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Original Article

Postural Control Characteristics during Single Leg Standing of Individuals with a History of Ankle Sprain: Measurements Obtained Using a Gravicorder and Head and Foot Accelerometry

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Abstract. [Purpose] This study aimed to validate the postural control characteristics of individuals with a history of ankle sprain during single leg standing by using a gravicorder and head and foot accelerometry. [Subjects] Twenty subjects with and 23 subjects without a history of ankle sprain (sprain and control groups, respectively) participated. [Methods] The anteroposterior, mediolateral, and total path lengths, as well as root mean square (RMS) of each length, were calculated using the gravicorder. The anteroposterior, mediolateral, and resultant acceleration of the head and foot were measured using accelerometers and were evaluated as the ratio of the acceleration of the head to the foot. [Results] There was no significant difference between the two groups in path length or RMS acceleration of the head and foot. However, the ratios of the mediolateral and resultant components were significantly higher in the sprain group than in the control group. [Conclusion] Our findings suggest that individuals with a history of ankle sprain have a higher head-to-foot acceleration ratio and different postural control characteristics than those of control subjects.
Key words: Recurrent ankle sprain, Postural control assessment, Postural strategy

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INTRODUCTION

An ankle sprain is the most common injury regardless of sex, age[1)], and type of sport[2)]. If a normal recovery process does not occur after an ankle sprain, persistent symptoms such as feelings of “giving way” and “ankle joint instability” remain. These symptoms can lead to surgical management in severe cases, and increase the risk of recurrent ankle sprains. In this regard, one of the main risk factors for recurrent ankle sprain is a deficit in static postural control.

Since Freeman’s landmark work in 1965[3)], instrumented force plate measures of static postural control have been widely reported[4–9)]. However, a consensus on the measurement of static postural control does not exist[10)]. As highlighted by Tropp et al.[5)] the forces acting on a force plate are the result of gravity and acceleration of body segments. Thus, the force plate measures gravity forces as well as the forces generated by the person to keep the center of gravity within the area of support. Therefore, even if the same center of pressure (COP) is measured, the movements of each body segment may be different.

Recently, an accelerometer that can measure small movements of a target site has attracted attention as an instrument for measuring postural control[11, 12)]. Accelerometers can measure movements in multiple body segments and are the best evaluation devices available compensating for the limitations of instrumented measures of postural control. We believe that measurement of the movements of each body segment will help enhance our understanding of postural control capacity and ankle sprain. Therefore, the purpose of our study was to validate the postural control characteristics of individuals with a history of ankle sprain during single leg standing using a gravicorder and head and foot accelerometry.

SUBJECTS AND METHODS

Subjects

Twenty persons with a history of ankle sprain (14 men, 6 women: age = 22.7 ± 3.4 years, height = 166.9 ± 7.1 cm, weight = 58.8 ± 8.9 kg) and 23 persons without a history of ankle sprain (18 men, 5 women: age = 23.4 ± 3.5 years, height = 167.3 ± 6.3 cm, weight = 64.0 ± 10.8 kg) volunteered to participate in this study. Inclusion criteria were similar to the criteria of Wikstrom et al.[6)] and were as follows: a score of 80 or less on the Karlsson scoring system[7)], a history of at least one recurrent ankle sprain 3 to 6 months

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before study participation, and a history of at least 1 unilateral ankle sprain that required non-weight bearing activity for at least 3 days. The Karlsson scoring system is based on eight different items (Pain, Swelling, Instability, Stiffness, Stair climbing, Running, Work activities, Support) which are self-assessed. The score correlates well with objective signs of ankle joint instability as measured by stress radiographs (anterior talar translation and talar tilt)[7]. We considered functional instability as a score of 80 points or less on the 100 point scale, and the subjects in the sprain group qualified with at least 1 item of the inclusion criteria. The subjects in the control group had a Karlsson score of 100 points. Written informed consent was obtained from each study participant, and the rights of all subjects were protected.

Methods

The COP and acceleration of the head and foot during single leg standing were measured. Subjects were instructed to stand as still as possible during testing, with their arms folded across their chests, while standing on one limb and raising the opposite limb by slight knee flexion[13]. The supporting limb was the right and dominant limb (limb used to kick a ball) in all subjects of the sprain and control groups. During single leg standing, subjects were instructed to stand as still as possible while focusing on a visual target placed 2 m in front of them. The COP was measured using a gravicorder (Twin Gravicorder G-6100; Anima Corp, Japan) at a sampling frequency of 100 Hz. Accelerometers (tri axial accelerometer, MVP-RF8-AC; Microstone Corp, Japan; acceleration range, ±20 m/s^2; frequency range, 0–100 Hz; A/D resolution, 10 bit; size, 45 × 45 × 18.5 mm; wireless, real–time vision) were placed on the forehead and lateral malleolus of the involved (dominant) leg to measure the acceleration of the head and right foot, respectively. The anteroposterior (AP) and mediolateral (ML) motion components were measured. Gravicorder and accelerometer data were collected at the same time, and data collection was started after establishing stable single leg standing. Each trial was 20 s in length and was repeated three times.

