INVESTIGATION OF LOWER LIMB FATIGUE ON TWO STANDING POSTURE

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Received 20 February 2012 *Accepted 2 April 2012*

Abstract

The purpose of this study was to investigate the different effect from the two standing posture on lower limb fatigue and discomfort. Sixteen subjects (eight females and eight males), aged between 23-29 years, participated in the experiment. They performed a sorting task in front of a grading table by picking and placing objects for 90 minutes in two posture (1) standing and (2) standing using a footrest. Muscle activity was recorded with surface EMG through disposable electrodes. The result shows that standing for ninety minutes developed fatigue in lower limb muscles and back muscles that lead to low back pain. Standing using a footrest result proper posture for prolonged standing period and reduce force at the back. It also results less fatigue and reduce the %MVC of EMG. So, it is recommended to attach a footrest in standing workstation to reduce the fatigue and discomfort.

Keywords:*fatigue, posture, standing,lower limb, EMG*

1. INTRODUCTION

Standing is a human natural position.We frequently standing for a prolonged period in our everyday life; while chatting to somebody, waitting in a line or waitting for a bus. Working in standing position is necessary for many occupations such as assembly line work, machine operation, working in belt conveyor line or even retail sales. Those kinds of work require workers stand for a long time (during working hours) and often limited in a small area. Furthermore, stationary standing is a posture often taken by workers when performing their job.

Working posture that workers adopt greatly affected on comfort and productivity. The poor repetitive, prolonged, static and forceful working posture may cause discomfort and injury. Therefore, employers should aware to the comfort and safety of workers in the workplace.

2. LITERATURE REVIEW

2.1. Working Posture

The posture that a person adopts when performing a particular task is determined by the relationship between the dimensions of the person’s body and the dimensions of the various items in his or her workspace [1]. The extent to which posture is constrained in this way is dependent upon the number and nature of the connections between the person and the workspace. These connections may be either physical (seat, worktop, etc.) or visual (location of displays, etc.).

Posture may be defined as the relative orientation of the parts of the body in space. To maintain such an orientation over a period of time, muscles must be used to counteract any external forces acting upon the body (or in some minority of cases internal tensions within the body) [1]. The most ubiquitous of these external forces is gravity. Consider a standing person who leans forwards from the waist. The postural loadings on the hip extensor or the back extensor muscles are proportional to the horizontal distance between the hip and lumbosacral joints, respectively, and the centre of gravity of the upper part of the body (i.e. the head, arms and trunk).

2.2. Muscle Fatigue

When the muscles remain static, people who consistently stand at work risk some injuries, fatigue, discomfort, and musculoskeletal disorders (MSD) [2,3,4,5]. Actually, any opportunity to change body position or make any movement can reduce the discomfort or fatigue.

There are some methods to reduce fatigue during prolonged standing in the workplace. One of these methods is providing footrest at the workstation [6]. Install a foot bar or footrest under the workstation allows person to changes the posture (rest a foot on it, shift body weight from one leg to the other). Thus, the purpose of this study was to investigate the different effect from the two standing posture on lower limb fatigue and discomfort.

2.3. Electromyography (EMG)

EMG is an experimental technique concerned with the development, recording and analysis of myoelectric signals. It was formed by physical variations in the state of muscle fiber membranes [7]. The EMG technique is based on the phenomenon of electromechanical coupling in the muscle. Electrical signals generated in the muscle eventually lead to a muscle contraction after an intermediate process [8].

The sweep of action potentials over the muscle membranes can be likened to waves. Information about electrical activity in the muscle can be represented as the height of the wave at a given point with respect to the other points, and also the density of the waves. This information is called an electromyogram

3. METHODOLOGY

3.1. Subjects

Sixteen subjects (eight females and eight males),agedbetween 23-29 years, participated in the experiment. All subjects had to be free of lower extremity problems, and they had no history of lower extremity or back problems. Before the experiment, the subjects were asked to fill out a form describing their age, stature and weight.

3.2. Apparatus and Material

NORAXON EMG and the sensor system were used to measure muscle activity. Noraxon dual disposable and self-adhesive Ag-AgCl electrodes (Noraxon USA, Inc., Scottsdale, USA) were pasted on selected muscles, and they were connected to a transmitter, TeleMyo 2400T G2-290, using the EMG cable. The transmitter with 8 channels (only 7 channels are needed) and the wireless system sent the EMG signal to the EMG software, MyoResearch XP Master Edition.

