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Performance of older adults under dual task during stair descent

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ABSTRACT

Background: Stair walking, especially in dual-task conditions, is a challenging daily routine for older adults. The purpose of this study is to investigate gait and postural control and explore the possible reasons for the fall risk encountered by healthy older adults under dual-task conditions during stair descent.
Methods: Thirty healthy older female adults (aged 67 ± 1 years, standing height of 1.64 ± 0.17 m, body mass of 66.01 ± 4.27 kg, and education of 8.92 ± 0.95 years) were randomly recruited from local communities and instructed to perform stair descent in a step-by-step manner on a standardized staircase under single-task (stair descent) and dual-task (stair descent with subtraction in series of three) conditions. Multivariate analysis of variance with repeated measures was performed to test the significance of multiple comparisons of kinematic variables in the single- and dual-task conditions. A paired *t*-test with Bonferroni adjustment was performed when a significant difference was detected.
Results: Gait speed, foot clearance, and hip flexion angle at the cross of the support leg decreased considerably, and step width increased remarkably among the healthy older adults under the dual-task condition relative to the situation in the single-task condition during stair descent.
Conclusion: The gait performance and posture control of the healthy older female adults were disturbed by the second cognitive task. These adults implemented a compensation strategy to enhance their body stability under the dual-task condition during stair descent.

Introduction

By 2050, approximately 400 million people worldwide will be over 80 years old.[1] Aging decreases mobility,[2] and this decrement leads to a decline in the number of daily activities, including level walking and going up and down stairs, that an individual can perform. This effect decreases the quality of life[3] and even contributes to falls[4] and death.[5] This scenario is likely to be burdensome for families and societies in developing and developed countries.

Stair walking is a routine activity and one of the five most difficult tasks for old adults.[6] More than four million old adults are treated for stair-related injuries in emergency departments annually in the United States, and 70.6% of them are women.[7] Compared with stair ascent, stair descent is more challenging[8] and requires greater mobility,[2] lower extremity strength,[9] and better balance control.[10] Daily stair descent which usually performs under dual-task conditions is particularly complicated.

A dual task typically requires performing a primary task while carrying out a concurrent secondary task.[9] It involves attention, working memory, executive functions, and other processes,[11,12] all of which can overload the cognitive function of the brain.[12] The cognitive function of adults decreases with age.[13] Therefore, performing dual tasks, especially during stair descent, is formidable for older adults.

Previous studies have found that under dual-task conditions, the motor and cognitive performance of younger adults decreases,[14] and the working memory and executive function of older adults decrease.[15] The hallux and heel trajectory of older adults also decrease.[11] However, the gait and posture control of older adults under dual-task conditions during stair descent have not been

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investigated, although these would contribute to the identification of the motion characteristics and mobility and stability deficits of older adults in such circumstances and could help prevent stair-related falls among such individuals.

The purpose of the present study is to investigate gait and postural control characteristics and explore the possible reasons for the fall risk encountered by healthy older adults under dual-task conditions during stair descent. The first hypothesis is that healthy older adults would perform a slower gait speed, narrower step width, and shorter single support time under a single-task condition than under a dual-task condition during stair descent. The second hypothesis is that healthy old adults would perform less foot clearance, greater pelvic and thorax movement, and less joint flexion of the swing leg under a dual-task condition than under a single-task condition during stair descent.

Materials and methods

Participants

Thirty healthy female older adults with right foot dominance, education of more than six years, and a Mini-mental State Examination score of more than 27 and without heart disease, joint replacements in lower extremities, arthritis, diabetes, visual deficits, vestibular deficits, falls in the last three years, or any type of neuromuscular problem that could prevent them from meeting the project requirements were recruited from three communities in Jinan, China (age of 67.0 ± 1.0 years, standing height of 1.64 ± 0.17 m, body mass of 66.01 ± 4.27 kg, and education of 8.92 ± 0.95 years). The participants enrolled voluntarily in this study and were blind to the hypotheses. The use of human participants in this study was approved by the Internal Review Board of Shandong Sport University. Each participant signed a written consent form before data collection.

Protocol

The experiment was conducted in a laboratory. Each participant was required to wear the same tight shirts, shorts, and standard shoes (Fig. 1). The participants were instructed to perform a 5 min warm up by walking at a self-selected speed, followed by stair descent in a step-by-step manner under the two experimental conditions described below randomly. A standardized staircase (five steps in total, 17.00 cm riser × 29.00 cm tread × 150 cm width), which was used in a previous study,[10] was utilized (Fig. 2). The participants were given 1 min of rest between trials. Three trials were provided to enhance the familiarity of the participants with the protocol.

Experiment conditions

Two experimental conditions were assigned to each participant in a random order.