Acceleration data were stored in Excel through a Wireless Vibration Recorder (MVP-RF-S Ver. 1.0.8; Microstone Corp, Japan). The head and foot accelerations were filtered by a high-pass filter with a cutoff frequency of 0.5 Hz to eliminate convergent gravity components around 0 Hz using vibrating displacement analysis software (MVP-RF-S Ver. 1.0.8; Microstone Corp, Japan). The resultant acceleration component (Re) was calculated from the filtered AP and ML accelerations. In addition, the root mean square (RMS) of the AP, ML and Re components was determined (AP acceleration RMS = AP Ac RMS, ML acceleration RMS = ML Ac RMS, resultant acceleration RMS = Re Ac RMS). Each acceleration was also calculated as the ratio of the head to foot acceleration and is presented as AP%, ML%, and Re%. The gravicorder data were calculated as the total path length (TL), AP length (APL), ML length (MLL), and RMS of each length.

Normality was confirmed for the gravicorder data and acceleration ratios using the Shapiro-Wilks test, and the independent t-test was used for between-group comparisons of these variables. The Mann-Whitney U test was used to compare other items between groups, and Wilcoxon's signed-rank test was employed to evaluate acceleration of the head and foot within each group. In addition, Spearman's rank correlation coefficients were calculated for COP and acceleration parameters (i.e., TL RMS-Re Ac RMS of the head and foot, APL RMS-AP Ac RMS of the head and foot, MLL RMS-ML Ac RMS of the head and foot). SPSS ver.17.0 for Windows was used for statistical analysis with a significance level of 5%.

RESULTS

The results of the gravicorder and accelerometer data are shown in Tables 1–3. In the comparison of the two groups, the gravicorder COP (Table 1) and acceleration (Table 2) values for the head and foot were similar. Within the control group, the acceleration of the foot was greater than that of the head for all 3 components (AP Ac RMS, ML Ac RMS, and Re Ac RMS). However, in the sprain group, the acceleration of the foot was significantly greater than that of the head for only the AP and Re trajectories (Table 2). The ratio of the head to foot acceleration was also calculated to account for individual differences in acceleration. A significantly greater ratio (%) for the ML and Re trajectories was found in the sprain group, relative to the control group (Table 3). When examining the relationship between the RMS of each trajectory length and acceleration, a significant positive correlation was found between Re Ac RMS of the head and TL RMS, as well as ML Ac RMS of the head and MLL RMS in the control group. No other significant correlations were found (Table 4).

DISCUSSION

Positive and negative findings have been reported for traditional COP parameters (gravicorder-based measurements) in subjects with ankle sprain and postural control deficit[10]. In the current study, we found COP parameters (TL, APL, MLL, and RMS of each length) were similar in individuals with a previous ankle sprain and healthy controls. These findings are in line with those of Hertel et al.[4], who only found a difference between chronic ankle sprain and healthy individuals when examining an alternative item, termed the "time to boundary." We also examined additional measures, including the acceleration of the head and foot. There were no significant differences between the groups for the RMS acceleration values of the head and foot, whereas the ratio of the ML and Re head to foot acceleration was greater in the sprain group. In addition, within the control group, the RMS acceleration of the foot was greater than that of the head for the AP, ML and Re trajectories, but was only significantly greater for two of the trajectories (AP and Re) in the sprain group. Collectively, these findings suggest that: healthy adults have postural control characteristics in which foot acceleration is greater than head acceleration during single leg standing, and the greater head-to-foot acceleration ratios suggest that the postural control characteristics of individuals with a previous

Table 1. Center of pressure (COP, cm) outcome measures

	TL		APL		MLL	
	Control	Sprain	Control	Sprain	Control	Sprain
Total	63.5± 14.8	65.7± 13.8	36.2± 9.2	38.4± 9.6	44.8± 10.3	45.6± 9.2
RMS	0.89± 0.16	0.91± 0.19	0.71± 0.16	0.76± 0.20	0.51± 0.08	0.49± 0.05

The t-test was used to compare the six traditional COP parameters: total COP path length (TL), COP path length in the anteroposterior direction (APL), COP path length in mediolateral direction (MLL), and the root mean square (RMS) of each COP path length. Values are mean ± SD.

Table 2. Acceleration (m/s^2) outcome measures

	AP Ac RMS		ML Ac RMS		Re Ac RMS	
	Control	Sprain	Control	Sprain	Control	Sprain
Head	0.07± 0.02	0.07± 0.01	0.11± 0.05	0.13± 0.03	0.13± 0.05	0.15± 0.03
foot	0.19± 0.09**	0.16± 0.05**	0.15± 0.05**	0.14± 0.05	0.24± 0.09**	0.21± 0.06**

The Mann-Whitney U test was used for between-group comparisons. Wilcoxon's signed-rank test was used for the within group comparisons of segment. (**Significant at $p < 0.01$.)
Anteroposterior acceleration RMS, AP Ac RMS; mediolateral acceleration RMS, ML Ac RMS; resultant acceleration RMS, Re Ac RMS. Values are mean ± SD.
**Significant at $p < 0.01$.

