants provided written informed consent before participating in the experiment.

2.2. Tasks

All participants had engineering drafting course, and all passed the course with at least B grade. Therefore, the task was to manual draw rough and detailed sketches and simple machine drawings, based on preliminary engineering concepts and specification on drafting sheets using drafting tools (e.g., pencil, ruler, etc.).

2.3. Apparatus

2.3.1. Used table

Two types of drafting tables used at the University drafting classes were implemented in this experiment. Those are fixed and adjustable tables, as shown in Fig. 1. Only fixed type is used in our school. This study was carried out to figure out the opportunity of using the adjustable table when it is compared to the fixed one.

2.3.2. Surface electromyography

Surface electromyography (sEMG) is often employed to get myoelectrical signals from active muscles. The sEMG measurements from two muscles in the participants' right limb using disposable pre-jelled surface electrodes. Bilateral muscular activities of erector spinae and rectus abdominis muscles were recorded during all sitting modes. The selected muscles were based on their direct involvement in the hand movement considered in the literature. Rectus abdominis fiber orientation was approximated at the level of the anterior superior iliac spine, and 2 cm lateral to the midline. Erector spinae muscle sites were determined at the level of the L4/L5 interspace and 2 cm lateral to the midline. The electromyography was recorded using the raw mode and a time interval of 0.1 second. The obtained signals of the EMG values (in microvolts) were recorded using "CASSY Sensor, Ag/AgCl" and were implemented in a standardized manner by Ramadan and Al-Shayea [15], with an inter-electrode center distance of 2 cm, and impedance <20 kU. The signals were amplified using Mespec 4000 System (CASSY Lab., Leybold Didactic Gmbh, Germany), band-pass filtered 20-500 Hz, and A/D converted and sampled at 1000 Hz (CASSY LAB Win 5.0, Leybold Didactic Gmbh, Germany).

2.3.3. Biomechanical evaluation model

A 2D static biomechanical model developed by Khalil and Ramadan [14] was implemented in the study. Some modifications to allow for consideration of the participant in a sitting posture instead of standing one were made to fit the study. The developed model inputs include the student's anthropometrical data, body weight, as well as the body posture angles to the horizontal levels using a digital camera. The seven postural angles are defined in details in [14]: These angles are inputted in the microcomputer model with other measures (weight, anthropometric measurements) to get results. The static option of the model was only utilized. The biomechanical model prints the followings: (1) A complete configure of a defined posture; (2) Position of each joint in the space (Cartesian Coordinates) considering the ankle joint as a reference; (3) Forces in the X and Y directions at each joint; (4) Torque at each joint; and (5) Compression force at L5/S1 joint.

Measurement of posture was made based on six adhesive markers that placed on the skin of the right ankle, knee, shoulder, elbow and wrist joints; and one marker placed at the hip joint. Each time the participant change his posture, a photo was taken to determine body posture using these markers to estimate the locations and positions of tile various anatomical regions.

2.3.4. Rating of perceived exertion

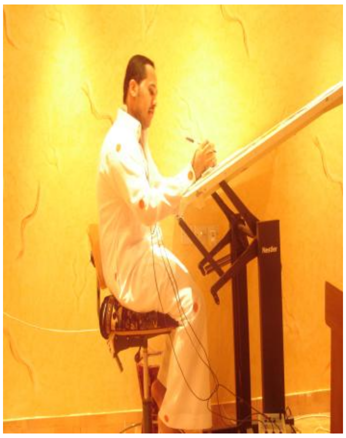
Each participant was asked to rate his perceived exertion (RPE) on eight body's regions at the end of each task using a 7-point ordinal scale in which a score of 1, 3, 5, and 7 correspond to completely comfortable, quite comfortable, just noticeable discomfort, and completely discomfort, respectively. It is felt that the modifying body part discomfort would provide finer discrimination when he was asked to put a mark instead of obtaining the scale by having participants choose a number between one and seven and placing that number on the picture body part. The eight regions are: eyes, neck, left shoulder, right shoulder, left hand, right hand, upper and lower back.

