INTRODUCTION

An impaired ability to control lateral balance contributes to falls in older adults [1]. When balance is disturbed, the whole-body center of mass (COM) motion needs to be regulated by an active control of the center of pressure (COP) to achieve postural stability. Since the base of support (BOS) provides a possible area for COP movement, the boundaries of the BOS have been considered as stability limits within which balance is maintained by rapidly moving the COP to keep the COM from going beyond the BOS. However, the area in which the COP can functionally move has been reported to decrease with aging [2], thereby constricting the limits of stability. Further, decreases in COP speed during voluntary sway movements have been seen in high fall-risk older adults [3]. Such reduced COP control would affect their ability to recover balance. This study investigated COP control during lateral perturbations in healthy elderly adult non-fallers and fallers. We hypothesized that elderly fallers would demonstrate a slower COP movement with a reduced functional area.

METHODS

Fifty-four community-dwelling older adults (38 Non-Fallers and 16 Fallers) received 60 randomly applied motor-driven lateral waist-pull perturbations with the speed ranging from 7.5 to 37.5 cm/s. Subjects stood in a comfortable position, placing each foot on a separate force platform (AMTI, Newton, MA) that recorded ground reaction forces at 600Hz. Kinematic data were obtained with a 6-camera motion capture system (Vicon 460, Oxford, UK) at 120Hz. Since crossover stepping with passively unloaded leg is a common strategy used by older adults to recover lateral balance [4], responses to the left lateral pull at 30cm/s, where the largest number of subjects (28 Non-Fallers and 7 Fallers) responded with crossover steps using the right leg, were used for all analyses.

The whole-body COM and combined COP positions in the medio-lateral (ML) directions were referenced to the left medial ankle and normalized to the left foot BOS width, while COP velocity prior to step-onset (SO) of the right leg was normalized to the stance width. Left peak hip abductor and ankle invertor moments prior to SO also were calculated. Furthermore, a single-link-plus-foot inverted pendulum model was used to define lateral stability limit at the instant of SO, which was derived using the following equation [5]:

\[
\tilde{X}_{SO} \leq 1 - \tilde{X}_{SO}
\]

where \(\tilde{X}_{SO}\) and \(\tilde{X}_{SO}\) are normalized COM position and velocity at SO in the ML direction, defined as \(\tilde{X}_{SO} = (X_{SO} - X_{ma}) / L_f\), \(\tilde{X}_{SO} = \tilde{X}_{SO} / (L_f \omega_b)\) (\(\omega_b = \sqrt{g/l}\)), \(L_f\): BOS width, \(X_{ma}\): medial ankle, \(l\): pendulum length). The lateral stability limit also was adjusted based on COP position at SO, considering it as a functional limit for COP movement. Stability margin was calculated as the shortest distance from the experimental data to the lateral stability limit defined based on both the BOS and functional limit.

An independent t-test was performed to examine group differences. Linear regression analyses were performed to examine the relationship between hip and ankle joint moments and COP measures. Significance level was set at \(\alpha = .05\).

RESULTS AND DISCUSSION

Fallers took more recovery steps than Non-Fallers (mean 2.4±0.4 vs 1.8±0.5). No significant difference was found in normalized peak COP velocity between Fallers and Non-Fallers (Fig.1).
However, normalized COP position at SO for Fallers was located significantly medial to that for Non-Fallers (Fig.1). This suggests that the area functionally used for COP movement to control the COM was significantly reduced in Fallers. In addition, although no significant group differences were detected, peak ankle invertor moment and peak hip abductor moment were significantly correlated with normalized COP position at SO \((p=.006)\) and peak COP velocity \((p=.032)\), respectively, implying different roles of hip and ankle muscles for COP control.

Although not statistically significant, Fallers demonstrated a smaller normalized COM velocity with a similar COM position at SO compared to Non-Fallers (Fig.2), resulting in a larger stability margin for the stability limit based on the BOS (Fig.3), which is consistent with the previous findings [6]. However, for these crossover steps, the stability margin became smaller than Non-Fallers when the stability limit was adjusted based on the COP position at SO (functional limit) (Fig.3).

These findings suggest that Fallers have reduced functional limits of stability for COM control in the ML direction, possibly due to decreased ankle invertor activity. This could be a cause for lateral instability requiring them to take more steps than Non-Fallers for balance recovery during crossover steps.

REFERENCES


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