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# Changes of Normal Adult Physiological States and Gait Parameters with Treadmill Inclined

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**Abstract.** [Purpose] The purpose of this study was to determine the standard alterations in normal adult physiological states and gait parameters resulting from changes in treadmill slope during the use of the treadmill as a medical reference. [Subjects] The subjects of this study were 12 normal, healthy volunteers without any orthopedic, respiratory or cardiovascular system problems. [Methods] The gait of subjects was measured using Optogait on an inclined treadmill for 3 minutes. Gait was measured at slopes of 0%, 9% and 18%. The subjects wore a Pansystolic murmur (PSM) training device over their xiphoid process in order to measure physiological changes. The speed of the treadmill was fixed at 5.0 km/h in order to maintain a constant walking speed. [Results] The subjects' gait parameters were observed to change significantly between slopes of 0% and 18% and the physiological states which showed significant changes were average heart rate, recovery heart rate, average respiratory rate, and angular displacement of the trunk. [Conclusion] The results of this study may be used as a medical reference for gait training on a treadmill, especially for treadmills with adjustable gradients.

**Key words:** Gait, Physiological state, Inclined treadmill

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## INTRODUCTION

Beginning with the analysis by Marey, there have been numerous examples of research on the topic of gait in fields such as physiotherapy and biomechanics[1)]. The early studies of body movement were dominated by kinematic analysis using image technology. In the 19th century, stride, foot angle or gait speed research were conducted through dynamic studies or footstep analyses outside the lab. Subsequently, many instruments have been developed which are capable of measuring various variables affecting gait, and human gait has been analyzed by investigating the characteristics of these variables. Recently, many studies comparing normal and abnormal gaits have been conducted[2)].

Gait disability of stroke patients is a major problem and 27–50% of these patients complain about the impact of stroke on their ability to walk[3)]. In stroke rehabilitation, the ability to walk independently is the most frequently mentioned goal, but this goal has focused on walking inside the home as opposed to outdoors[4)]. Nevertheless, the need of stroke sufferers to improve their ability to walk outdoors and participate more fully in society is a demand frequently presented to stroke rehabilitation therapists and researchers[5)].

Gait analysis of patients has been successfully used to measure treatment effects[6)]. Gait analysis measuring devices have been effectively used by therapists for more than ten years[7)]. Bovi et al.[8)] analyzed differences in kinematic, kinetic and EMG analyses according to age group to produce clinical references. Although the existence of specific lesions can be elucidated from gait analysis, some diseases in their early stages do not affect gait, but become manifest in the later stages[9, 10)]. Human gait speed is a basic factor to consider and an important indicator to assess[11, 12)]. Gait speed is useful as a clinical indicator for evaluation of COPD, MS, Parkinson's disease and various cardiovascular diseases[13)]. Disability related to gait is also closely related to movement limitation, increased risk of falls and potential mortality[14)]. It has been shown that treadmill exercise, which is often used in stroke patient gait rehabilitation, produces better results than general gait exercise[15)]. The treadmill is widely used in the study of the biomechanics of human gait and has the advantage of producing selective and stable gait in a controlled environment[16)]. Van Ingen Schenau[17)], showed that gait achieved on a treadmill at a constant belt speed and gait observed on level ground are the same. The treadmill is used as an exercise device for cardiovascular patients because it is simple to operate and economical in its application[18)]. As mentioned above, human gait is an important factor in measuring health conditions and treatment effectiveness. Moreover, many gait studies have focused on walking on level ground[19, 20)] but fewer studies have investigated inclined surfaces[21–24)]. Studies of inclined surfaces are important for understanding the causes of fall and for rehabilitation requirements[21–24)].

The purpose of this study was to investigate kinematic gait and physiological changes induced by changes of treadmill gradient.