1) Single-task condition: Each participant was asked to perform stair descent at a self-selected speed.
2) Dual-task condition: Each participant was asked to perform stair descent while performing subtraction in a series of three from randomly selected numbers (a computer-generated list in the range of 100–300) aloud. The numbers were spoken out in native language by an instructor at the beginning of descent. The answers were recorded by an instructor while a participant was on the third step of the staircase.

Data collection

Thirty-five reflective markers were placed on selected critical body landmarks of each participant (Fig. 1). The 3D trajectories of the reflective markers on the participants at the third step of the staircase were recorded at a sampling rate of 100 Hz by eight infrared cameras (VICON, Oxford Metrics Ltd., Oxford, United Kingdom). Three successful trials were obtained for each condition. A successful trial was defined as that in which the participant continuously descended from the top of the staircase to the ground without pausing, adjusting his/her steps, calculating aloud, and losing any markers.

Data reduction

The raw 3D trajectories of the reflective markers were filtered using a fourth-order Butterworth low-pass digital filter at a cutoff frequency of 13 Hz.[16] The 3D trajectories of the hallux, heel, thorax, pelvis, hip joint, knee joint, and ankle joint were extracted with a

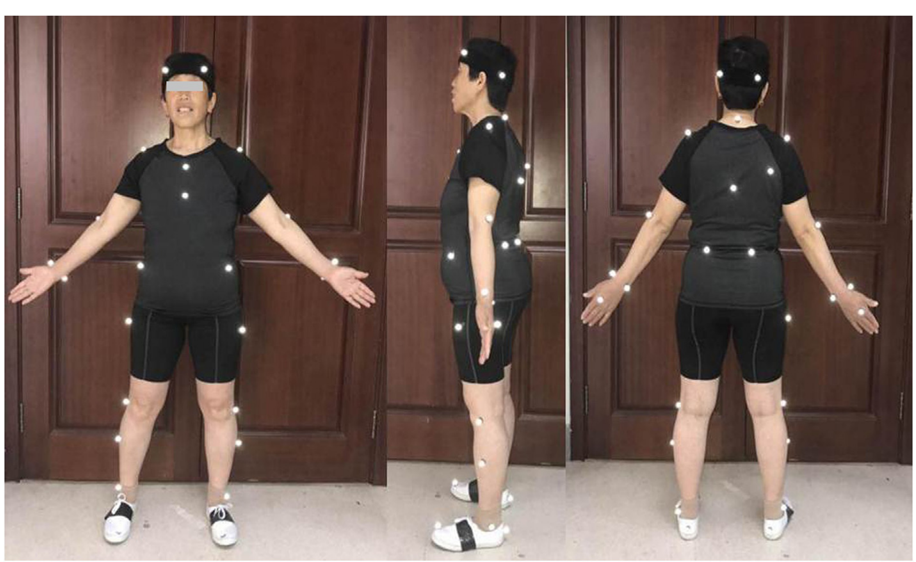

Fig. 1. 35 markers placed on participant.

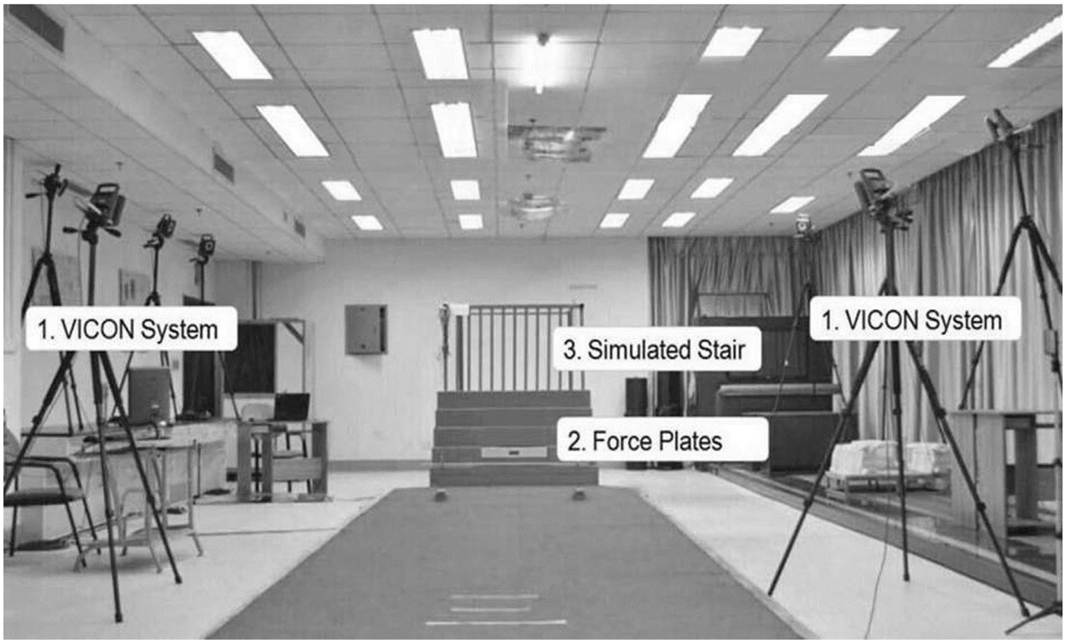

Fig. 2. Experiment setup and instrumentation.

