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ORIGINAL

# The Effect of Gaze Angle on Muscle Activity and Kinematic Variables during Treadmill Walking

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**Objective:** The purpose of this study was to determine how gaze angle affects muscle activity and kinematic variables during treadmill walking and to offer scientific information for effective and safe treadmill training environment.

**Method:** Ten male subjects who have no musculoskeletal disorder were recruited. Eight pairs of surface electrodes were attached to the right side of the body to monitor the upper trapezius (UT), rectus abdominis (RA), erector spinae (ES), rectus femoris (RF), bicep femoris (BF), tibialis anterior (TA), medialis gastrocnemius (MG), and lateral gastrocnemius (LG). Two digital camcorders were used to obtain 3-D kinematics of the lower extremity. Each subject walked on a treadmill with a TV monitor at three different heights (eye level; EL, 20% above eye level; AE, 20% below eye level; BE) at speed of 5.0 km/h. For each trial being analyzed, five critical instants and four phases were identified from the video recording. For each dependent variable, one-way ANOVA with repeated measures was used to determine whether there were significant differences among three different conditions ($p$<.05). When a significant difference was found, post hoc analyses were performed using the contrast procedure.

**Results:** This study found that average and peak IEMG values for EL were generally smaller than the corresponding values for AE and BE but the differences were not statically significant. There were also no significant changes in kinematic variables among three different gaze angles.

**Conclusion:** Based on the results of this study, gaze angle does not affect muscle activity and kinematic variables during treadmill walking. However, it is interesting to note that walking with BE may increase the muscle activity of the trapezius and the lower extremity. Moreover, it may hinder proper dorsiflexion during landing phase. Thus, it seems to reasonable to suggest that inappropriate gaze angle should be avoided in treadmill walking. It is obvious that increased walking speed may cause a significant changes in biomechanical parameters used in this study. It is recommended that future studies be conducted which are similar to the present investigation but using different walking speed.

**Keywords:** Gait, Gaze angle, Muscle activity, Kinematic variables

## INTRODUCTION

Gait motion, which is the basic motion in all sports, is a motion that shifts the center of mass while supporting the body weight with the legs and maintaining the balance of the entire body (Chae, 2006). Such walking exercise is used as the most popular exercise of modern people who can easily reach a state of lacking exercise, and treadmill walking has been embraced for its convenience.

A treadmill is an exercise machine designed to allow a person to walk or run on top of a belt on the bottom that spins automatically. It became popular as interest in walking or running heightened. Treadmill walking gait exercise is easily accessible, inexpensive, and hasrelatively few limitations associated with weather and/or location. Moreover, it allows the exercise load to be adjusted easily by applying the speed and inclination that are personally suitable (Yoon, Yi, Kim, Mun, & Yang, 2000). However, as compared to normal outdoor gait, it is more difficult to train or develop various muscles by treadmill gait, and because the exercise performed in limited space, the exercise itself is simple and can easily become boring (Park, Oh, Kim, & Choi, 2011).

As supplementary measures for addressing the issues of treadmill exercise, as an aerobicexercise, being too simple or boring, methods of playing music or attaching an LCT-TV to the treadmillare used to suit the preferences of individuals (Bang, 2007). However, using a display device can cause improper posture from fixed gaze, which can have a negative effect on musculoskeletal system of the human body. Eltayeb, Staal, Hassan, and Bie (2009) reported that poor posture from long-term use of a visual display terminal (VDT) acts as the primary cause of upper musculoskeletal pain. Gerr, Monteilh, and Marcus (2006) reported that

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muscle tension from using VDT reduced blood flow due to static load on the neck and shoulder, while also causing muscle fatigue and pain. Ortiz-Hernandez, Tamez-Gonzalez, Martinez-Alcantara, and Mendez-Ramirez (2003) stated that tilting the head to look at the monitor can exert pressure on the spinal discs to cause chronic problems in the neck, shoulder, and back areas.

With respect to studies on treadmill and gaze angles, most have demonstrated that watching TV or reading a book during treadmill walking or running exercise can diminish the ability to react to accidents, making the person more vulnerable to injury. Cordoand Flanders (1990) reported that when the gaze angle is fixed, it has a negative effect on movement control and body coordination when performing a specific motion. Nigg, De Boer, and Fisher (1995) reported that instability in the center of mass during gait can affect the balance of each body part, as well as respiration and heart activities, which can become a major cause of excessive energy consumption, while Turner, Helliwell, Siegel, and Woodburn (2008) reported that improper gait motion can cause diseases in the joints, muscles, and body structure.