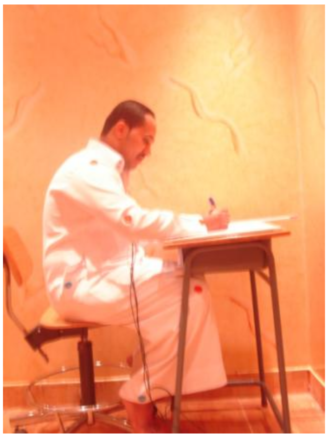
2.4. Experimental protocol

The anthropometric data were measured after the participant was given a clear explanation of the experiment objectives and procedures. Six reflective spherical markers were placed on specific bony landmarks on the subject's right upper limb. Surface electrodes were then attached to two defined muscles. The maximum voluntary contraction (MVC) for each assigned muscle was measured at the beginning of the experiment. The tests for the MVCs were taken according to the suggestion of Hislop et al. [16]. A maximal resistance was applied to all tested muscles since normal participants were recruited in this study. The reading of EMG recorded and analyzed. Electromyographic data were analyzed with normalized root mean square (nRMS).

The chair height was adjusted in such a way to make the desk and sitting elbow lengths are nearly the same. Posture measured by replaying the record photos and tracing stick figures from the image of the subject on the screen. The stick figures could then be used to obtain angular measurements of posture. Each stick figure gives us seven postural angles. Only working postures were be measured; other postures (resting, stretching, fidgeting, etc.) were not photographed and measured; although the frequency of occurrence of these movements was recorded. The averages of the calculated stresses from all photos were considered for the statistical analysis.

Rating of perceived exertion (RPE) was considered as a way of measuring the intensity level of the physical activity due to hand task. At the end of each task, the participant was asked to take a 5-min break or more if required. During the break, the participant was asked to rate the perceived exertion on eight monitored muscles and the experimental data were preliminarily checked by the researcher.





Adjusted surface table Fixed surface table

Fig.1. Experimental set up with adjusted and fixed surface tables

III. RESULTS

3.1. Biomechanical Evaluation

3.1.1. Estimated back muscle force:

The averages of the estimated back muscle exerted by each participant at each table type during all working period were computed and compared using a paired t-test. The result revealed that drafting with using the fixed type was significantly more stressful than drafting using the adjusted one, $t(7)=-9.044$, $p<.0001$, as shown in Fig. 2.

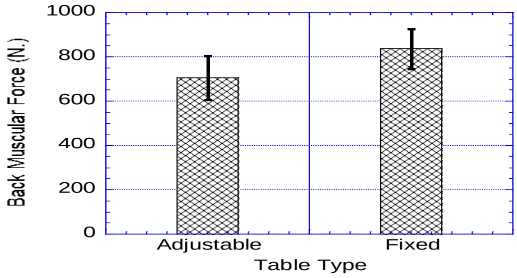


Fig.2. Effect of the table type on estimated back muscle force

3.1.2. Estimated compression force acting at L5/S1

The averages of the estimated compression force acting at L5/S1 exerted by each participant at each table type during all working period were computed and compared using a paired t-test. The result revealed that drafting with using the fixed type was significantly more stressful than drafting using the adjustable one, $t(7)=-4.415$, $p<0.003$, as shown in Fig.3.

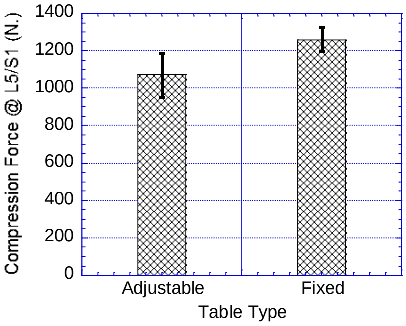


Fig.3. Effect of the table type on estimated compression force acting at L5/S1

3.2. sEMG assessment

3.2.1. Erector spinae muscle activities

The averages of the erector spinae muscle activities exerted by each participant at each table type during all working period were computed and compared using a paired t-test. The result revealed that erector spinae muscle activities during drafting with using the fixed type was significantly more stressful than muscular activities during drafting using the adjustable one, $t(7)=-5.452$, $p<0.001$, as shown in Fig. 4.

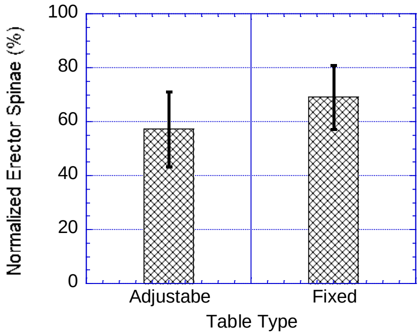


Fig.4. Effect of table type on erector spinae muscle activities.

