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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 in life provide a foot pad for checkout staff to let them stand on it at work, thereby reducing standing fatigue caused by standing for a long time. The inclined platform is the same as the foot pad mentioned above. That is, the staff stepped on it and relieved standing fatigue to a certain extent.
OBJECTIVE: The study aims to analyze how the standing angle affects fatigue among prolonged standing workers and tries to find an inclined platform with a specific angle to reduce standing fatigue.
METHODS: This experiment studied fatigue of the inclined platforms with different angles on prolonged standing workers, eight participants were selected to participate in the test. The plantar pressures and sEMG (Surface Electromyography) were used to collect the physiological information change of prolonged standing participants in the lower limb and waist. The visual analogue scale was used as a subjective method to measure the psychological fatigue.
RESULTS AND CONCLUSION: The study highlights the relationship between standing angle and lower limb fatigue. The inclination of the standing platform has different effects on the participants under different time conditions. 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 the third sampling point (40 minutes). After that self-regulation of lower limb muscles is better when standing on an inclined platform between 5° and 10°, it has a certain effect on alleviating lower limb fatigue. This knowledge is crucial for the design of the inclined working platforms fitting the needs of prolonged standing workers.

Keywords: Prolonged standing, standing angle, inclined platform, surface electromyography, lower limb fatigue

1. Introduction

Many kinds of workers, such as supermarket checkout workers, assembly and quality-control workers, and healthcare workers, are required to stand for prolonged periods. Prolonged standing allows workers to perform in a simple and efficient way and makes workers more productive in specific working conditions and contributes to high productivity in the industry [1]. After prolonged standing work, the lower back and lower limbs are statically contracted, resulting in weakened function of the calf muscles, workers may feel discomfort and experience muscle fatigue, pain in lower back and limb, which even cause occupational injuries 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

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prolonged standing highly represented [4]. Discomfort and muscle fatigue are often accompanied with mental fatigue, which is considered to be factors of inattention, lack of concentration and decline in positivity [5].

Subjective evaluation of psychological fatigue caused by prolonged standing is usually conducted through 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 and on potentially related objective measures, 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 end 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 the surrounding calf measurement [9]. Zender et al. investigated the impact of floor type on subjective or biomechanical/physiological objective measures believed related to standing discomfort, these findings suggest that common product interventions (such as insoles and floor mats) may have little effect on controlling the leg edema of industrial workers who have been aligned for 8 hours[10]. However, few studies have used the inclined platforms as an intervention to reduce lower limb fatigue. Therefore, the aim of this project was to study the specific impact on inclined platforms at different angles among prolonged standing workers and 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, average height was 174.1 cm (SD $\pm$7.3 cm) and average weight was 65.5 kg (SD$\pm$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. Except for 0° (no inclination), there are three different angles of inclined platforms, 5°, 10°, 15° respectively. As shown in Fig. 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 must sit on the sofa and rested for 30 minutes before the experiment, and then conducted the experiment and data collection. Each participant only conducted one set of experiments per day, that is, standing at only one angle for 80 minutes per day. The participants were required to wear flat shoes during the experiment. Participants were asked to wear everyday shoes with almost no inclination. The shoe itself has no height and heel, so as to avoid experimental errors caused by wearing shoes. Prior to participation, all participants signed an informed consent form indicating their participation was voluntary and were informed of study objective and procedures.

2.1. Data collection

All data on the muscle activity of the participants were recorded, stored and analyzed using Mangold-10 wireless Bluetooth multi-channel physiology instrument, as shown in Fig. 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

Fig. 1. 5°, 10°, 15 ° inclined platform from left to right.

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

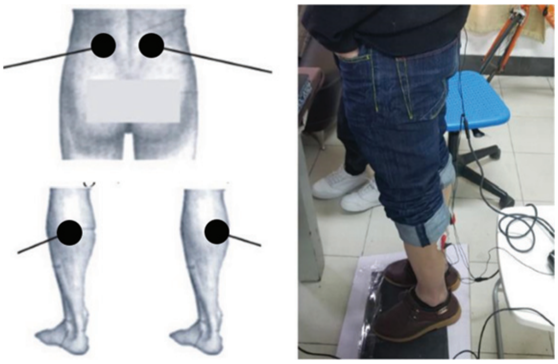

Fig. 3. Surface electrode patch positions.

experimental results, all relevant personnel at the lab site were asked to turn off communication equipment and keep quiet.

The participant's measured parts needed to be cleaned in advance to ensure the stability and accuracy of the sEMG. The electrodes were attached to the participant's skin and the activity of three muscles during standing was measured: left erector spinae, left and right gastrocnemius muscles. Figure 3 shows the location of the sEMG electrode 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 group experiments.

In this experiment, the muscle electrical signal data 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 collected data every 20 minutes for 80 minutes while standing on the same angle platform, a total of 5 times. The first data collection starts from 0 minutes. After the collection of the raw sEMG signals were processed, the amplitude-frequency comprehensive analysis method was used to analyze the physiological information changes of the muscle activities. As shown in Fig. 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 of fatigue.