Previousstudies have mostly included analysis of gait characteristics (Bergmann, Graichen, & Rohlmann, 1993; Burnfield, 2010) and muscle activities (An, Kim, & Lee, 2007; Cipriani, 1995; McArdle, Katch, & Katch, 2001) according totreadmill speed or inclination. However, muscle activity and kinematic studies on gaze angle during treadmill walking are almost non-existent. Moreover, studies on working environment and postural analysis related to computer use have been actively pursued, but proper placement of monitors duringtreadmillexercise has not been studied. Accordingly, the objective of the present study was to use electromyography (EMG) and 3D image analysis to conduct quantitative assessment on the effects of gaze angles during treadmill walking onmuscle activity and kinematic variables.

## METHODS

### 1. Participants

The participants in the present study consisted of 10 male adults who did not have any musculoskeletal anomalies (mean height 173.0 ±5.3 cm, mass 72.3±10.6 kg, and age 28.1±4.3 yrs).

### 2. Experimental setup

#### 1) EMG

In the present study, an 8-channel wired EMG measurement system (QEMG-8, Laxtha Inc., Korea, gain = 1,000, input impedance > $10^{12}$ Ω, CMRR > 100 dB) was used for analysis of the relationship between muscle activities and gaze angles during treadmill walking (Figure 1). For the EMG measurement, 8 surface electrodes were attached to the upper trapezius (UT), rectus abdominis (RA), erector spinae (ES), rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA), medial gastrocnemius (MG), and lateral gastrocnemius (LG) on the right-hand side of the participant, as shown in Figure 2 (U. S. Department of Health and Human Services, 1993). The grounding electrode was attached to the anterior superior iliac spine (ASIS) and the surface electrodes were attached after eliminating all hair in the area and cleaning the area with alcohol to minimize skin resistance. Moreover, for standardization of EMG data, the maximal voluntary isometric contraction (MVIC) of each muscle was measured in all participants prior to the experiment (Table 1). EMG data on MVIC and gait motion were collected at sampling frequency of 1,024 Hz over 5 sec.

**Figure 1.** A view of the experimental setup

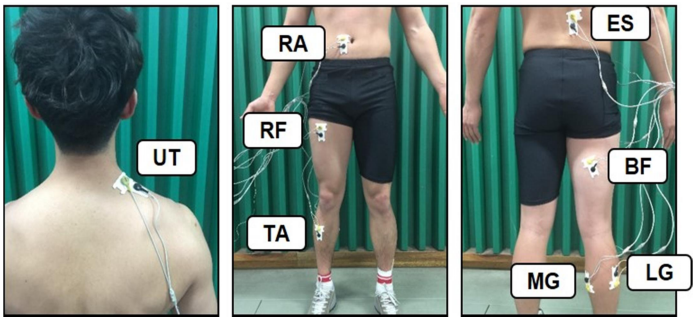


**Figure 2.** Muscles of interest and electrode placements

**Table 1.** Maximum voluntary isomeric contraction

| Muscle | MVIC |
|---|---|
| Upper trapezius (UT) | Shoulder elevation |
| Rectus abdominis (RA) | Trunk flexion |
| Erector spinae (ES) | Trunk extension |
| Rectus femoris (RF) | Knee extension |
| Biceps femoris (BF) | Knee flexion |
| Tibialis anterior (TA) | Ankle dorsi flexion |
| Medial gastrocnemius (MG) | Ankle plantar flexion |
| Lateral gastrocnemius (LG) | |

### 2) 3-D kinematics

In the present study, 2 digital camcorders (60 Hz, Sony HDR -HC9) were set up behind and on the right side of the participant for 3D motion analysis during treadmill walking, with shooting speed of 60 fields/s and shutter speed of 1/725 sec. Moreover, for establishing a coordinate system for body joint centers, reflective markers with diameter of 0.8 cm were attached to 6 locations (shoulder, hip, knee, ankle, toe, and heel) on the right side.

### 3) Synchronization

For synchronization of EMG and image data, the switch attached to the signal tuner (Visol Inc., Korea) was pressed at an arbitrary point during treadmill walking to simultaneously cause a 5 V electrical signal to be sent from A/D board connected to the EMG device and 2 LEDs to turn on. Afterwards, the analysis events and phases were synchronized in relation to the point when the 5 V electrical signal was generated in the EMG data and the point when the LED signal occurred in the image data.

## 3. Datacollection

To become acclimated to the treadmill speed and maintain a stable posture during the actual gait motion during experiment, the participants warmed up for 10 min at the same treadmill speed prior to the actual experiment. Subsequently, for inducing changes in gaze angles during gait motion, a standing-type display device was set up in front of the treadmill (MAHA3, Taeyong, Korea) to allow the height to be controlled to 3 conditions; eye level (EL), 20% above eye level (AE), and 20% below eye level (BE) (Figure 3). The height of the display device used in the experiment was set in standing position for standardization with each participant and the experiment was conducted after checking to see if differences in gaze angles occurred as a result of changes in the height for the 3 test conditions.