Table 3. Head-to-foot acceleration ratio (%) outcome measures

AP%		ML%		Re%	
Control	Sprain	Control	Sprain	Control	Sprain
0.42±0.15	0.51±0.20	0.78±0.20	1.00±0.22**	0.59±0.16	0.73±0.22*

The t-test was used for comparisons between groups. Anteroposterior acceleration ratio (AP%), mediolateral acceleration ratio (ML%), and resultant acceleration ratio (Re%). Values are mean ± SD. *Significant at $p < 0.05$. **Significant at $p < 0.01$.

Table 4. Correlations between COP and acceleration parameters

	Acceleration of the head	Acceleration of the foot
	r	r
Control		
TL RMS - Re Ac RMS	0.527*	0.305
APL RMS - AP Ac RMS	0.062	0.419
MLL RMS - ML Ac RMS	0.571**	0.145
Sprain		
TL RMS - Re Ac RMS	0.231	−0.049
APL RMS - AP Ac RMS	0.145	−0.190
MLL RMS – ML Ac RMS	0.193	0.443

Spearman's rank correlation coefficient was calculated for COP and acceleration parameters. RMS of the total COP path length (TL RMS), RMS of the anteroposterior COP path length (APL RMS), RMS of the mediolateral COP path length (MLL RMS), RMS of the anteroposterior acceleration (AP Ac RMS), RMS of the mediolateral acceleration (ML Ac RMS), and RMS of the resultant acceleration (Re Ac RMS).
*Significant at $p < 0.05$. **Significant at $p < 0.01$.

ankle sprain may be different from those of a healthy control. These points are further discussed in detail below.

Two strategies are employed for postural control during static standing in order to steady the center of mass, namely the hip and ankle strategies. These strategies change with aging, and the ankle strategy is used by adults, whereas elderly individuals utilize the hip strategy[14]. The subjects in the current study were adults in their twenties, and we considered these postural control strategies to be reflected by the acceleration of the head and foot. The acceleration of the foot was measured using an accelerometer placed on the lateral malleolus of the involved (dominant) leg. Therefore, movement of the lateral malleolus with subtalar joint motion reflected acceleration of the foot. As shown in Fig. 1[9], the large amplitude motion of the lateral malleolus, with changes in the COP, is perceived as ML acceleration. Furthermore, when movement in the frontal and horizontal planes of the talus is limited, supination and pronation of the subtalar joint is reflected by internal/external rotation and forward/backward tilt of the lower thigh through the talocrural joint. These motions are perceived as AP acceleration. Since the base of support during single leg standing is a unilateral plantar surface, the lateral direction of the base of support is narrow, and disruptions in the lateral direction are likely to occur. To control for this disruption in the lateral direction, the using the foot and ankle, supination and pronation of the subtalar joint are used. For people with a history of ankle sprain, supination of the subtalar joint induces unstable and ankle sprain movements. Therefore, during single leg standing, in order to control for the joint disruption, the ratio of the head-to-foot acceleration, par-

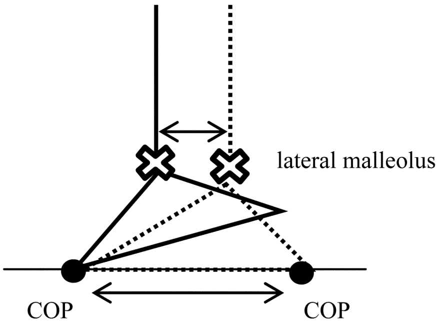

Fig 1. Relationship between the ankle lateral malleolus and COP deviation due to foot-ankle control (based on Tropp[9]). The schematic diagram shows how the position of the ankle lateral malleolus deviates due to changes in the center of pressure (COP) associated with foot movement in the frontal plane.

ticularly in the ML trajectory, is likely to increase.

We also considered the relationship between acceleration and trajectory length. A significant positive correlation was found between the Re Ac RMS of head and TL RMS, as well as the AP Ac RMS of head and APL RMS in the control group. In contrast, there were no significant correlations in the sprain group. We believe that these findings suggest the influence of another joint. Tropp et al.[9] measured COP, joint alignment, and peroneal muscle activity during single leg standing in controls and patients with functional instability. A high correlation was found between COP and ankle alignment/peroneal muscle activity in the control group, whereas a high correlation between COP and superior pelvis alignment was obtained in the functional instability group. In other words, individuals with functional instability employ the hip strategy. Martinez-Ramirez et al.[12] measured lumbar acceleration during the Star Excursion Balance Test (elevation of the lower limb in eight directions during single leg standing). They also suggested that people with a history of ankle sprain use the hip strategy for postural control. In the present study, it was difficult to decide which particular joint may have played a compensatory role. However, in the sprain group, the greater head-to-foot acceleration ratio, with no significant relationship between each trajectory length and the acceleration of the head, suggests that other joints were involved in postural control. Therefore, a future challenge is to better define postural control characteristics in individuals with a history of ankle sprain using acceleration of the lumbar and hip regions, along with electromyogram and kinematic analyses of the trunk and lower limb.

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