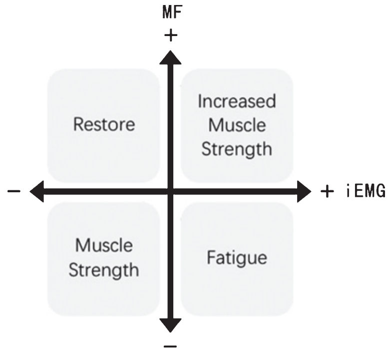

Fig. 4. Schematic diagram of the amplitude-frequency joint analysis method.

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 frequency, 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 file as a data source for subsequent processing.

2.3. Data analysis

2.3.1. Objective data analysis

1) The primordial sEMG signals of two gastrocnemius muscles of eight participants in four groups of experiments were recorded, 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 measurement data of the left and right gastrocnemius muscles are basically the same, so

during data analysis, the experimenter averages the corresponding values of the two sets of data, 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 for the significance difference test. Then we compare the iEMG signals of the gastrointestinal muscles at different angles in different time periods. Next, the MF values of the gastrocnemius muscles of the participants were standardized and the significance difference test was performed. Then we compare the MF value of the gastrointestinal muscles at different angles in different time periods.

2) The primordial sEMG signals of the erector spinae of eight participants in four groups of experiments were recorded, the iEMG values were calculated. Next, the MF values of the erector spinae of the participants were standardized and the significance difference test was performed. Then we compare the MF value of the erector spinae at different angles in different time periods.

2.3.2. *Subjective data analysis*

The subjective scale used in the experiment is a visual analog scale divided into 11 scales from 0–10, which represent different feelings from painless to intolerable, the smaller the value, the higher the psychological comfort, as shown in Table 1. Participants needed to stand for 80 minutes to complete each group of experiments, they filled in numeric rating scale every 20 minutes to score their own subjective fatigue value. After each participant completed four sets of experiments, four sets of subjective fatigue value were collected. The subjective psychological fatigue data of all the participants were averaged, and results of inclined platforms at different angles were compared.

Table 1
Subjective visual analog scale

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

Table 2
Significance analysis of iEMG signals of the gastrocnemius muscles at different angles

	0 min	*20 min*	*40 min*	*60 min*	*80 min*
	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*

3. Result

After the gastrocnemius muscle data analyzing, as shown in Fig. 5 and Table 2, it can be known that the iEMG signals of the gastrocnemius muscle standing on inclined platforms at different angles is significant, $p = 0.030 < 0.05$, that is, the iEMG signal of the gastrocnemius muscle standing on different inclined platforms has significant differences. The data lower than 0.05 were marked with'*', so the gastrocnemius muscle iEMG value standing on the 0° platform is 5°, 10°, 15° in the 40 min, 60 min, 80 min time period are significant differences ($p < 0.05$). From analysis of Fig. 6 and Table 3, the MF value of the gastrocnemius muscle standing on inclined platforms at different angles is also significant, $p = 0.046 < 0.05$, that is, the MF value of the gastrocnemius muscle standing on different inclined platforms has significant differences. The MF value of the gastrocnemius standing on the 0° platform and 5°, 10°, 15° in 80 min time period is significant difference ($p < 0.05$). According to the results, it is known that standing platforms with different inclined angles have big effect on alleviating lower limb fatigue.

In the same way, after the erector spinae data analyzing, it can be known from Fig. 7 and Table 4 that

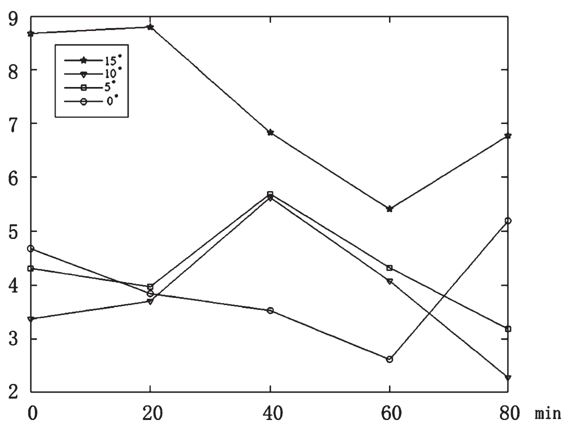

Fig. 5. Changes in iEMG value of the gastrocnemius muscle of the inclined platform at different angles.

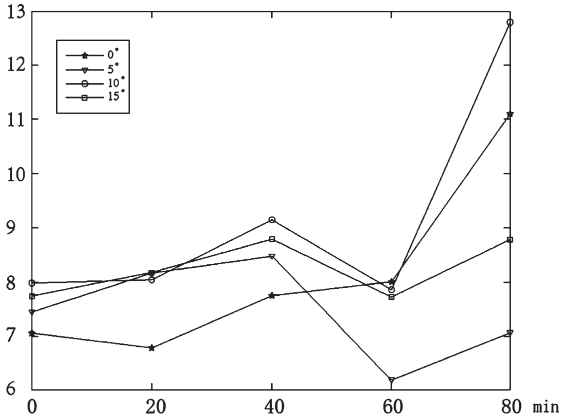

Fig. 6. Changes in MF values (%) of gastrocnemius muscles of inclined platforms at different angles.