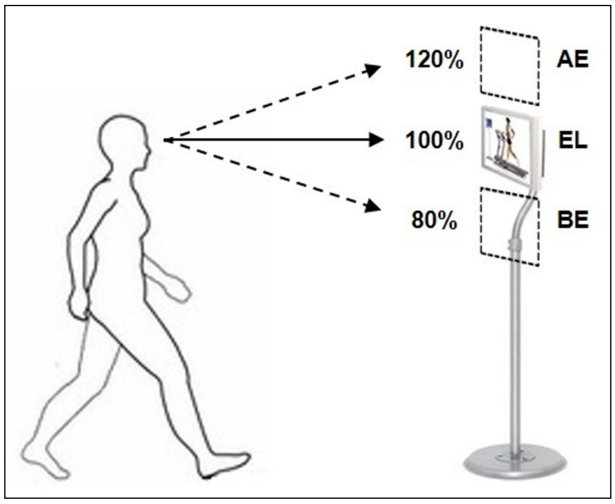


**Figure 3.** The use of differentgaze angles during treadmill walking

Treadmill walking wasperformed under 3 different conditions with different display device position in random order, and to prevent fatigue in the muscles being measured, gait motions for each of the 3 conditions were performed within 3 min. For most natural and consistent gait motion during EMG and image data measurements, data were collected from continued gait motion after 10 min of warm up without the participant being aware. Moreover, to set the treadmill gaitspeed, average gait speed for males and the characteristics of treadmill gait were taken into account together, and as a result, the speed was set to 5.0 km/h (Auvinet et al., 2002; Chung et al., 2005; Neumann, 2013).

## 4. Data analysis

### 1) Events and phases

In the present study, major events and phases were set, as shown in Figure 4, for analysis of treadmill gait. Five events were defined as right heel contact 1 (RHC1), left toe takeoff (LTO), left heel contact (LHC), right toe takeoff (RTO), and right heel contact 2 (RHC2), while 4 phases were defined as RHC1~LTO as initial double limb stance (IDLS), LTO~LHC as initial single limb stance (ISLS), LHC~RTO as terminal double limb stance (TDLS), and RTO~RHC2 as terminal single limb stance (TSLS). Data analysis used mean values from 3 gait cycles (RHC1 ~RHC2) from EMG and image data obtained for 5 sec during treadmill walking for each experimental condition.

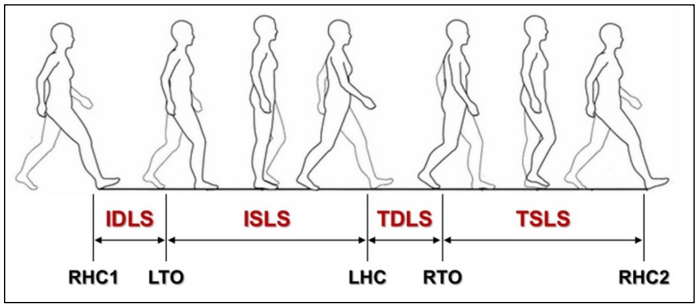


**Figure 4.** Critical Instants and phases of treadmill walking

### 2) EMG

The EMG data collected during treadmill gaitmotion underwent full wave rectification after band pass filtering of 10~350 Hz. As shown in the equation below, EMG data measured during gait motion were standardized as MVIC values for each muscle to calculate the average and peak integrated EMG (IEMG) values. Average IEMG was presented as the average value of a specific phase after dividing the EMG value actually measured during gait by MVIC value, while peak IEMG was presented as the peak value among data calculated via the 50 ms moving average within a specific phase after dividing the EMG value actually measured during gait by MVIC value.

$$nEMG \quad \frac{EMG_{\mathrm{raw}}}{EMG_{\mathrm{max}}} \times 100$$

Here, $nEMG$ is the standardized IEMGvalue; $EMG_{\mathrm{raw}}$ is EMG value within a specific phase during gait; and $EMG_{\mathrm{max}}$ is the MVICEMG value.

### 3) 3-D kinematics

Kwon3D 3.1 program (Visol Inc., Korea) was used for 3D motion analysis and direct linear transformation (Abdel-Aziz & Karara, 1971) was used to derive the 3D coordinate values. A second-order Butterworth low-pass digital filter was used to minimize the noise that occurs when establishing the image coordinates, with the cut-off frequency set to 6 Hz. Each Joint angle of the lower extremity was calculated using the scalar products of the vector.