3.3 Procedures

Subjects performed a sorting task in front of a grading table by picking and placing objects for 90 minutes for each condition. Subjects were required to stand in a limited working space (0.5 m x 0.5 m) while performing the sorting task. There was no rest given during the experiment, but the subjects were allowed to adjust their posture within the constrained space. All subjects stood barefoot. Figure 1 shows the workstation. The dimensions of the workstation were within the limit of a normal horizontal work area (for a lower table) and a maximum horizontal work area (for the grading table). The reach envelope (normal and maximum area) depended on the subjects' anthropometric measurements and was not related to population average measurements.

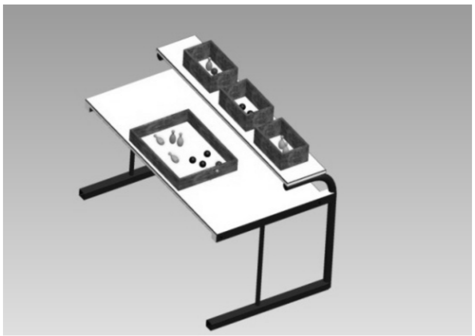

Figure 1. Workstation

Subjects sorted mixed objects and placed them in three target boxes on the grading table. The first box was for the green, the second box was for the blue and the third box was for the other color. The duration of each picks up and placement was three seconds. Figure 2 shows the experimental task.

(a) (b)

Figure 2. Experimental positions: (a) standing (b) standing using a footrest

Each subject was required to perform the same task .The first experiment involved the standing position and the second experiment involved standing and using the footrest. For the second experiment, the footrest (Figure 3) was placed under the table; thus, if the operators felt pain or discomfort while standing they could place their feet on the footrest.

Figure 3. Footrest

Four lower leg muscles (soleus, medial gastrocnemius, lateral gastrocnemius, tibialis anterior) and two back muscles (Lumbar erector spinae (LES) and Thoracic erector spinae (TES)) were chosen for observation in the experiment.

3.4. Measurement and Data Collection

Muscle activity was recorded with surface EMG through disposable electrodes. Electrode positions were based on the Surface EMG for non-invasive assessment of muscles (SENIAM). These individual recommendations were based on 2 general recommendations. First, SENIAM recommends placing the sensor halfway between the most distal motor endplate zone and the distal tendon. Second, SENIAM recommends placing the sensor on the surface away from the 'edge' with other subdivisions or muscles so that the geometrical distance of the muscle to these subdivisions and other muscles is maximized. In other words, the electrode pair was placed in a central position over the belly muscle.

Raw EMG was collected at 1500 samples/s. For recordings of the upper body, ECG bursts that may contaminate the EMG recording were cleaned by ECG reduction. Digital filtering was used at 10 Hz - 400 Hz. Full wave rectifications were used to convert negative amplitudes to positive amplitudes to remove systematic bias. The non-reproducible part of the signal was minimized by applying digital smoothing algorithms RMS (root mean square) that outlined the mean trend of signal development.

To overcome the variation in electrode sites, subjects' day-to-day measures of the same muscle site were normalized to Maximum voluntary contraction (MVC) and calibrated by the microvolt value to percent of maximum innervations capacity. Subjects performed MVC tests before the experiment in specific positions [7]. The MVC tests were measured for three seconds and were repeated three times.

3.5. Data Analysis

Paired t-tests wereperformed to test the hypothesis that using footrest makes the difference to the % MVC of EMG.

4. RESULTS

4.1. Subject Anthropometry data

The anthropometric data regarding body dimensions for the standing workstation were also measured. Table 1 shows the subjects anthropometry data

Table 1. Subjects anthropometry data

	Male (n=8)		**Female (n=8)**	
	mean	**SD**	**mean**	**SD**
Age (years)	24.6	1.5	25.5	1.2
Height (m)	169	9.4	155.4	2.9
Mass (kg)	70.3	23.8	50.7	6.7
Standing elbow height (cm)	104.9	6.2	95.1	1.8
Arm reach forward (cm)	84.9	14.4	77.4	5.9

4.2. Force Generated

The first experiment involved the standing position and the second experiment involved standing while using the footrest. For the second experiment, the footrest was placed under the table; thus, if the operators felt pain or discomfort while standing they could place their feet on the footrest. Figure 4 shows the body sketch for standing and standing using a footrest

F1 and F2 in standing (a) are the force generated to support the body weights by legs. It equals to half of body weight multiple to gravity (9.8m/s^2), for each F1 and F2. Each leg supports half of body weight because both of the legs are place on the floor, consequently, each of the leg support equal amount of body weight.

Therefore, in the standing condition the amount of F1 and F2 is equal.