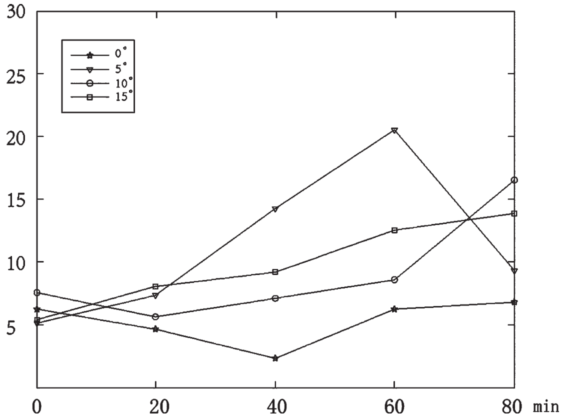

Fig. 7. Changes in iEMG values of erector spinae of inclined platform at different angles.

Table 3
Significance analysis of gastrocnemius muscle MF signal at different angles

	0 min	*20 min*	*40 min*	*60 min*	*80 min*
	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*

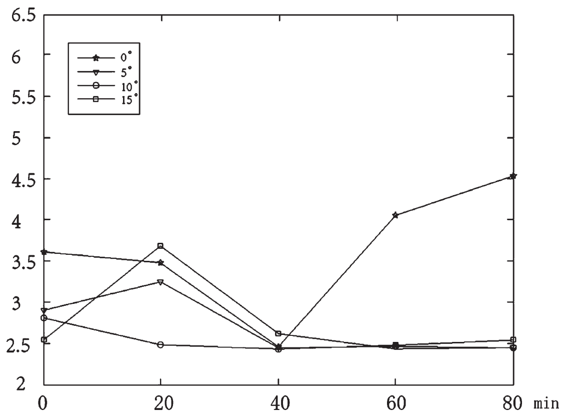

Fig. 8. Changes in MF value (%) of erector spinae of inclined platform at different angles.

Table 4
Significance analysis of iEMG signals of 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
Significance analysis of MF signals in 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
Subjective fatigue value on inclined platform at different angles

Angles	0°	5°	10°	15°
Subjective fatigue value	3	2.125	2.75	4.75

the iEMG signals of the erector spinae standing on inclined platforms at different angles is not significant, $p = 0.192 > 0.05$. From analysis of Fig. 8 and Table 5, it can be seen that the MF value of the erector spinae standing under the inclined platform at different angles is $p = 0.836 > 0.05$, that is, the MF value of the erector spinae standing on different inclined platforms is not significant ($p > 0.05$). Therefore, according to the analysis of experimental data, it is known that standing platforms with different inclined angles have little effect on alleviating lumbar muscle fatigue.

For the subjective analyzing, it can be seen from Table 6, that the subjective fatigue of standing on a 15° inclined platform is the largest due to the large tilt angle, and the subjective fatigue of standing on a 5° and 10° inclined platform is less than that of standing on flat ground. The influence of the overall tilt angle on human subjective comfort is 5°>10°>0°>15°. Standing on a 5° to 10° inclined platform is more conducive to self-regulation.

4. Discussion

The goal of the study is to highlight the relationship between standing angle and lower limb fatigue. The results indicate that inclined platform affect the lower lime fatigue after prolonged standing. Our correlation between inclined platform and fatigue is similar to that reported in the review by Nelson et al. [8], where the authors did sloped surface with low back pain. When participants stood on inclined platforms at all angles for a short time, the iEMG value of the lower limb muscles decreased, and the MF value increased. This indicated that the muscles were recovering, and when standing at 0°, the amplitude is even greater. 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. Large inclination leads to excessive force on the lower limb, indicating that the body was less comfortable and more prone to fatigue. Therefore, it is known from the analysis of experimental data that when standing on an inclined platform with a small inclination angle, that is 5° to 10°, it has a certain effect on alleviating lower limb fatigue.

When standing on a 15° inclined platform, the lower limb's self-adjusting ability seems to be less, and the body fatigue is high, which is not to be 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. It can be seen the iEMG value of the lower limb muscles will reach a maximum value when the participant stands for about 40–60 minutes. After 60 minutes, the lower limb muscles are slowly in a state of recovery, and the lower limb muscles' self-regulating effect of standing on inclined platforms at different angles is: 10°>5°>0°>15°. The subjective scales experiment also shows the similar results, 5 °>10 °>0 °>15 °. So, 5 to 10 degrees are a better choice when design and make standing platform for prolonged standing workers. Further study will analyze more detailed inclination angles and try 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 are effective in reducing body fatigue from both the subjective and objective aspects. The lower limb fatigue is really affected by the angles of inclined platform. These data suggest that prolonged standing comfort can be improved through proper platform design.

These data are valuable for designer and manufacturers to design future products that promote more neutral postures and increase the comfort of users. Results from the study will also be useful to updating ergonomic standards and guidelines.

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Conflict of interest

None to report.

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