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The effect of the standing angle on reducing fatigue among prolonged standing workers

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Abstract. *Background*: Many occupations require workers to stand for prolonged periods, which can cause discomfort, pain and even injures. Some supermarkets provide a footpad for checkout staff to let them stand on it while working. The assumption is that standing fatigue can be reduced by this system. An inclined platform might have the same effect and could relieve standing fatigue to a certain extent.

Objective: This study aims to analyze how the standing angle affects fatigue among prolonged standing workers.

Methods: Inclined platforms with four different angles were used by eight participants. sEMG (Surface Electromyography) was used to collect physiological information on prolonged standing participants and a visual analogue scale was used as a subjective method to measure the experienced fatigue.

Results and conclusion: When participants stand on inclined platforms at 0°, 5° and 10°, the iEMG (Integrated Electromyography) values of the gastrointestinal muscle were not significantly different until 40 minutes on the platform. After 40 minutes, the iEMG decreases when standing on an inclined platform between 5° and 10°. The experienced fatigue is also lowest at 5 and 10 degrees. This knowledge can be useful for designing inclined working platforms for prolonged standing workers. It is advised to study long term effects in real working situations.

Keywords: Prolonged standing; Standing angle; Inclined platform; Surface Electromyography; Lower limb fatigue

1. Introduction

Many workers, such as supermarket checkout workers, assembly, quality-control and healthcare workers, are required to stand for prolonged periods of time. Prolonged standing can allow workers to perform their work in a simple and efficient way and can make workers more productive in specific working conditions and can contribute to high productivity in the industry [1]. After prolonged standing work, the lower back and lower limbs are statically loaded, resulting in discomfort of the calf muscles and workers may experience muscle fatigue, pain in lower back and limbs, which even can cause occupational injuries doing this work day by day [2]. Ryan stated that checkout workers in the supermarket had the highest rates of musculoskeletal symptoms of almost all body areas [3]. The lower back, lower limbs and feet were the body areas with the highest rates. A positive and significant correlation was found between proportion of time spent standing and symptoms in the lower limbs and feet. Plantar fasciopathy is also common among individuals in the workplace, with job descriptions requiring prolonged standing [4]. Discomfort and muscle fatigue are often accompanied by mental fatigue, which is considered to be factors of inattention, lack of concentration and decline in positivity [5].

Subjective evaluation of experienced fatigue caused by prolonged standing is often studied by using a questionnaire survey. Local muscle fatigue can be technically identified by observing changes in the amplitude and frequency of the electromyogram signal over time. When the amplitude of the signal increases and the power frequency decreases, it indicates that the muscle being evaluated is in a fatigue state [6].

Many studies have investigated the effect of interventions on prolonged standing workers. Cham et al. investigated the influence of flooring on subjective discomfort and fatigue during standing. They found that floor mats characterized by increased elasticity, decreased energy absorption, and increased stiffness, resulted in less discomfort and fatigue [7]. Nelson et al. found that standing on a sloping platform significantly reduced the subject's feeling of lower back discomfort and attributed this phenomenon to a reduction in lumbar lordosis and an increase in varying the posture [8]. According to Lin et al, the type of floor and standing time can significantly affect the subjective score of leg discomfort and lower leg circumference [9]. Zender et al. investigated the impact of floor type on subjective and biomechanical/physiological measures related to standing discomfort. Their findings suggest that common product interventions (such as insoles and floor mats) may have little effect on controlling the leg edema of industrial workers after eight hours work[10]. However, few studies have used the inclined platforms as an intervention to reduce lower limb fatigue. Therefore, the aim at this project was to study the specific impact of inclined platforms from different angles among prolonged standing workers to try to find a new solution.

2. Methods

The study was carried out at the Ergonomics Lab of Donghua University. Eight college students (5 males, 3 females) aged 22-26 were recruited as participants. Their average height was 174.1 cm (SD ±7.3 cm) and average weight was 65.5 kg (SD±6.2 kg) and all participants were healthy without musculoskeletal problems. Each participant was required to stand on the inclined platform for 80 minutes. Participants performed the task of standing and typing throughout the experiment. Next to the 0° (no inclination), there are three different angles of inclined platforms, 5°, 10°, 15° respectively as shown in Figure 1. They participated in four sets of experiments within four working days. In order to ensure that the fatigue status of the participants is the same, each participant had to sit on a sofa and rested for 30 minutes before the experiment, and then the experiment was conducted. Each participant only conducted one set of experiments per day, that is, standing at only one angle for 80 minutes. Participants were asked to wear everyday shoes with almost no inclination. The shoe itself had to have no height and heel to avoid experimental errors caused by wearing shoes. Prior to participation, all participants signed an informed consent form indicating their participation was voluntary and that they were informed of the study objective and procedures.