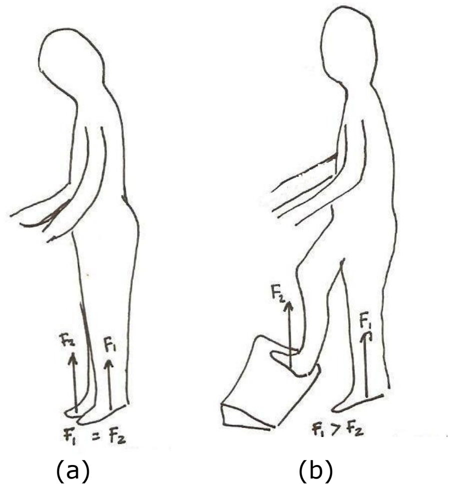

Figure 4. Body sketch for (a) Standing and (b) standing with a footrest

Furthermore, the amount of F1 and F2 for standing using a footrest is not equal. Figure 4 (b) shows that when standing using a footrest, one leg is on the floor and the other leg on the footrest. The force generated by the one that on the floor (F1) is greater than those on the footrest (F2). It is because the leg those on the floor support most of body weight while the other leg resting on footrest.

4.3. Physiological Effect

Figure 5 shows a graph of %MVC for ninety minutes standing (ninety minutes of exposure time was divided into 18 time intervals of 5 minutes). The results of %MVC showed a continuous increased for all muscles. The greatest muscle activity occurred in the soleus muscles, which also had the highest mean %MVC for lower leg muscles. It was followed by the peroneus, lateral gastrocnemius, medial gastrocnemius and tibialis anterior. Moreover, for back muscles, LES had the highest mean of %MVC.

Ninety minutes of standing using the footrest tends to stabilize and decrease the %MVC of EMG. Figure 6 shows the %MVC while standing with footrest.The mean %MVC standing was greater than that standing using footrest.

The paired t-test was used to find the difference in mean %MVC between the two conditions. The result showed found that there was no different mean %MVC between the two conditions. But, the mean %MVC when standing is higher than when standing and using a footrest.

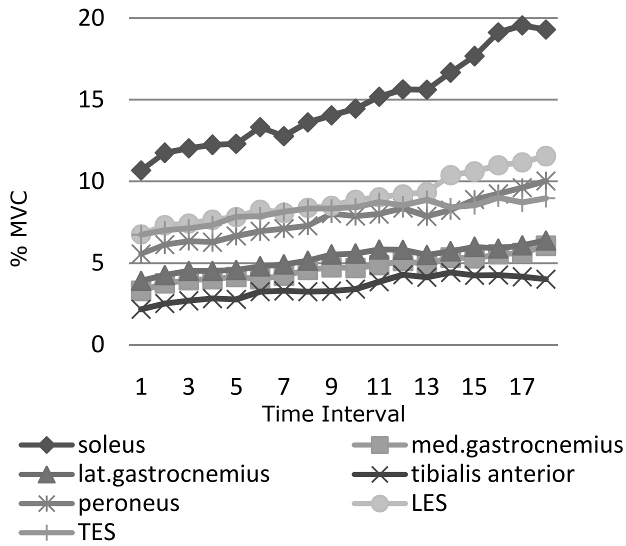

Figure 5. Percentage of MVC while standing for 90 minutes

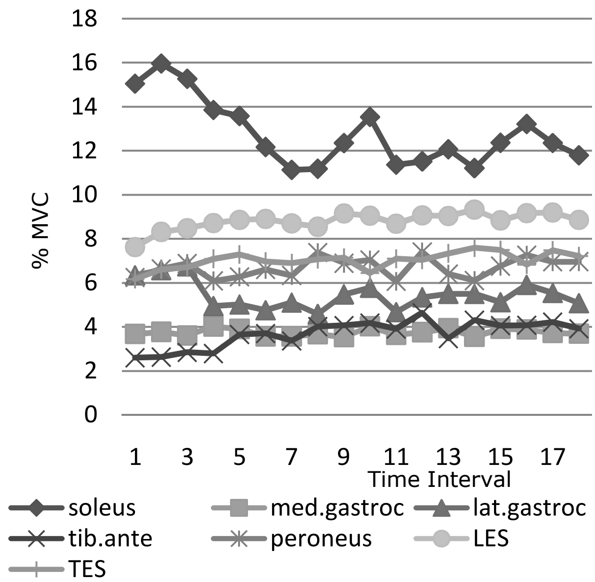

Figure 6. Percentage of MVC while standing with footrest for 90 minutes

Studies by Bjorksten and Jonsson (1977) reported that when the period of muscle contraction exceeds an hour, the endurance limit of force may be as low as 8% MVC[9]. This value is characterized as fatigue. Based on these values, the initialization of fatigue can be determined.the initialization of fatigue when standing in these two conditions shows in Table 2.