Vicon Nexus 1.7.1 instrument (Vicon Motion Systems Ltd., West Way, Oxford, United Kingdom). The mean value of the three trials for each variable was used in the statistical analysis.

Definitions of variables

Step cycle was defined as the period from the right foot landing to the consecutive left foot landing. Single-support phase was defined as the period from the left foot takeoff to the consecutive left foot landing. Cross was defined as the instant at which the left hallux or heel is right above the second step edge. Thorax was defined as a segment composed of the seventh cervical vertebra, tenth lumbar vertebra, upper manubrium, lower manubrium, and middle right scapula. Pelvis was defined as a segment composed of the left and right anterior superior spine and left and right posterior superior iliac spine.

Thorax and pelvis tilt angles were defined as angles of the pelvis relative to the transverse plane that projected to the sagittal plane. Thorax lateral flexion and pelvis oblique angles were defined as angles of the pelvis relative to the transverse plane that projected to the frontal plane. Thorax and pelvis rotation angles were defined as angles of the pelvis relative to the frontal plane that projected to the transverse plane. Hip flexion/extension, abduction/adduction, and internal/external rotation angles were defined as the angles of the thigh relative to the pelvis that projected to the sagittal, frontal, and transverse planes, respectively. Knee flexion/extension, valgus/varus, and internal/external rotation angles were defined as the angles of the shank relative to the thigh that projected to the sagittal, frontal, and transverse planes, respectively. Ankle dorsal/plantar flexion, inversion/eversion, and pronation/supination angles were defined as the angles of the foot relative to the shank that projected to the sagittal, frontal, and transverse planes, respectively. Lower extremity joint at the anatomical position was defined as zero degree.

Gait speed was calculated as step length divided by the step time in a step cycle. Step width was calculated as the medial—lateral horizontal distance between the toes at right and left foot landing. Single support time was calculated as the time cost of the single support phase. Foot clearance was calculated as the minimum vertical distance between the left foot and stair marker at the cross. The thorax/pelvis rotation range of motion was calculated as the difference between the maximum and minimum thorax/pelvis rotation angle during a step cycle.

The positive values represent the thorax/pelvis anterior tilt (anterior lower than posterior), contralateral side up (lead side lower than contralateral side), external rotation (contralateral side ahead of lead side in the direction of progression), hip flexion/abduction/internal rotation, knee flexion/varus/internal rotation, and ankle dorsal flexion/eversion/supination. The negative values represent the opposite of what the positive values represent.

Table 1
Comparison of kinematics between single task and dual task conditions during stair descent.

	Single Task Mean ± SD	Dual Task Mean ± SD	P value	Effect Size
Gait speed (m/s)	0.57 ± 0.09	0.52 ± 0.07*	<0.001	0.63
Single support (step time)	0.77 ± 0.03	0.76 ± 0.02	0.041	0.40
Step width (LL)	0.12 ± 0.04	0.13 ± 0.04*	0.002	0.25
Foot clearance (cm)	10.11 ± 3.89	9.47 ± 3.45*	0.005	0.17
Thorax rotate ROM (deg)	5.33 ± 2.15	7.81 ± 4.27	0.024	0.77
Pelvis rotate ROM (deg)	7.11 ± 2.85	6.70 ± 3.72	0.532	0.12
Hip flexion angle at cross of support leg (deg)	17.72 ± 5.24	13.33 ± 8.45*	0.006	0.64

*Significant difference between the two conditions ($p < 0.007$). The abbreviation of LL is leg length and ROM is range of motion.

