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Investigating the Physiological Effects of Standing, Using a Sit/stand Stool and Standing with a Footrest During Static Tasks

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Abstract: This study focuses on comparing the physiological effect and the mechanism of fatigue and discomfort during standing, sit/standing and standing with footrest conditions. Sixteen subjects were involved in the study, eight females and eight males with no previous lower extremity problems. The subjects sorted objects by picking them up and placing them on a grading table. This study showed that using the sit/stand stool and footrest reduced the perceived discomfort and %MVC. However, compared to using the footrest, using the sit/stand stool increased skin temperature and may lead to swelling. Ninety percent of the subjects preferred using the footrest if they had to work in the standing position again. It is recommended to apply the sit/standing position or to add the footrest to standing workstations. However, it is also preferable to add a footrest rather than use the sit/stand stool in prolonged standing work because it is more economical, and the posture assumed when using the footrest is not significantly different compared to the standing condition.

Key words: Standing, sit/stand stool, footrest, fatigue, static task.

INTRODUCTION

Standing work tasks improve productivity and cause fewer lumbar pains than sitting work tasks (Kawano, 2005). However, standing still requires a low-level contraction of fatigue-resistant muscle fibers. For the lower limbs, and particularly the soleus muscle, the contraction is about 10% of its maximal voluntary contraction (MVC) (Okada, 1973 as quoted by Caron, 2002).

Prolonged standing is considered as one occupational risk factor for MSDs. These include clinical syndromes such as tendon inflammations and related conditions (tenosynovitis, epicondylitis, bursitis), nerve compression disorders (carpal tunnel syndrome, sciatica), and osteoarthritis, as well as less standardized conditions such as myalgia, low back pain and other regional pain syndromes not attributable to a known pathology (Punnett & Wegman, 2004).

The first European Survey on the work Environment in year 1991-1992 reported that more than a quarter of the workforce has indicated that they work in painful or tiring positions at least half of the time (Madeleine & Arendt-Nielsen, 1998). The roles of cumulative trauma disorders (CTDs), repetitive strain injuries (RSIs) and musculoskeletal disorders (MSDs) in everyday occupations have recently garnered increased attention (Shinnar, A., Indelicato, Altimari, & Shinnar, S., 2004). These problems are widespread in many countries and are associated with substantial costs and reduced quality of life.

Therefore, there is a need to analyze all of the effects, mechanisms, and methods to overcome the consequences of prolonged standing. Multiple literature sources suggest that standing stress can be reduced by the following: (1) softer floors (i.e., mats), (2) better shoes, (3) footrest, (4) walking, and (5) sit/stand chairs (Konz & Rys, 2003).

In contrast with Konz & Rys (2003), Chester, Mandy, Rys & Konz (2002) found that leg volume and circumference change the most when using a sit/stand chair. Researchers have monitored some variables during prolonged standing; however, the research tends to focus on the comparison of flooring (soft versus hard floor) and type of shoes, with limited muscle selection recorded. The investigation of footrests is limited and rare. Therefore, the aims of the present study focus on the comparison of physiological effect and the mechanism of fatigue and discomfort during standing, sit/standing and standing with footrest conditions.

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II. Methodology:

2.1. Subjects:

Sixteen subjects (eight females and eight males), aged between 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. Next, the experimental procedures were explained

2.2 Apparatus and Material:

Subjective and objective measurements were performed. The objective measurements were EMG recordings and skin temperature. The subjective measurement was perceived discomfort using the Borg CR 10 scales.

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. A Lutron infrared thermometer (TM-956, range $-30^{o}C$ to $305^{o}C$, 0.95 emissivity values) was used to record the skin temperature.

2.3 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.

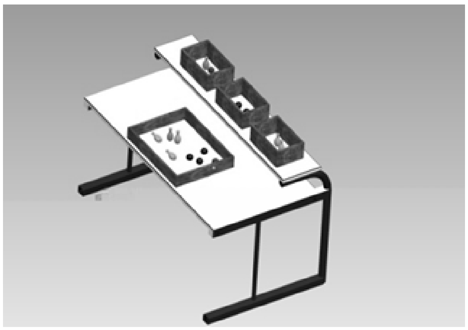


Fig. 1: Workstation.

