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The effect of aging on vertical postural control during the forward and backward shift of the center of pressure

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ABSTRACT

Preventing fall-related injuries is becoming a priority as the world population ages. This study's purpose was to examine the effect of aging on vertical postural control in the community-dwelling elderly. Thirty-six elderly individuals and twenty-two healthy young adults were asked to shift their centers of pressure (COPs) as far as possible while standing. The COP position, angle of each lower leg joint, and postural muscle activities were measured using a force plate, three-dimensional motion analyzer, and electromyogram, respectively. The vertical position of the center of mass (COM) was also measured to assess the change in vertical postural control. The backward COP shift in the elderly group was significantly smaller than that in the young group, and both the forward and backward COM shifts were significantly smaller in elders relative to those in youths. The COM position in the elderly group during the backward COP shift was also significantly lower than that in the young group. Knee and ankle joint movements differed between the two groups during the backward COP shift. Factor analysis indicated that dorsal and ventral muscle groups were involved in the COP shift. Specifically, the relationship between the biceps femoris muscle and the voluntary COP shift was reinforced in the elderly group. These findings suggest that the vertical postural strategy changes in the elderly during the backward COP shift.

1. Introduction

Falls are the most serious cause of hip and wrist fractures and head injuries among the elderly [1]. Major factors contributing to falls among the elderly are the reduced physiological capacity that occurs with aging and decreased balance [2–4]. Furthermore, the risk of falls among the elderly is affected by the interactions of the organism, environment, and task [5]. More than 30% of community-dwelling elderly people and those in long-term care facilities report at least one indoor fall per year [1], with 10–15% of these falls resulting in significant injury [6]. The most common problem among the elderly is reported to be incorrect transfer or weight-shifting performed by the individual (i.e., self-paced) [1].

A smooth shift of the center of pressure (COP) and center of mass (COM) is essential for transferring or shifting body weight during activities of daily living, and analyses of such shifts have often been used in previous studies [7–10]. In terms of balance ability, the elderly have been reported to show smaller maximum displacement [7] and greater reaction and movement times [8] during a voluntary COP shift when compared to those in the young. COP has been measured and analyzed in the anterior-posterior (A/P) and/or medial-lateral (M/L) directions, because COP movement is performed two-dimensionally within the base of support [9]. Although researchers have focused on the A/P and/or M/L directions with respect to the COM in relation to the COP [10], the actual COM has three-dimensional (3-D) motion, because the vertical direction is added to these directions. Recent studies have reported that higher COM positions decreased postural stability and lower COM positions improved standing stability [9,10]; thus 3-D postural control requires vertical changes as well as A/P and M/L changes. However, to our knowledge, no study has attempted to clarify postural control further in humans during the erect stance through examining the COM in the vertical dimension.

In this study, we aimed to evaluate the effect of aging on vertical postural control by investigating the COM in the vertical direction during a task involving a self-paced dynamic shift in the COP. We

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anticipated that the vertical position of the COM would differ between elderly and young individuals because of differences in the adopted postural strategy [3,4]. Additionally, we hypothesized that changes in the vertical postural strategy as a consequence of aging would be related to activity in the postural muscles, which specifically control the knee joint and thereby movement in the vertical axis [11].

2. *Methods*

2.1. *Participants*

Twenty-two healthy young adults (Y-Group: 13 women and 9 men; mean age, 20.6 ± 1.0 years) and 36 healthy elderly adults (E-Group: 36 men; mean age, 69.5 ± 3.2 years) participated. The body characteristics in both groups were similar (Table 1). Young participants were randomly selected from among college students who volunteered to participate in this study. Elderly participants >65 years old with no history of any neurological or orthopedic diseases or ophthalmologic conditions that could contribute to movement dysfunction were randomly selected from among community-dwelling elderly who had registered with the employment agency. None had had a history of falls for at least 6 months before enrollment in the study or took any medication that could affect balance [12]. All study participants provided written informed consent to participate, and the procedures were approved by the ethics committee of Hokkaido University School of Medicine (no. 11-03).

2.2. *Experimental tasks*

Participants stood with bare feet and their legs shoulder-width apart on a force plate (Kistler, Type 9286A, Switzerland) with their arms crossed in front of their chests. Visual feedback information about the COP position was provided to participants from a computer monitor, and the start position of the COP was located 5.0 cm in front of the middle of the line joining both medial malleoluses to ensure a backward motion range. After the examiner checked the steady state of the COP within 1 cm of the start position, the power to the monitor was turned off, and each trial was started. Participants performed the three tasks of: (1) maintaining a static stance; (2) shifting to the maximum forward COP position; and (3) shifting to the maximum backward COP position [13]. Participants were instructed to shift the COP as far as possible and not to raise their toes or heels and to stably maintain their COP position. Participants were given no instruction regarding the use of leg joints in order to avoid a bias in postural strategy. Each task was performed 3 times in a random order, with sufficient rest between tasks to prevent fatigue.