## 5. Statistical analysis

One-way analysis of variance with repeated measures was performed using SPSS 23.0 to test the statistically significant differences in muscle activities and kinematic variables according to differences in gaze angles during treadmill walking, while contrast was used for post-hoc test when statistically significant differences were found. Here, the significance level was set to $p<.05$.

# RESULTS

## 1. Muscle activity

### 1) Average and peak IEMG in the IDLS

The average and peak IEMG for each muscle in the IDLS phase did not show any statistically significant differences among gaze angles during treadmill walking. However, the average IEMG value of UT tended to be higher under AE condition than under EL and BE conditions. Moreover, the peak IEMG value of RA tended to be higher under BE condition than under EL condition (Figure 5-6).

### 2) Average and peak IEMG in the ISLS

The average and peak IEMG for each muscle in the ISLS phase did not show any statistically significant differences among gaze angles during treadmill walking. However, the average and peak IEMG values of most leg muscles, such as BF, TA, and LG tended to be higher under BE condition than under EL condition (Figure 7-8).

### 3) Average and peak IEMG in the TDLS

The average and peak IEMG for each muscle in the TDLS phase did not show any statistically significant differences among gaze angles during treadmill walking (Figure 9-10). However, the peak IEMG value of ESand RF tended to be higher under AE and BE conditions than under EL condition.