Subjects sorted mixed objects and placed them in three target boxes on the grading table. The first box was for green objects, the second box was for blue objects and the third box was for objects of another color. The green and blue objects represented good products (with different quality levels), and the other colored objects represented defective products. Based on the pilot test, the duration of each pick up and placement was three seconds. Each subject was required to perform the same task. Figure 2 shows the experimental task.

(a) (b) (c)

Fig. 2: Experimental positions: (a) standing (b) using sit/stand stool; (c) standing using a footrest.

The first experiment involved the standing position, the second experiment used the sit/stand stool and the third experiment involved standing and using the footrest. For the third 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.

Fig. 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.

2.4 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, with respect to the longitudinal location of the sensor on the muscle, SENIAM recommends placing the sensor halfway between the most distal motor endplate zone and the distal tendon. Second, with respect to the transversal location of the sensor on the muscle, 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 (Konrad, 2005). The MVC tests were measured for three seconds and were repeated three times.

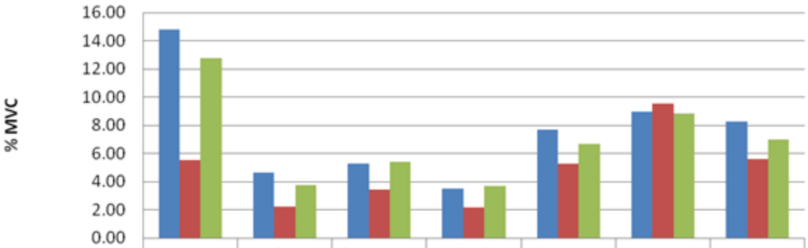
Skin temperature was measured at the selected lower leg muscles, dorsal arch and elbow at the beginning of the experiment and every 15 minutes. The skin temperature at the elbow was also recorded every 15 minutes as a control temperature. The location of temperature measurement was marked with a permanent marker to ensure identical measurement locations throughout the experiment. The ambient temperature was set to 25ºC - 26ºC and controlled by an air conditioning system. Perceived discomfort or general fatigue, discomfort in the upper back, lower back, hips, upper leg, knee, lower leg, ankle and foot were rated by the subjects using the Borg CR 10 scales at the beginning and every 30 minutes during the experiment.

Results:

Percent MVC of EMG:

A comparison of the three conditions showed that standing appears to have a higher percentage MVC (%MVC), followed by using the footrest and the sit/stand stool. ANOVA was used to investigate the difference in %MVC among the three conditions.

We found that there was a difference in the mean %MVC for the soleus ($p=0.00$) muscle. Post hoc analysis revealed that there was a significant difference between standing with the sit/stand stool ($p=0.00$) and standing with the footrest ($p=0.002$). Figure 4 shows the comparison of mean %MVC for the three conditions.



	soleus	med.gastrocnemius	lat.gastrocnemius	tibialis anterior	peroneus	LES	TES
standing	14.78	4.68	5.28	3.49	7.69	8.96	8.25
sit/stand stool	5.52	2.27	3.42	2.17	5.26	9.52	5.62
footrest	12.77	3.74	5.44	3.68	6.68	8.81	7.03

Fig. 4: Comparison of mean %MVC for the three conditions.

Time to Muscle Fatigue:

Studies by Bjorksten and Jonsson (1977) reported that when muscle contraction exceeds one hour, the endurance limit of force may be as low as 8% MVC. This value is characterized as fatigue (Bernard, 1997). Based on these values, the initialization of fatigue can be determined by the %MVC over 90 minutes of exposure for the three conditions. The 90 minutes of exposure were divided into 18 time intervals of five minutes each.