Insert Figure 1 here

2.1 Data Collection

All data on the muscle activities of the participants were recorded, stored and analyzed using a Mangold-10 wireless Bluetooth multi-channel physiology instrument, as shown in Figure 2. The System is equipped with electrodes to detect the participant's sEMG signals. The signals are susceptible to external environmental factors because of the small input amplitude and low stability. In order to prevent noise and electromagnetic field radiation from affecting the experimental results, all relevant employees at the lab site were asked to turn off communication equipment and keep quiet.

Insert Figure 2 here

The electrodes were attached to the participant's skin and the activity of three muscles during standing was recorded: left erector spinae, left and right gastrocnemius muscles. Figure 3 shows the location of the sEMG electrodes used to measure the selected lower limb fatigue. The position of the electrode path needed to be marked after each experiment to ensure that the testing positions were the same during the other days of the experiments.

Insert Figure 3 here

In this experiment, the muscle signals were continuously measured on the inclined platform for each angle. The measurement order of the four angles is 0°, 5°, 10°, 15° from front to back. Participants data were collected every 20 minutes during the 80 minutes while standing on the same angle platform (in total of 5 recordings) times. The first data collection starts from minute 0. After the collection of the raw sEMG signals, the amplitude-frequency comprehensive analysis method was used to analyze the physiological information changes of the muscle activities. As shown in Figure 4, the amplitude frequency analysis method divides the sEMG signal into four quadrants of iEMG and MF (Median Frequency) spectrum changes to determine the increase or decrease of muscle strength and recovery from fatigue.

Insert Figure 4 here

2.2 Data Processing

The iEMG value reflects the cumulative electrical discharge of the muscle and the MF reflects the average power frequency of the EMG signal characteristic values. With the occurrence of muscle fatigue, the iEMG value and MF value are constantly changing, and the iEMG value generally increases. The average power spectrum will move to the left, that is, to the low frequencies, so the MF value will decrease. Therefore, the MF value and iEMG value are selected as the evaluation indicators of sEMG changes in muscle activities.

The sEMG signal obtained by the Mangold-10 system is an unfiltered and unprocessed waveform. The system will convert the raw data through an analog-to-digital converter and export it to txt text as a data source for further processing.

2.3 Data Analysis

2.3.1 Objective Data Analysis

1) The sEMG signals of two gastrocnemius muscles of eight participants in four groups of experiments were recorded and the iEMG values were calculated. If there were multiple participants taking part in the experiment at the same time, the participants were required not to communicate with each other, nor to observe each other and check the scores of others. The measured data of the left and right gastrocnemius muscles are basically the same, so during data analysis, the experimenter averaged the corresponding values of the two sets of data. The changes in iEMG value of the gastrointestinal muscles standing on the inclined platform at different angles were analyzed in MATLAB version 2017. After obtaining the value of iEMG, data were imported into SPSS version 24 and significant differences were calculated. The iEMG signals of the gastrointestinal muscles were

compared at different angles for different time periods. Next, the MF values of the gastrocnemius muscles of the participants were standardized and the test on significance differences performed. Then the MF value of the gastrointestinal muscles were compared at different angles in different time periods.

In addition, the MF values of the erector spinae of the participants were standardized and the difference was tested. The MF value of the erector spinae was compared for different angles and for different time periods.

2.3.2 Subjective Data Analysis

The subjective scale used in the experiment was an 11-point visual analog scale from 0-10, which represent different feelings from painless to intolerable, the smaller the value, the higher the experienced fatigue, as shown in Table 1. Participants needed to stand for 80 minutes and every 20 minutes their subjective fatigue value was recorded. The experienced fatigue data of all the participants were averaged, and results of different platform angles were compared.

Insert Table 1 here

3. Results and discussion

The difference in iEMG signals of the gastrocnemius muscle standing on inclined platforms at different angles was significant, $p=0.030<0.05$. Standing on the inclined platforms the iEMG value of the lower limb muscles decreased at all angles for a short time and the MF value increased. Figure 6 and table 3 show that the MF value of the gastrocnemius muscle standing on inclined platforms at different angles is also significantly different. ($p=0.046<0.05$). At 80 minutes the MF is lowest at 5 degrees and highest at 10 degrees. According to the results, standing platforms with different inclined angles have an effect on alleviating the lower limb fatigue.