**Table 1.** Kinematic gait analysis by treadmill grade

| | 0 % | 9 % | 18 % |
|---|---|---|---|
| Cadence (steps/min) | 117.6 ± 2.6 | 118.2 ± 4.2 | 124.5 ± 5.5 $^{*,\dagger}$ |
| Step time (sec) | 0.5 ± 0.0 | 0.5 ± 0.0 | 0.5 ± 0.2 $^{*,}$ |
| Stride time (sec) | 1.0 ± 0.2 | 1.0 ± 0.4 | 0.9 ± 0.4 $^{*,}$ |
| Step length (cm) | 70.9 ± 1.5 | 70.9 ± 2.5 | 67.2 ± 2.9 $^{*,\dagger}$ |
| Stride length (cm) | 142.1 ± 3.0 | 141.6 ± 5.0 | 134.3 ± 5.9 $^{*,\dagger}$ |
| Single limb support (%) | 29.5 ± 0.7 | 29.1 ± 0.8 $^{*}$ | 28.7 ± 0.7 $^{*,\dagger}$ |
| Double limb support (%) | 40.9 ± 1.5 | 41.8 ± 1.5 $^{*}$ | 42.6 ± 1.5 $^{*,\dagger}$ |
| Stance phase (%) | 70.5 ± 0.7 | 70.9 ± 0.8 $^{*}$ | 71.3 ± 0.7 $^{*,\dagger}$ |
| Swing phase (%) | 29.5 ± 0.7 | 29.1 ± 0.8 $^{*}$ | 28.7 ± 0.7 $^{*,\dagger}$ |

Values are mean ± SD, $^{*}$indicates comparison between 0 % and 9 %, 9 % and 18 % ($p<0.05$). $^{\dagger}$ indicates comparison between 9 % and 18 % ($p<0.05$).

## SUBJECTS AND METHODS

The subjects of this study were 12 healthy students attending S college which is located in S town. Subjects gave their informed consent to participation in this study as required by our Institutional Review Board.

The study inclusion criteria included the following: subjects agreed with the purpose of this study, subjects had no existing neurologic problems, subjects had no existing orthopedic problems such as lower limb fracture or sprain/strain, subjects had no existing ROM of lower limb problems, and subjects had no existing respiration or cardiovascular system problems during walking.

The average age of the subjects was 35.4 ± 2.7 years, their average height was 173.5 ± 3.1 cm, their average weight was 71.5 ± 7.1 kg, and their average BMI was 24.3 ± 1.3.

A gait analysis device (Optogait, Microgate Inc., Italy, 2010) was used to measure the subjects' gait parameters.

Kinematic gait variables measured included cadence, step time, stride time, step length, stride length, single limb support frequency, double limb support frequency, stance phase frequency and swing phase frequency.

PSM training (Zephyr Technology Corp., New Zealand, 2010) was used to measure physiological changes. The average heart rate and breath rate of each subject was measured during a 3-minute gait test for physiological changes. After the 3-minute gait test, the subjects' recover heart and breaths rate were measured during a 3-minute recovery period. In addition, anterior and posterior body sway was measured.

In order to prevent unnatural motions, subjects practiced walking on level ground with a PSM worn on their xiphoid process. The subjects wore shoes and walked on a treadmill for 3 minutes at incline grades of 0%, 9% and 18%. Subjects rested sufficiently between each gait test. The speed of the treadmill was fixed at 5.0 km/h to maintain a constant walking speed.

All collected data were analyzed using SPSS version 18.0. The average and standard deviation of all variables were calculated. One-way repeated AVOVA was used for comparisons between kinematic gait analysis and physiological changes at the different treadmill slopes. Fisher's Least Significant Difference (LSD) was conducted for the post hoc evaluation. The level of statistical significance was chosen as $\alpha=0.05$.

## RESULTS

The results of kinematic gait versus treadmill slope demonstrated significant differences in cadence, step time, stride time, step length, stride length, single limb support, double limb support, stance phase and swing phase ($p<0.01$) (Table 1).

In the post hoc analysis results, significant cadence differences ($p<0.05$) were found between grades of 0% and 18% and between 9% and 18%. Step time between grades of 0% and 18% and between 9% and 18% were found to be significantly different ($p<0.05$). Stride time between grades of 0% and 18% ($p<0.05$) and between 9% and 18% ($p<0.05$) were found to be significantly different. Step length between grades of 0% and 18% and between 9% and 18% were found to be significantly different ($p<0.05$). Stride length between grades of 0% and 18% and between 9% and 18% were found to be significantly different ($p<0.05$). Single limb support between grades of 0% and 9%, between 0% and 18%, and between 9% and 18% were found to be significantly different ($p<0.05$). Double limb support between grades of 0% and 9% ($p<0.05$), between 0% and 18% ($p<0.05$), and between 9% and 18% ($p<0.05$) were found to be significantly different. Stance phase between grades of 0% and 9%, between 0% and 18%, and between 9% and 18% were found to be significantly different ($p<0.05$). Swing phase between slopes of 0% and 9%, between 0% and 18%, and between 9% and 18% were found to be significantly different ($p<0.05$).