As shown in Figure 5, the results suggested a continuous increase for all muscles while standing. The increase in %MVC for the soleus was 10.68% to 19.31%, the medial gastrocnemius was 3.29% to 6.06, the lateral gastrocnemius was 3.91% to 6.39%, the tibialis anterior was 2.17% to 4.01%, the peroneus was 5.57% to 10.03%, the LES was 6.75% to 11.55% and the TES was 6.74% to 8.98%.

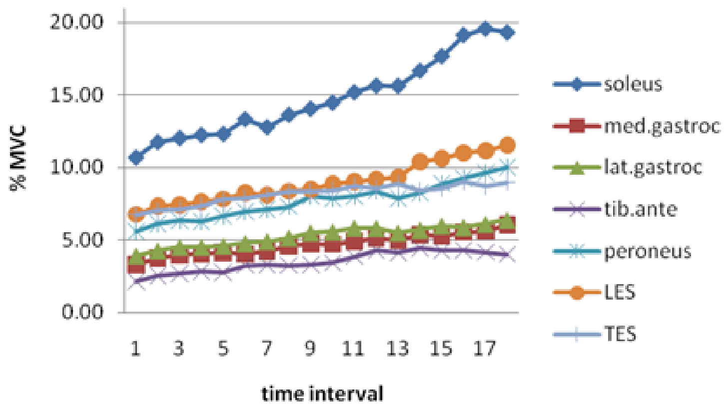


Fig. 5: Percentage of MVC while standing for 90 minutes.

The 90 minutes of work while using the sit/stand stool also increased the %MVC of EMG; however, it was not as great of an increase as that observed for standing (Figure 6). The increase in the soleus was 3.13% to 6.15%, the medial gastrocnemius was 1% to 3.06%, the lateral gastrocnemius was 1.94% to 3.92%, the tibialis anterior was 1.47% to 2.48%, the peroneus was 3.1% to 6.38%, the LES was 6.24% to 8.23% and the TES was 4.85% to 6.74%.

The 90 minutes of standing and using the footrest tended to stabilize and decrease the %MVC of EMG in the end of time interval, as shown in Figure 7. The decrease occurred in the soleus was from 15.05% to 11.79% and in the lateral gastrocnemius was from 6.34% to 5.07%. Stabile and slight increase of %MVC occurred in the medial gastrocnemius was from 3.67% to 3.68%, the tibialis anterior was from 2.6% to 3.92%; the peroneus was from 6.25% to 6.96%; the LES was from7.62% to 8.86%; and the TES was from 6.17% to 7.22%.

Based on the value suggested by Bjorksten and Jonsson (1977), the initialization of fatigue for the three conditions was determined (Table 1).

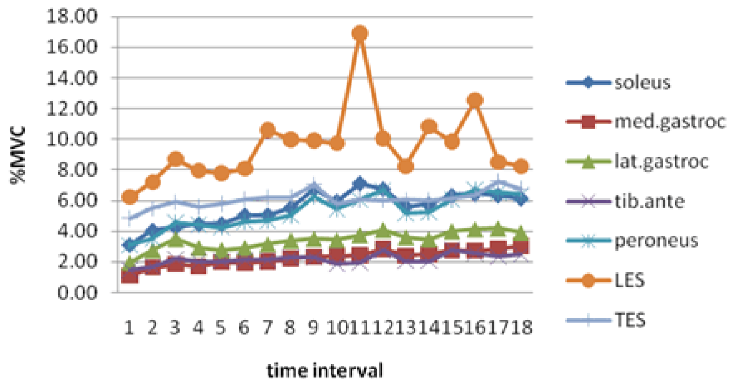


Fig. 6: Percentage of MVC while using the sit/stand stool for 90 minutes.

Table 4.2: Time to muscle fatigue during standing.