Met opmerkingen [PV-I1]: to results

Insert Figure 5 here

Insert Table 2 here

Insert Figure 6 here

Insert Table 3 here

The erector spinae data shown in Figure 7and Table 4 indicate that the iEMG signals of the erector spinae standing on inclined platforms at different angles do not differ significantly ($p=0.192$). Figure 8 and table 5 show that the MF value of the erector spinae standing under the inclined platform at different angles do not differ significantly as well (p=0.836). This shows that standing platforms with different inclined angles have no effect on alleviating lumbar muscle fatigue.

Met opmerkingen [PV-I2]: to results

Insert Figure 7 here

Insert Table 4 here

Insert Figure 8 here

Insert Table 5 here

Regarding the questionnaires table 6 indicates, that the subjective fatigue of standing on a 15 ° inclined platform is the largest. Standing on a 5 ° and 10 ° inclined platform shows lower fatigue values.

Insert Table 6 here

Met opmerkingen [PV-I3]: there is no table or figure on comfort

Met opmerkingen [PV-I4R3]:

The goal of the study was to highlight the relationship between standing angle and lower limb fatigue. The results indicate that an inclined platform affects the lower limb fatigue after prolonged standing. Our correlation between the inclined platform and fatigue is similar to that reported in the review by Nelson et al. [8], where the authors did use a sloped surface in combination with low back pain. Standing on the inclined platforms the iEMG value of the lower limb muscles decreased at all angles for a short time and the MF value increased. This indicated that the muscles were recovering. Standing at 0 °, the amplitude is even greater indicating more muscle activity. When standing on inclined platforms at 0°, 5°, and 10°, the iEMG value of the myoelectric signals of the gastrointestinal muscle were not significantly different at the second sampling point (20 minutes). After standing at the third sampling point (40 minutes), that is, standing for more than 40 minutes, when standing on the 5° and 10° platforms, the iEMG value of the lower limb muscle showed a downward trend, and the MF value showed an upward trend, which indicated that self-regulation of lower limb muscles is better when standing on an inclined platform between 5 ° and 10 °. When standing on a 15 ° platform, the iEMG value of the overall sEMG signals in the initial state was too large. An explanation could be that large inclination leads to excessive force on the lower limb, corresponding to the fact that the body was less comfortable and more fatigued. This study indicates that when standing on an inclined platform with a small inclination angle (5 ° to 10 °), the limb fatigue is alleviated.

When standing on a 15° inclined platform, the lower limb's self-adjusting ability seems to be less, and the body fatigue is higher, which is not advised for prolonged standing. Standing on the inclined platform at angles between 0° and 10°, the muscle fatigue does not change much, that is, standing at different inclined platforms has no significant influence on the erector spinae. It can be seen in the iEMG value of the lower limb muscles that it will reach a maximum value when the participant stands for about 40-60 minutes. After 60 minutes, the lower limb muscles seem to be in a state of recovery, for the angles 5° and 10°. This is shown in the iEMG of the gastrocnemius, but as well in the experienced fatigue data. So, 5 to 10 degrees is probably a better choice when designing a standing platform for prolonged standing workers. Further study is needed to analyze more detailed inclination angles and see whether the effects also can be found on long term use. It is advised to extend the standing time to analyze whether the inclined standing platform still functions for a longer period of time.

These results need to be considered within the context of the limitations of the study. This is a laboratory study the simulated tasks, workers may have many kinds of postures in real world situation.

5. Conclusion

Experiments verified that inclined platforms can be effective in reducing body fatigue. It is affirmed by both subjective and objective data. These data suggest that it is worthwhile to study prolonged standing and check if it improves by proper platform design.

These data could be used by designers and manufacturers to design future products that promote less fatigue and increase the comfort of users. Results from the study will also be useful to updating ergonomic standards and guidelines.

Acknowledgments

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Table 1. Subjective visual analog scale

0 °		*0min*	*20min*	*40min*	*60min*	*80min*
Painless	0					
	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					
Severe pain	10					

Table 2. iEMG values of the gastrocnemius muscles at different angles of the floor (*=significantly different)

	0min	*20min*	*40min*	*60min*	*80min*
	0°	0°	0°	0°	0°
5°	0.13	0.360	0.025*	0.037*	0.027*
10°	0.715	0.356	0.021*	0.038*	0.042*
15°	0.002*	0.008*	0.013*	0.006*	0.015*

Table 3. MF values of the gastrocnemius muscle at different floor angles (*=significantly different)