2.3. *Data acquisition and processing*

Force and muscle activity data were digitized at a frequency of 1 kHz by an NI Compact DAQ (National Instruments, Austin, TX, USA), and the COP position was subsequently calculated with force data using a customized program (Labview 2009; National Instruments, Austin, TX, USA). Surface electromyography (EMG) data were collected using the Delsys EMG system (Bagnoli-2EMG System; DELSYS, Boston, MA). Activity was recorded for each of the following 6 postural muscles according to previous studies [2,3,11,12]: the rectus abdominis (RA), erector spinae (ES), rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA), and gastrocnemius (GAS) muscles. EMG sensors were attached to the belly of the target muscle, and reference electrodes were attached to the iliac crest, the head of the fibula, and the lateral malleolus [2,3,11,12].

A 3-D motion analysis system with 6 cameras at a sampling rate of 100 Hz was used to compute the angles of the hip, knee, and ankle joints and the position of the COM (Motion Analysis Corporation, Santa Rosa, CA, USA). Reflective markers were attached based on the anatomical landmark locations used by Winter [14]. All markers were located bilaterally, except for those at the top, front, and back of the head; the acromion process; the angulus inferior scapulae; and the sacrum. Positive values of calculated joint angles show flexion and dorsal flexion, and negative values show extension and plantar flexion.

All off-line data processing was performed with the customized Matlab program (Mathworks, Natick, MA, USA). COP and COM data were low-pass filtered with a zero-lag, second-order Butterworth filter with a cut-off frequency of 10 Hz. The distance from the start position to the maximum COP and COM positions in either the anterior or posterior direction was subsequently measured for each task. The A/P displacement of the COP and the COM was normalized by dividing it by the length of each participant's foot [14]. Vertical displacement was calculated by subtracting the start position of the COM from the COM position during the maximum COP shift and subsequently normalized by each participant's height. Surface EMG data were rectified and band-pass filtered from 10 to 500 Hz using a fourth-order Butterworth filter. The magnitude of muscle activity was evaluated using the mean amplitude of each muscle's activity in maintaining a stable COP after the completion of a COP shift. The change in each joint angle was calculated by subtracting the value obtained during the static stance from the joint angle at each maximum COP shift.

2.4. *Statistical analysis*

All statistical analyses were performed using PASW Statistics 18 (SPSS Inc., Chicago, IL). All data are shown as the mean and standard deviation of the three trials for each task in each group. An analysis of variance (ANOVA) was used to examine the interactive effects of age and movement direction. If a significant interaction was identified, the simple main effect was further analyzed with a post-hoc paired *t*-test with Bonferroni corrections. A p value <0.05 was considered statistically significant. The effect sizes from the ANOVA are expressed as eta-squared (η^2) values, and the effect sizes for differences in the means are expressed as Cohen's d values [15].

After performing the ANOVA for muscle activities among tasks in each group, we conducted an exploratory factor analysis with the principal factor method to identify the factor structure of the muscle activities for postural strategy during the COP shift. An optimal factor solution was determined based on eigenvalues of >1.0 [16], and on an examination of the scree plot using all 6 muscle activities. For the optimal factor solution, principal axis factoring with varimax rotation and Kaiser's normalization were used to determine the latent variables that best explained the observed variability in each EMG. After the rotation, any variable that significantly loaded on more than one factor (with an absolute value >0.4) was identified and removed [17].

Table 1
Descriptive statistics of the participants according to age.

	YG (n = 22)		EG (n = 36)	
	Mean ± SD	Range	Mean ± SD	Range
Age (year)	20.6 ± 1.0	20–24	69.5 ± 3.2*	65–78
Height (cm)	165.9 ± 8.9	152–181	163.9 ± 5.2	153–172
Weight (kg)	58.4 ± 9.5	44–75	62.8 ± 5.2	49–85
BMI (kg/m^2)	21.1 ± 2.1	17.6–25.3	23.4 ± 2.4	19.3–28.7

YG: young group, EG: elderly group, BMI: body mass index, SD: standard deviation
* $p < 0.05$ between the YG and EG groups.