No	Muscles	Time to fatigue (minutes)		
		Standing	Sit/standing	Standing with footrest
1	Soleus	5th (10.68%)	5th (15.5%)	5th (15.5%)
2	Medial gastrocnemius	-*	-	-
3	Lateral gastrocnemius	-	-	-
4	Tibialis anterior	-	-	-
5	Peroneus	45th (8.03%)	-	-
6	LES	30th (8.27 %)	15th (8.7%)	10th (8.31%)
7	TES	35th (8.14 %)	-	-

• value below 8%

3.3 Skin Temperature Changes:

Skin temperature changes were measured every 15 minutes and normalized to the elbow temperature measurements. The temperature at the elbow is stable; it is designated as the control temperature (Cham and Redfern, 1999). Skin temperature changes at the muscles showed that the sit/stand stool condition had a higher value, followed by standing and using the footrest. Figure 5 shows the mean of the skin temperature changes of the three conditions. ANOVA was used to investigate the change in skin temperature among the three conditions. The result indicated that there was no significant difference in skin temperature changes between the three conditions.

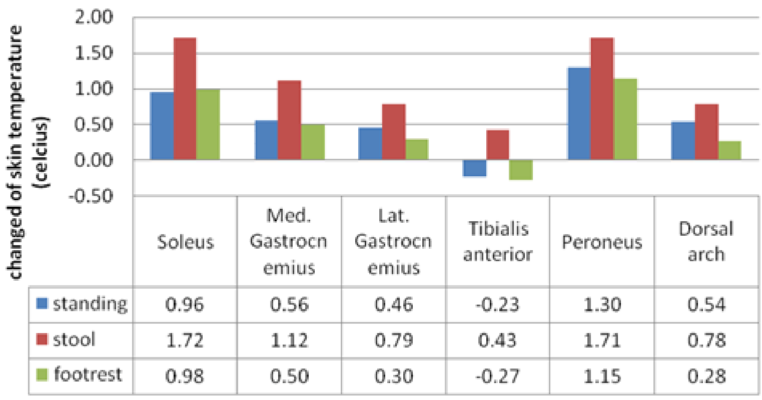
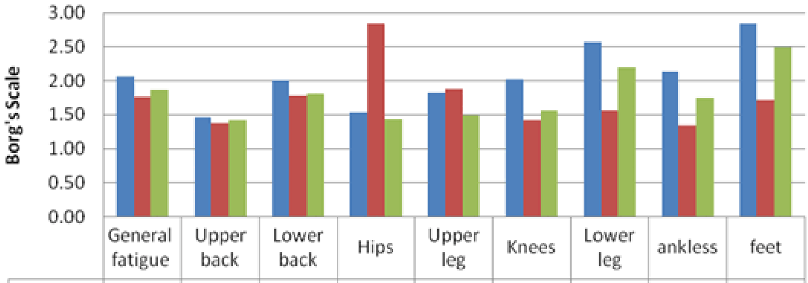


Fig. 5: Comparison mean of skin temperature changes for the three conditions.

3.4 Perceived Discomfort:

The discomfort ratings for the three conditions were on a scale of 0 – 10, with 10 being maximal discomfort. Perceived discomfort over multiple body parts and general fatigue had a higher value in the standing condition, followed by standing and using a footrest. However, the perceived discomfort at the hips (2.84) was higher while using the sit/stand stool. Figure 6 shows the means of the perceived discomfort rating for the three conditions.

ANOVA revealed a significant difference among the mean perceived discomfort ratings of the three condition at the hips (p= 0.021) for the sit/stand stool condition. However, post hoc analysis revealed that the difference was not significant. In fact, 90% of the subjects would choose to use the footrest if they had to work in the standing position again.



	General fatigue	Upper back	Lower back	Hips	Upper leg	Knees	Lower leg	ankless	feet
standig	2.07	1.47	2.01	1.54	1.82	2.02	2.57	2.14	2.84
stool	1.76	1.37	1.78	2.84	1.87	1.42	1.57	1.35	1.72
footrest	1.86	1.42	1.81	1.43	1.49	1.56	2.20	1.75	2.49

Fig. 6: Comparison of the mean of the perceived discomfort ratings for the three conditions.