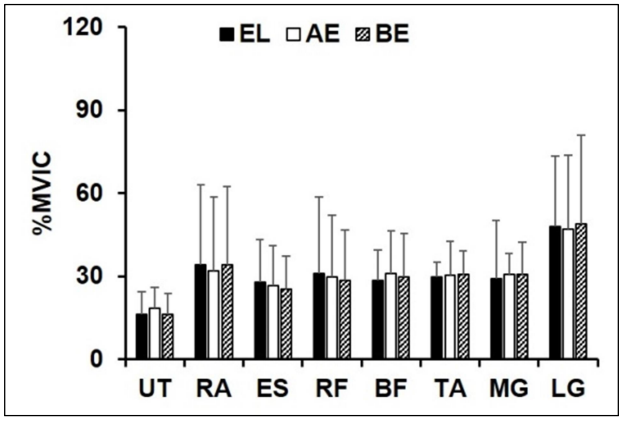


**Figure 5.** Average IEMG in the IDLS

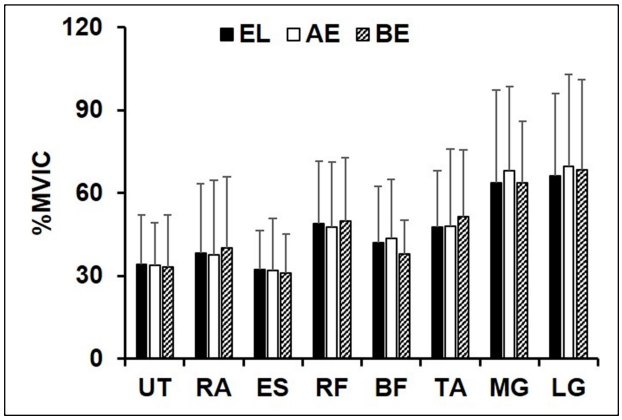


**Figure 6.** Peak IEMG in the IDLS

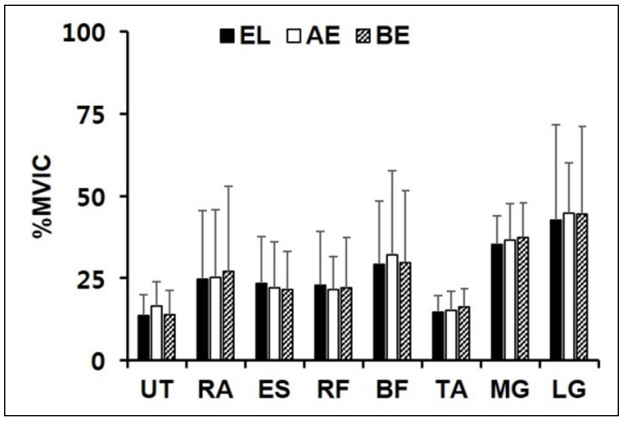


**Figure 7.** Average IEMG in the ISLS

### 4) Average and peak IEMG in the TSLS

The average and peak IEMG for each muscle in the TSLS phase did

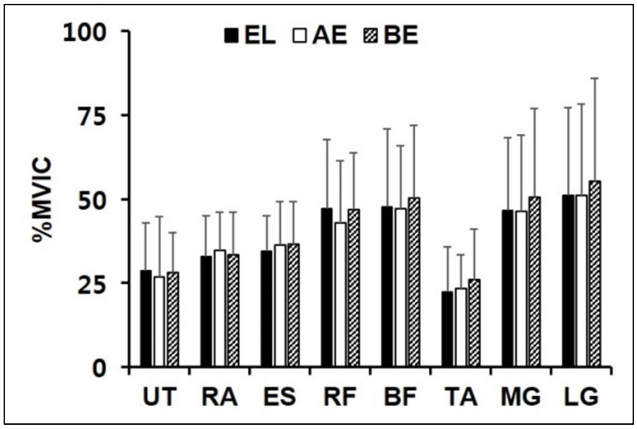


**Figure 8.** Peak IEMG in the ISLS

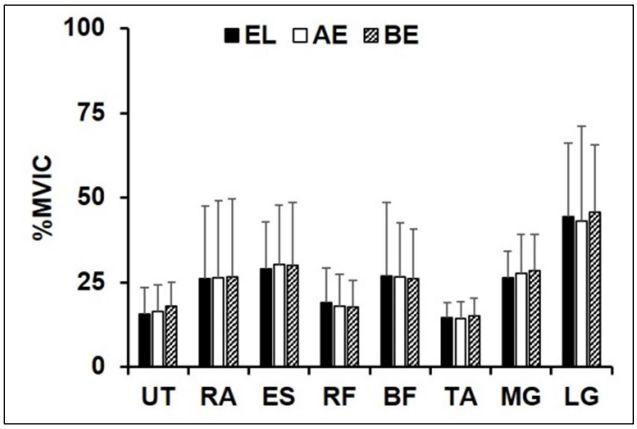


**Figure 9.** Average IEMG in the TDLS

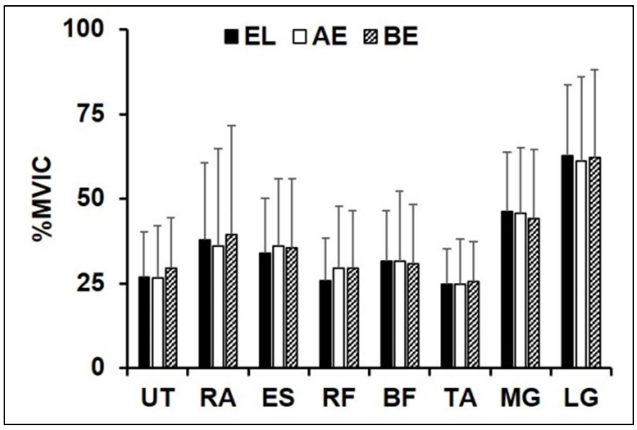


**Figure 10.** Peak IEMG in the TDLS

not show any statistically significant differences among gaze angles during treadmill gait (Figure 11-12).

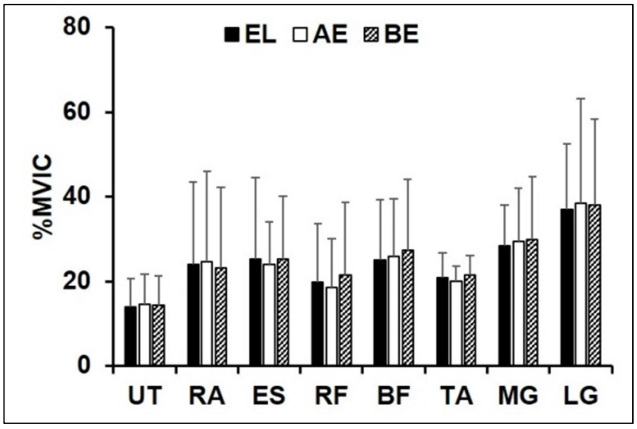


**Figure 11.** Average IEMG in the TSLS

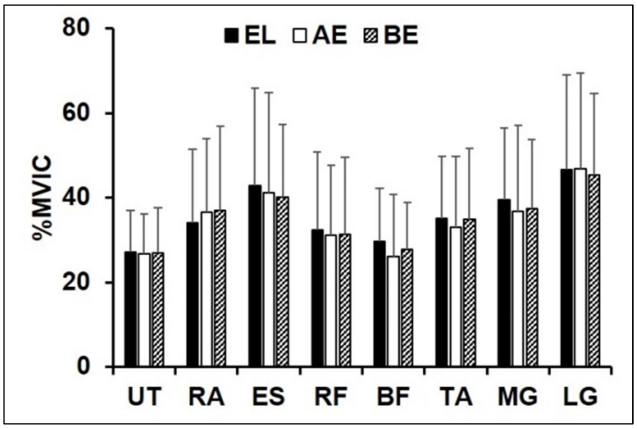


**Figure 12.** Peak IEMG in the TSLS

## 2. Kinematic Variables

### 1) Temporal parameter

The time required for each phase did not show statistically significant differences among gaze angles during treadmill walking (Figure 13).