Table 2. Time to muscle fatigue

No	Muscles	Time to muscle fatigue (minutes)	
		Standing	Standing with footrest
1	Soleus	5th (10.68%)	5th (15.5%)
2	Medial gastrocnemius	- *	-
3	Lateral gastrocnemius	-	-
4	Tibialis anterior	-	-
5	Peroneus	45th (8.03%)	-
6	LES	30th (8.27 %)	10th (8.31%)
7	TES	35th(8.14 %)	-

* (-) the value below 8%

5. DISCUSSION

5.1.Standing

Present procedures of experiments result a tendency of the subjects to stand statically. Although the limited movement allowed, but subjects rarely take this opportunity. Most of them just shifted the body weight to one part of their body to relieve pain and fatigue. Figure 4 shows in standing posture, the force generated to support the body weights are allocated equally for each leg. However, for prolonged standing time subjects tend to shift the body weight to one leg to relieve pain and fatigue, lean on one side of the body. These postures have changed the natural standing position that would lead to fatigue and pain on the back and hips.

The posture also affects the effects of physiological factors. This study showed that ninety minutes of standing work increase the %MVC of EMG. These results were in line with the result another study that found fatigue occurred with an increase in normalized RMS or %MVC [10,11].

A number of investigators have recommended average force exposure limits to prevent fatigue. These limits range from 0% to 15% of %MVC for continuous exertions. Sjogaard et al. (1988) found that muscular fatigue occurs at EMG levels as low as 5% MVC if sustained for one hour([9]. Other studies, by Bjorksten and Jonsson (1977), have reported that, when the period of muscle contraction is extended to more than an hour, the endurance limit of force may be as low as 8%MVC [9]. Therefore, this value is characterized as fatigue. Fatigue in the soleus muscle occurs in the first 5 minutes of standing. However, in the peroneus, LES and TES, fatigue occurs after 45 minutes, 30 minutes and 35 minutes, respectively. The medial gastrocnemius, lateral gastrocnemius and tibialis anterior were not fatigued. This indicates that fatigue also occurs in back muscles, which leads to low back pain

5.2. Standing Using a Footrest

Using a footrest in a standing workstation allowed the operators to relieve pain and fatigue by put one leg to it. Body weight automatically shifted in one leg only which is to leg that still on the floor, on the other leg (on the footrest) will relax. Unlike standing still, when the subject put one foot on footrest, this does not cause changes in the normal standing posture, it keep the back straight. Furthermore, this posture reduces the pressure at the back. This can be seen from Figure 7, that shows mean %MVC at back muscles (TES and LES) when standing and using a footrest are lower than standing without footrest. In addition, by providing the footrest, the operator with the reflexes replaced the fatigue legs to be placed on the footrest. And body remains in erect posture.

Although, forces generates by foot on the floor is larger than the other foot which on the footrest, footrest provides support to the lower back and increases the circulation to the legs and courage proper posture. It reduces stress placed on the feet, relieves pressure on the back and promotes postural changes by shifting the body weight from one foot to another foot [12].

The present study also showed that using a footrest in standing work involves a pronounced reduction the %MVC of muscles and a reduction in perceived discomfort compared to standing condition. Muscle fatigue occurs in the soleus muscle after 5 minutes standing and in the LES after 10 minutes; however, because the %MVC tends to decrease over time, the fatigue was less than those for standing alone or standing with a sit/stand stool after 90 minutes of exposure.

The idea of providing a footrest at a workstation is to allow the person to rest one foot on it and shift body weight from one leg to the other, thereby varying low back posture over the course of time. This means that the body may change positions by shifting weight from one foot to another to relieve some of the pressure on the back. This promotes proper blood circulation and muscle pumping, and reduces the compression by body weight. Finally, it produces a better condition with less fatigue and more comfort for standing work. Thus, it minimizes the energy requirements by holding the upper body erect for long periods, and it confirms that a footrest reduces the consequences of prolonged standing fatigue. To reduce fatigue, static conditions, pressure, and good blood circulation are all critical

5. CONCLUSION

Within the scope of this study, it can be concluded that:

1. Standing for ninety minutes developed fatigue in lower limb muscles and back muscles that lead to low back pain.
2. Standing using a footrest result proper posture for prolonged standing period and reduce force at the back. It also results less fatigue and reduce the %MVC of EMG.
3. It is recommended to attach a footrest in standing workstation to reduce the fatigue and discomfort.

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BIOGRAPHY

Sari Julia Sartika, MEng, Sc., received her Master in Engineering Design and Manufacture at University of Malaya in 2010 and degree in Industrial Engineering at Andalas University in 2007. She works at PT PLN Batam. Her research interest in ergonomics includes prolonged standing effect, muscle activity, anthropometry, Ergonomics design, occupational safety and health and work studies.

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