	0min	*20min*	*40min*	*60min*	*80min*
	0°	0°	0°	0°	0°
5°	0.25	0.80	0.83	0.88	0.023*
10°	0.10	0.52	0.11	0.96	0.046*
15°	0.30	0.37	0.22	0.92	0.041*

Table 4. Statistical data of the iEMG values of the erector spinae at different angles

	Sum of Squares	*df*	*Average Squared*	*F*	*Significance*
Between Groups	8.23	3	2.743	1.691	0.192
Within the Group	45.43	28	1.623		
Total	53.663	31			

Table 5. Statistical data of MF signals of the erector spinae at different angles

	Sum of Squares	*df*	*Average Squared*	*F*	*Significance*
Between Groups	3.617	3	1.206	0.285	0.836
Within the Group	118.37	28	4.228		
Total	121.98	31			

Table 6 Average experienced fatigue value on inclined platform at different angles of 8 participants

Met opmerkingen [PV-I5]: please add sd

Angles	0°	5°	10°	15°
Average fatigue value	3	2.125	2.75	4.75
Standard deviation	0.476	0.104	0.238	0.759

Fig. 1 5 °, 10 °, 15 ° inclined platform from left to right, the front of the toe is pointed to the right

Fig. 2 Mangold-10 wireless Bluetooth multi-channel physiology system made in Germany

Met opmerkingen [PV-I6]: this is ok

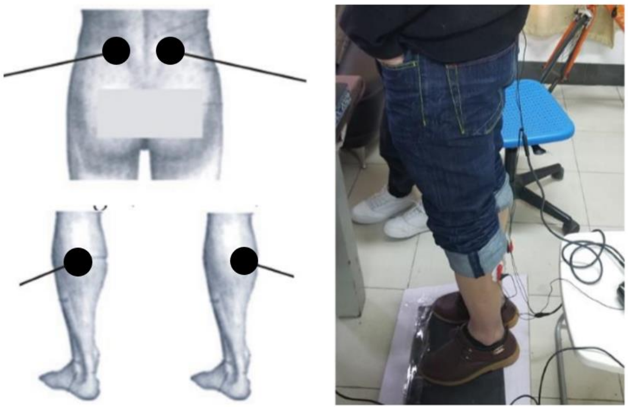

Fig. 3 Surface electrode patch positions

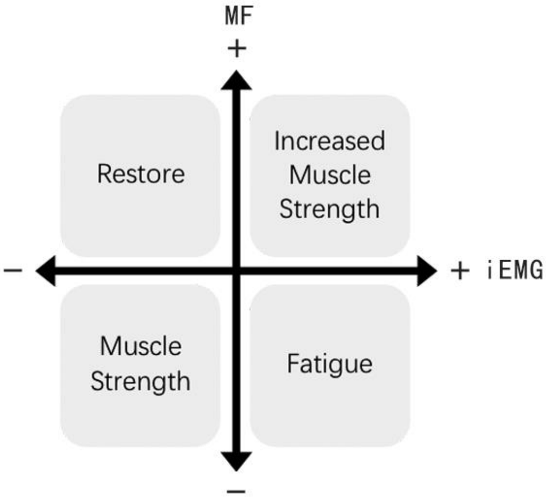

Fig. 4 Schematic diagram of the amplitude-frequency joint analysis method

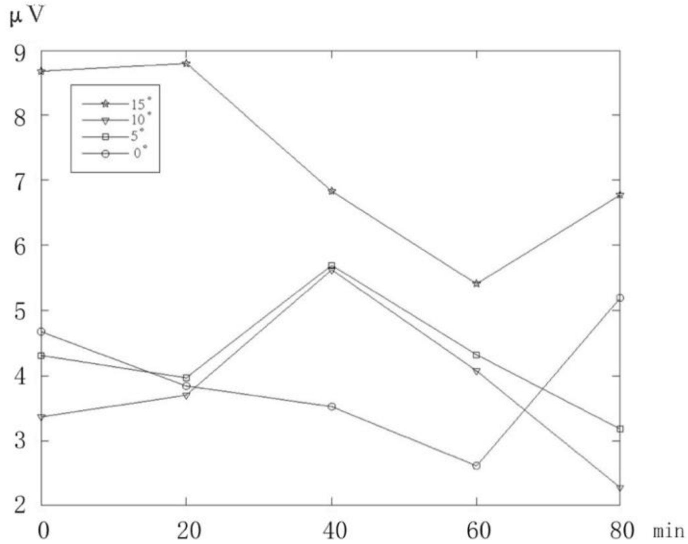

Fig. 5 Changes in iEMG value of the gastrocnemius muscle of the inclined platform at different angles