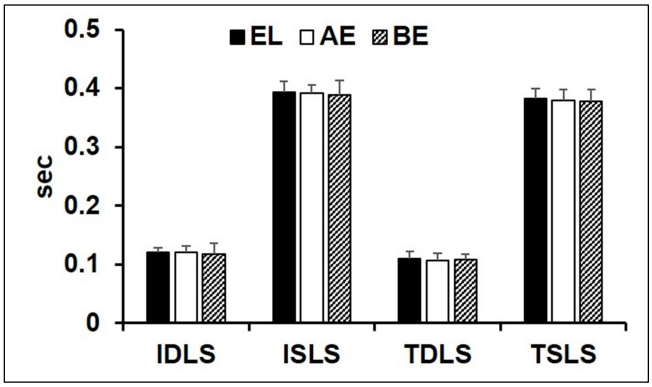


**Figure 13.** Temporal parameter

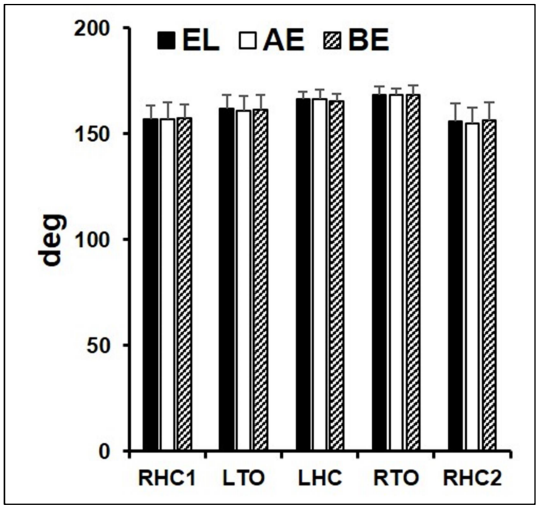


**Figure 14.** The joint angle of hip

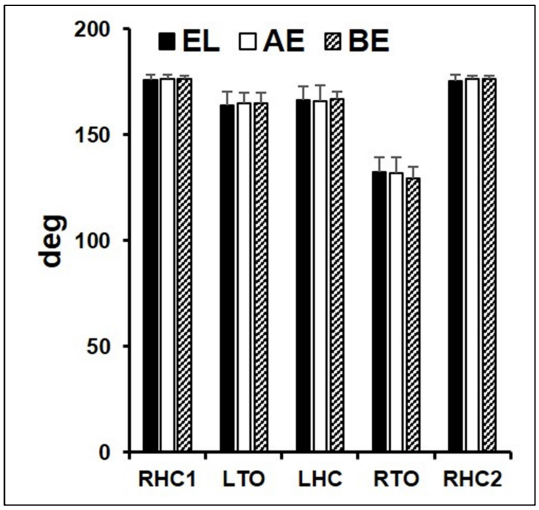


**Figure 15.** The joint angle of knee

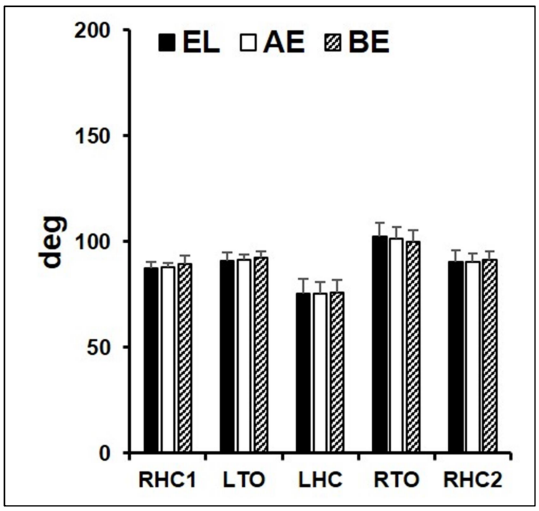


**Figure 16.** The joint angle of ankle

### 2) Joint angle

The joint angle for each event did not show statistically significant differences among gaze angles during treadmill walking in all leg joints (Figure 14-16). However, in RHC1 and RHC2 (when the right foot contacts the ground during the gait motion), ankle joint angle tended to be higher under BE condition than under EL and AE conditions. Moreover, varus-valgus angle of the knee joint and inversion-eversion angle of the ankle joint at the point of right foot touching down during gait did not show statistically significant differences according to gaze angles (Figure 17-18).