In the post hoc results for the physiologic changes related to treadmill slope, the average heart rate was significantly different between grades of 0% and 9%, between 0% and 18%, and between 9% and 18% ($p<0.05$). The recovery heart rate was found to be significantly different between grades of 0% and 9% and between 0% and 18% ($p<0.05$). The average respiratory rate was significantly different between grades of 0% and 18% ($p<0.05$). The angular displacement of the trunk was found to be significantly different between grades of 0% and 9%, between 0% and 18%, and between

**Table 2.** Physiological changes by treadmill grade

| | 0% | 9 % | 18 % |
|---|---|---|---|
| Average heart rate (bpm) | 97.8 ± 9.1 | 127.1 ± 16.5 * | 168.2 ± 18.5 *,† |
| Recovery heart rate (%) | 87.1 ± 7.9 | 71.1 ± 4.7 * | 63.6 ± 8.2 * |
| Average respiration rate (breaths/min) | 24.8 ± 3.1 | 25.3 ± 4.1 | 30.1 ± 5.0 * |
| Recovery respiration rate (%) | 70.3 ± 18.1 | 71.4 ± 19.3 | 78.8 ± 13.1 |
| Angular displacement of the trunk (°) | −4.1 ± 4.6 | 0.1 ± 1.7 | 9.5 ± 7.3 *,† |

Values are mean ± SD, *indicates comparison between 0 % and 9% and 9 % and 18 % ($p<0.05$).
† indicates comparison between 9 % and 18 % ($p<0.05$).

9% and 18% ($p<0.05$) (Table 2). The recovery respiratory rate did not significantly differ.

## DISCUSSION

This study found that normal gait parameters and physiological changes occur depending on treadmill slope. The speed of the treadmill was set at 5.0 km/h (approximately 1.4 m/s) which is equivalent to a normal adult gait speed[25]. Other studies used self-selected walking speeds and reported different walking speeds as the incline angle increased[21, 22, 26]. McIntosh et al.[27] reported that the walking speed increased with incline while the other studies[21, 22, 26] walking speed decreased as the incline angle increased. The gait parameters at a 9% treadmill incline showed significant changes in single limb support, double limb support, stance phase and swing phase. However, with an 18% treadmill incline, significant changes were observed in all gait parameters. Step length and stride length decreased as incline angle increased. Kawamura and Sun reported a similar results but McIntosh and Leroux reported the opposite[21, 22, 24, 27]. A possible reason for the differences in our finding is that under constant speed, subjects tried not to push back from the slope, which would result in increased cadence, but decreased step length. McIntosh explained the reason for their differing results as being the short walkway (7 m) which did not allow subjects to settle into a regular gait pattern, implying a longer walkway and an additional method for measuring stride length and cadence are necessary[27].

In the present study, the angular displacements of the trunk were 0.1°at the 9% grade incline, −4.1°at the 0% grade, and +9.5°at the 18% grade. These results are similar to those reported in the study of Vogt and Banzer in which only walking at an 18% grade incline resulted in major angular displacement of the trunk relative to the pelvis. In the standing position, humans try to maintain balance by keeping the body's center of gravity within the base of support, but human walking needs forward propulsion of the body, and normal subjects lean forward during level walking[28, 29]. Thus, angular displacement of the trunk during walking can assist in propelling the body forward[30]. We attached the PSM training device at the xiphoid process of each subject, while Vogt and Banzer put a marker at the T12 level. Vogt and Banzer's study was undertaken in order to compare pelvic (S1) and thoracic (T12) kinematic changes during level and incline walking, but our study only measured the angular displacement at the level of the xiphoid process (T9 level)[29].

Usually, determination of exercise load in exercise prescription and training is made by heart rate or subjective evaluation of patient symptoms, but this approach produces risk factors for patient injury[2]. Therefore, therapists need to adjust the grade of the treadmill slope, as necessary.

In our study, the average heart rate and recovery heart rate increased significantly for subjects during use of the incline treadmill. Notably, their recovery heart rate decreased with use of the incline treadmill. Yanagisawa's study noted that an abnormal heart recovery rate in elderly subjects was related to a higher mortality rate. Thus, therapists should evaluate heart recovery rate when creating an exercise program using a treadmill for elderly patients[18].

Many virtual reality trainings have utilized a treadmill in the treatment of stroke patients[31–33]. If these virtual reality trainings utilize treadmill slope, it may increase the therapeutic effects for the patient.

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