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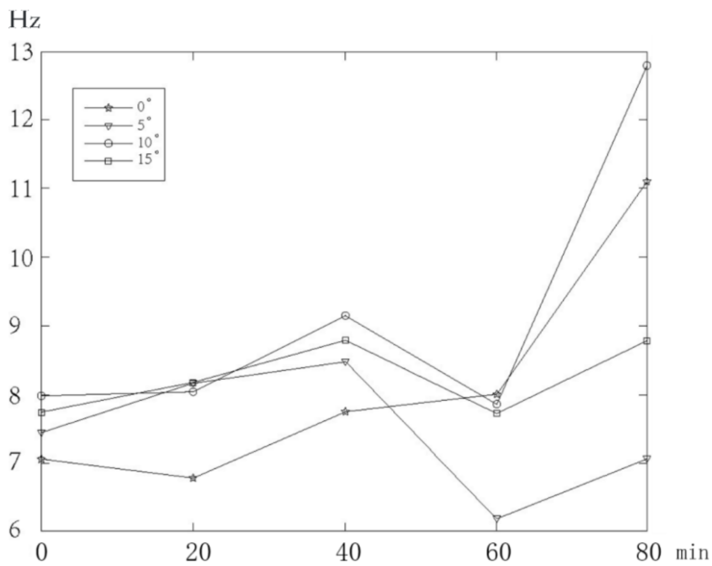

Fig. 6 Average MF values of gastrocnemius muscles of inclined platforms at different angles

Met opmerkingen [PV-I8]: add unit to y-axis

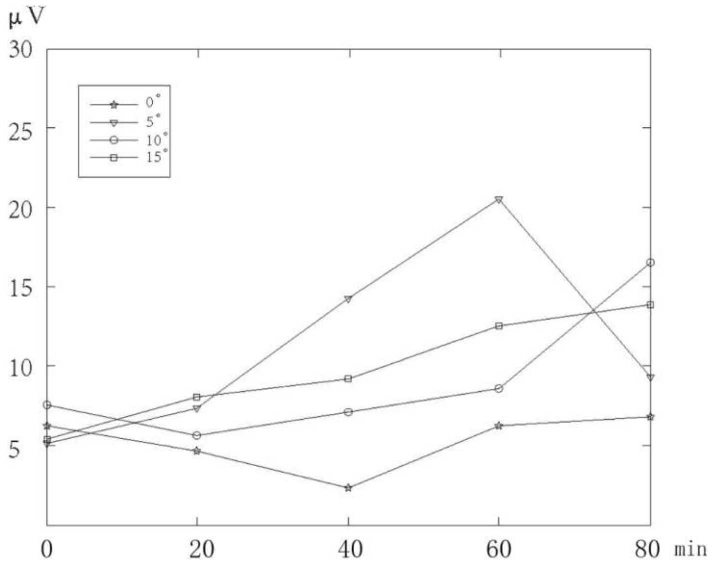

Fig. 7 Changes in iEMG values of erector spinae of inclined platform at different angles

Met opmerkingen [PV-I9]: add unit to y-axis

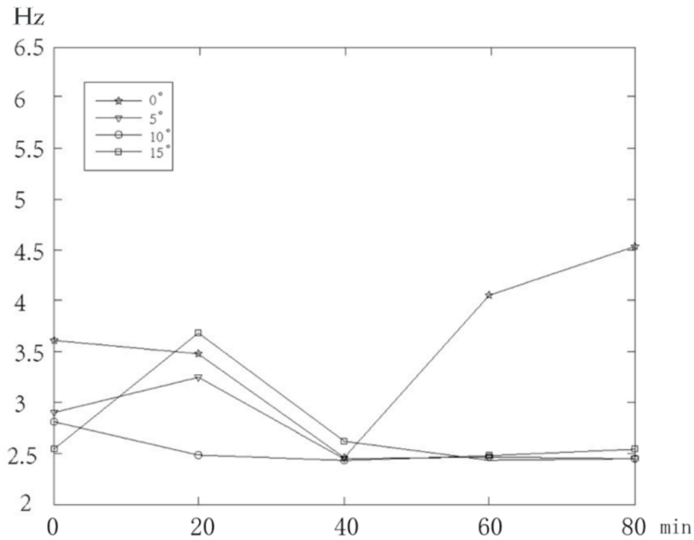

Fig. 8 Changes in MF value of erector spinae of inclined platform at different angles

Met opmerkingen [PV-I10]: add unit to y-axis