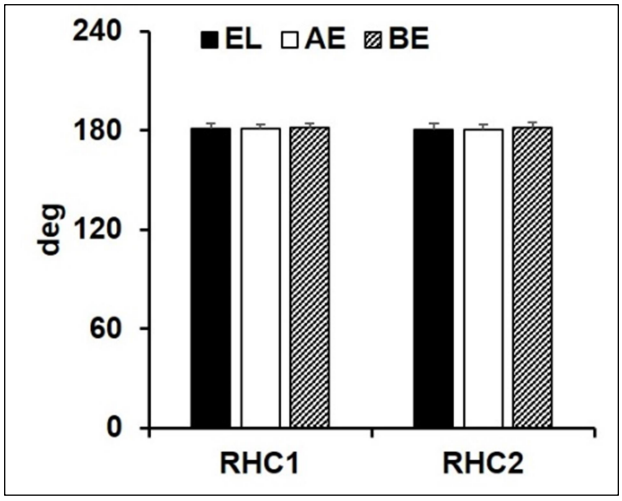


**Figure 17.** Varus-valgus of knee

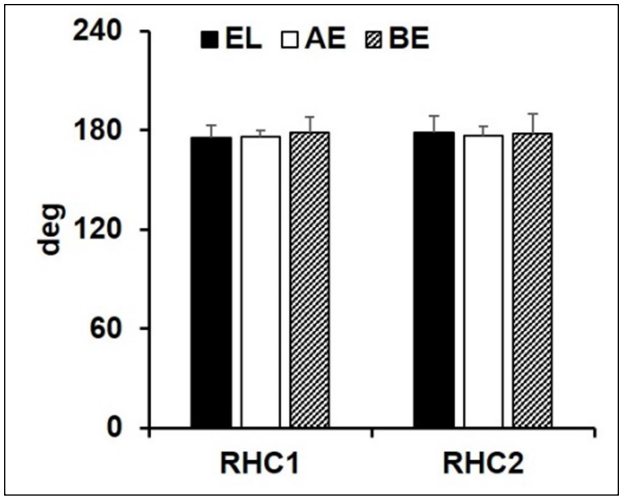


**Figure 18.** Inversion-eversion of ankle

### 3) Linear parameters

Cadence and step length did not show statistically significant differences among gaze angles during treadmill walking (Figure 19-20).

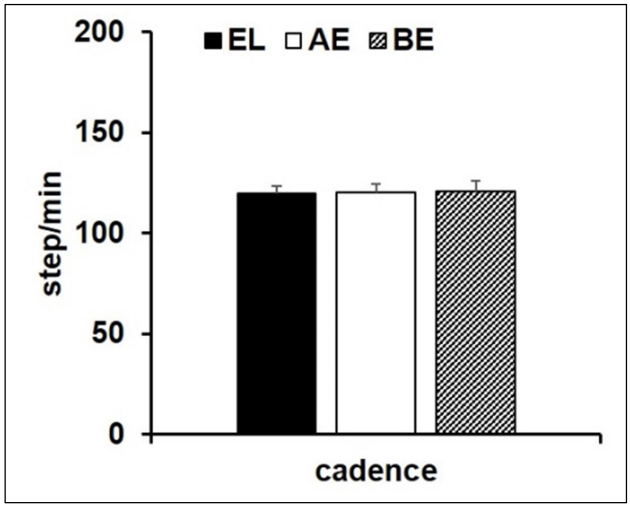


**Figure 19.** Cadence

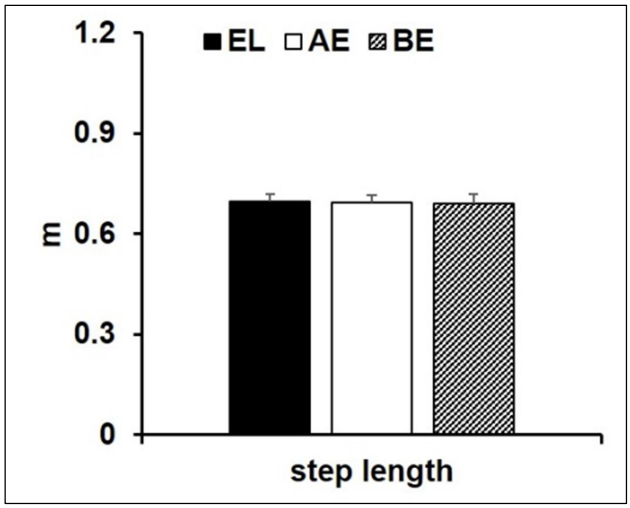


**Figure 20.** Step length

## DISCUSSION

The average IEMG value among gaze angles in IDLS phase during treadmill walking tended to be higher under AE condition than under EL and BE conditions, while the peak IEMG value of RA tended to be higher under BE condition than under EL condition. However, both muscles did not show statistically significant differences. Neumann (2013) indicated that during normal gait, the muscles in the neck and trunk align in the middle section of the spine to generate minimal muscle activity, while Jung and Lee (2003) reported that truncal muscle activity increases to maintain body balance and minimize shaking. Unlike such results from precedent studies, the present study showed that muscle activities in the trunk area, such as UT or RA, did not change significantly when the gaze moved up or downward during gait. It is probable that because the treadmill speed of 5 km/h used in the present study was a very stable gait speed for maintaining normal gait motion, regardless of changes in gaze angle, it did not have a major impact on truncal muscle activities.