IV. Discussion:

The results of this study indicate that the standing condition results in the highest %MVC and perceived discomfort, followed by standing with the footrest and using the sit/stand stool. Fatigue was indicated if the %MVC increased more than 8%. Skin temperature changes were highest when using a sit/stand stool, followed by the standing position. The present study shows that using the sit/stand stool for work that requires prolonged standing increases the %MVC of lower leg muscles (LES increase 6.3%) compared to that for standing alone. However, for the other lower leg muscles, using the sit/stand stool had a lower mean of %MVC. Furthermore, fatigue only occurred in the lower back (LES) after 15 minutes using the sit/stand stool. This was 15 minutes earlier than in the standing condition (fatigue occurred after 30minutes). And fatigue occurred in the hips after 30 minutes. It is hypothesized that using a sit/stand stool helps to maintain a standing position while also supporting the body weight. The reduction of %MVC of the muscles indicated that the stool supported the body weight rather than the lower extremities.

Using a sit/stand stool also increased the skin temperature. The greatest skin temperature changes occurred in the soleus (1.46°C to 2.1°C, increase 78.7%) and the peroneus (1.19°C to 2.14°C, increase 43.2%). Moreover, the changes in skin temperature over the muscles suggested that using the sit/stand stool resulted in higher temperatures than the standing condition because of problems related to blood circulation to the lower extremities. Problems with blood circulation may cause swelling, an increase in the circumference of the extremities, and an increase in skin temperature. These results are similar to those obtained in a study by Chester, Mandy, Rys & Konz (2002), who found that leg volume changes the most when using the sit/stand chair, as compared to standing and sitting separately.

However, using the sit/stand stool resulted in lower ratings for perceived discomfort of all body parts and general fatigue, as compared to standing, except for the hips and upper leg, which experienced greater ratings of 85% and 3%, respectively. These results are also in line with a study reported by Chester, Mandy, Rys & Konz (2002), who found that the use of sit/stand chairs caused slight discomfort in the upper back, hips and upper leg. In present study, the discomfort may be related to posture, and the sit/stand stool itself may have a hard seat. Although the sit/stand stool supported the body weight, the cushions were not thick, and the seat was hard because the base was made from wood. When using the sit/stand stool, some parts of the upper legs were supported by the seat of the stool. This position, over a long time, increases discomfort in the upper legs.

The present study also showed that compared to the standing condition, using a footrest in standing work involved a pronounced reduction in the %MVC of the muscles, a reduction in the change in skin temperature and a reduction in perceived discomfort. Muscle fatigue occurred in the soleus muscle after 5 minutes and in the LES after 10 minutes of standing; however, because the %MVC tended to decrease over time, the fatigue was less when using a footrest compared to that during standing alone or standing with a sit/stand stool after 90 minutes of exposure. The hypothesis was that providing a footrest at a workstation would allow the person to rest one foot on it and shift the body weight from one leg to the other, thereby varying the low back posture over time.

This finding indicates that the body may change positions by shifting weight from one foot to another to relieve some of the pressure on the back, or to create movement while standing for a long time. the opportunity to change body position would promote proper blood circulation and muscle pumping and would reduce the compression of the body weight. Finally, it would produce a better working condition with less fatigue and more comfort for standing work. By holding the upper body erect for long periods, this condition would minimize the energy requirements, and the footrest would reduce the consequences of prolonged standing fatigue. Static conditions, pressure, and good blood circulation are all critical for reducing fatigue.

Conclusion:

Within the scope of this study, we concluded that

1. The %MVC of EMG and perceived discomfort were higher while standing, followed by using the footrest and the sit/stand stool.
2. Skin temperature changes were greater while using the sit/stand stool, followed by standing and using the footrest.
3. Using the sit/stand stool and footrest reduced the perceived discomfort and % MVC. However, compared to using the footrest, using the sit/stand stool increased the skin temperature and may have led to swelling. Ninety percent of the subjects reported that they would choose to use the footrest if they had to work in a standing position again.
4. It is recommended to apply the sit/standing condition or add a footrest to standing workstations. However, adding the footrest is preferred over the sit/stand stool in prolonged standing work because it is more economical, and the posture is not very different from that in the standing position

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