3.2.2. Rectus abdominis muscle activities

The averages of the rectus abdominis muscle activities exerted by each participant at each table type during all working period were computed and compared using a paired t-test. The result revealed that rectus abdominis muscle activities during drafting with using the fixed type was not significantly less stressful than muscular activities during drafting using the adjustable one.

3.3. Rating of perceived exertion

The reported scale from each participant regarding eyes, neck, right shoulder, lift shoulder, right arm, lift arm, upper back and lower back for each subjective measure was reported based on each table type. Those values were employed for the statistical analysis. There were significant stresses at working on fixed table when compared to working on adjusted table in terms of perceived exertion rating between the adjusted and fixed table, as follows: (1) eyes, $t(7)=-2.524$, $p<0.04$; (2) neck, $t(7)=-38.978$, $p<0.0001$; (3) right shoulder, $t(7)=-25.00$, $p<0.0001$; (4) left shoulder, $t(7)=-17.00$, $p<0.0001$; (5) right arm, $t(7)=-5.572$, $p<0.001$; (6) left arm, $t(7)=-3.528$, $p<0.01$; (7) upper back, , $t(7)=-63.3$, $p<0.0001$; and (8) lower back, $t(7)=-42.728$, $p<0.0001$, as shown in Fig.5.

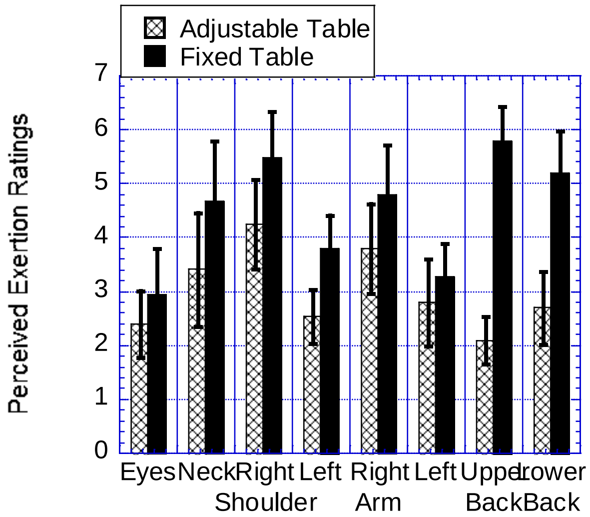


Fig.5. Effect of table type on perceived exertion at different body regions

IV. DISCUSSION AND CONCLUSION

The results of this study after evaluation of table type indicated that a less biomechanical stress and a more comfortable posture was obtained by students who are using an adjustable inclined surface table as compared with the horizontal surface table. The adjustable inclined surface table did support the muscle system in non-stressed postures. The analysis was based on the prediction of musculoskeletal stresses using the biomechanical model which capable to handle static modes. The analysis was also supported by using EMG to measure the erector spinae and rectus abdominis muscle stresses and supported by a psychophysical measure of comfort. Therefore, the drafting table is needed to be redesigned to provide mobility. Mobility here means an adjustment for the table height and surface inclination so that the student can stand or sit with a more upright trunk and less of the neck flexion. Also, the study proved statistically that the current horizontal table forced the students to lean forward increasing trunk effort for a long period of time yielded a full muscle fatigue. This is in agreement with the finding of other investigators who have evaluated the use of sloping furniture using different posture evaluation techniques (Damecour et al. [8]; Lee et al. [3]; Antle et al. [9]; Workineh and Yamaura [5]; Keester and Sommerich [4]). Further investigations of sloping furniture might benefit from factoring out the visual and anatomical determinants of posture and from attempting to characterize and evaluate changes posture that occurs dynamically.The evident from the agreement of biomechanical stress measures, EMG values, and psychophysical comfort scales proved the capability of the newly available approaches. Therefore, the finding here in this study did show the effective methodology that employs a body posture recording and an analyzing technique during students work. The simplicity of this methodology will help the designer to use the model in the field studies as well as in the laboratories. In addition, the biomechanical model eliminates the draw backs of the past methodologies by including the time history of the postures and dynamic mode of the entire movement.

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