During treadmill walking with changes in gaze angles, most of the leg muscles, such as BF, TA, and LG, inthe ISLS phase, tended to show higher average and peak IEMG values under BE condition than under EL condition. The ISLS phase covers the point from left toe takeoff to left heel contact, which is a single limb support phase where the right leg supports the body weight. Therefore, under BE condition, when the gaze moves downward, the center of mass of the head and trunk moves forwards, as compared to EL condition, and as such, muscle activities in the right leg muscles increased slightly to support the body. It is believed that this was the result of achieving stability and controlling the forward movement of the center of mass caused by downward movement of the gaze under BE condition, just as a study by Ounpuu (1990) reported that muscle activities of RF and BF increase to control the impact on the front foot when the center of mass moves forward during gait.

In the TDLS phase, the peak IMEG value of ES and RF tended to be higher under AE and BE conditions than under EL condition, but the differences were not statistically significant. A study by Nigg et al. (2006) on gait stability reported that muscle activities in the legs increased during gait due to simultaneous use of not only the ankle joints, but also the knee and hip joints, to increase body stability. However, in the TDLS phase of the present study, there were no major differences in muscle activities of ES and RF during propulsive motion from extension of the hip and knee joints. It is believed that this was because the experiment in the present study was conducted with stable, normal gait speed, and thus, changes in gaze angles via upward or downward movement did not act as factors that diminished body stability.

In the TSLS phase, average and peak IEMG values for each muscle did not show statistically significant differences. The TSLS phase covered the point of right toe takeoff to right heel contact, representing the phase when the left leg is supporting the ground. Therefore, muscle activities on the right side of the body would not show significant changes according to changes in gaze angles.

Cadence and step length, which are related to gait stability and time required per phase, did not show statistically significant differences among gaze angles during treadmill walking. Based on these results, it is believed that because the experiment was conducted with the speed of treadmill gait fixed at a relatively stable level, changing gaze angles did not have a major impact on cadence, step length, and time required per phase of gait motion. Joint angle during events may have been affected. When the right foot touched the ground, as in events RHC1 and RHC2, the ankle joint angle tended to be higher under BE condition than under EL and AE conditions, although the differences were not significant. A study by Ahn (1997) on stability of gait posture reported that when gait motion is unstable, rigid motion is generated with plantar flexion of the ankle joints, while flexion and extension in the knee joints decrease. However, it is believed that because the gait speed used in the present study was appropriate for normal gait, changes in gaze angles did not cause instability in gait posture.

To summarize the findings in the present study, changes ingaze angles during treadmill walking did not have negative effects on the human

musculoskeletal system. It is determined that the treadmill gait speed used in the experiment was a relatively stable speed, which did not cause abnormal. Moreover, the height of the display device that was applied, which was standardized relative to the standing position of the participants to create changes in gaze angles, did not reflect minute changes in gaze angles according to changes in step length during actual gait motion. It is believed that such limitation in the present study may have acted as a limiting factor in the results of the study.

## CONCLUSION

The objective of the present study was to conduct a quantitative assessment on the effects of changes in gaze angles during treadmill exercise on muscle activity and kinematic variables. It is believed that the findings in the present study may provide objective data on stable gait posture that can help prevent injuries during treadmill exercise. For this objective, EMG and 3D motion analyses were conducted on 10 male adults with no musculoskeletal anomalies, from which the following conclusions were derived:

First, average and peakl EMG values for each phase did not differ between 3 conditions of gaze angle.

Second, time required per phase and joint angles for each event did not show differences between 3 conditions of gaze angle.

Third, cadence and step length during treadmill walking did not show differences between 3 conditions of gaze angle.

To summarize these findings, the changes in gaze angle at typical gait speed of 5 km/h did not create statistically significant differences in muscle activitypatterns, joint angles, and linear parameters. However, under BE condition, the average values of UT, leg muscles, and ankle joint angle during landing appeared higher, and thus, improper gaze angle may cause changes in treadmill gait. Moreover, increasing gait speed may have a direct impact on kinetic variables, and thus, future studies should examine the effects on kinetic variables using different gaze angles, increased gait speed, and varying gait speeds.

## ACKNOWLEDGEMENTS

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