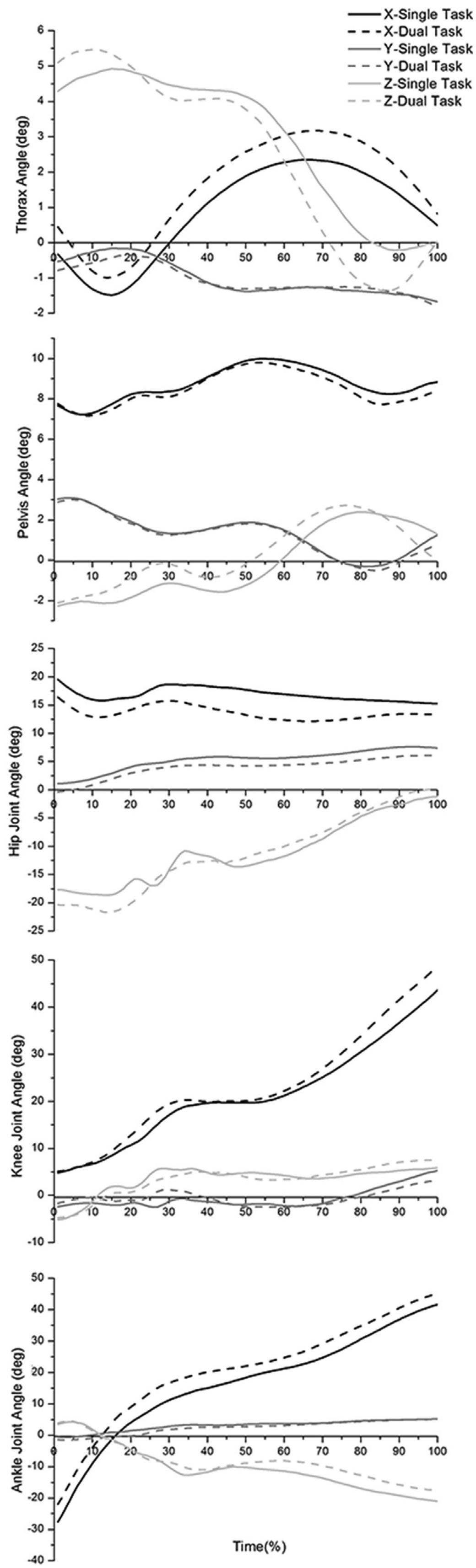

Fig. 3. Thorax, pelvis, and support leg joint angle in a step cycle at single task and dual task conditions. x represents hip joint flexion/extension, knee joint flexion/extension, ankle joint plantar/dorsal flexion. y represents hip joint abduction/abduction, knee joint valgus/varus, ankle joint inversion/eversion. z represents hip joint, knee joint and ankle joint internal/external rotation.

Statistical analysis

Multivariate analysis of variance with repeated measures was performed to test the significance of the multiple comparisons of the kinematic variables between the single- and dual-task conditions. A paired *t*-test was performed when a significant difference was found. A type I error rate lower than or equal to 0.007 was considered an indication of statistical significance after applying Bonferroni correction. All data analyses were performed using version 16.0 of SPSS (Chicago, IL, USA). Effect size (ES) was calculated as the mean difference between two groups divided by the pooled standard deviation of the groups.

Results

The results showed a significant multivariate effect on the kinematic variables of healthy older adults between the single- and dual-task conditions during stair descent ($P < 0.001$, value of Pillai's Trace = 0.315, $F(1,3) = 4.608$, and $\eta^2 = 0.315$).

The step width ($P = 0.002$, $ES = 0.25$) significantly increased, gait speed ($P < 0.001$, $ES = 0.63$) significantly decreased, and single support time ($P = 0.041$, $ES = 0.40$) did not significantly increase among the healthy older adults under the dual-task condition relative to the situation in the single-task condition during stair descent in a step cycle (Table 1).

The thorax and pelvis rotation range of motion did not significantly increase ($P > 0.007$, $EF > 0.12$), thorax tilt and pelvis rotation showed an increase, and thorax rotation decreased among the healthy older adults under the dual-task condition relative to those in the single-task condition during stair descent in a step cycle (Table 1 and Fig. 3).

Foot clearance ($P = 0.005$, $ES = 0.17$) significantly decreased and hip flexion angle at the cross of the support leg significantly decreased ($P = 0.006$, $ES = 0.64$) among the healthy older adults under the dual-task condition relative to those in the single-task condition during stair descent in a step cycle (Table 1, Fig. 3). The curve of hip abduction and external rotation, knee valgus/varus and internal rotation, and ankle supination and external rotation of the support leg in the dual-task condition were nearly similar to those in the single-task condition. However, hip flexion exhibited a minor decrease trend, and knee flexion and ankle dorsal flexion showed a minor increase trend (Fig. 3). The curves of the hip and knee joints and the ankle joint angle of the swing leg in the dual-task condition were nearly similar to those in the single-task condition (Fig. 4).

Discussion

The results partially support our first hypothesis that healthy older adults would perform a slower gait speed, narrower step width, and shorter single support time under a single-task condition than under a dual-task condition during stair descent. The results of this study showed that the gait speed significantly decreased in the dual-task condition relative to that in the single-task condition during stair descent, which indicated that the performance of the healthy older female adults was disturbed by the second cognitive task and thus slowed down the enhancement of body stability.[14,17] The results of this study also showed that the step width significantly increased in the dual-task condition relative to that in the single-task condition during stair descent, which indicated that the healthy older adults had an increased lateral base of support. According to the theory of Borelli, stability increases as

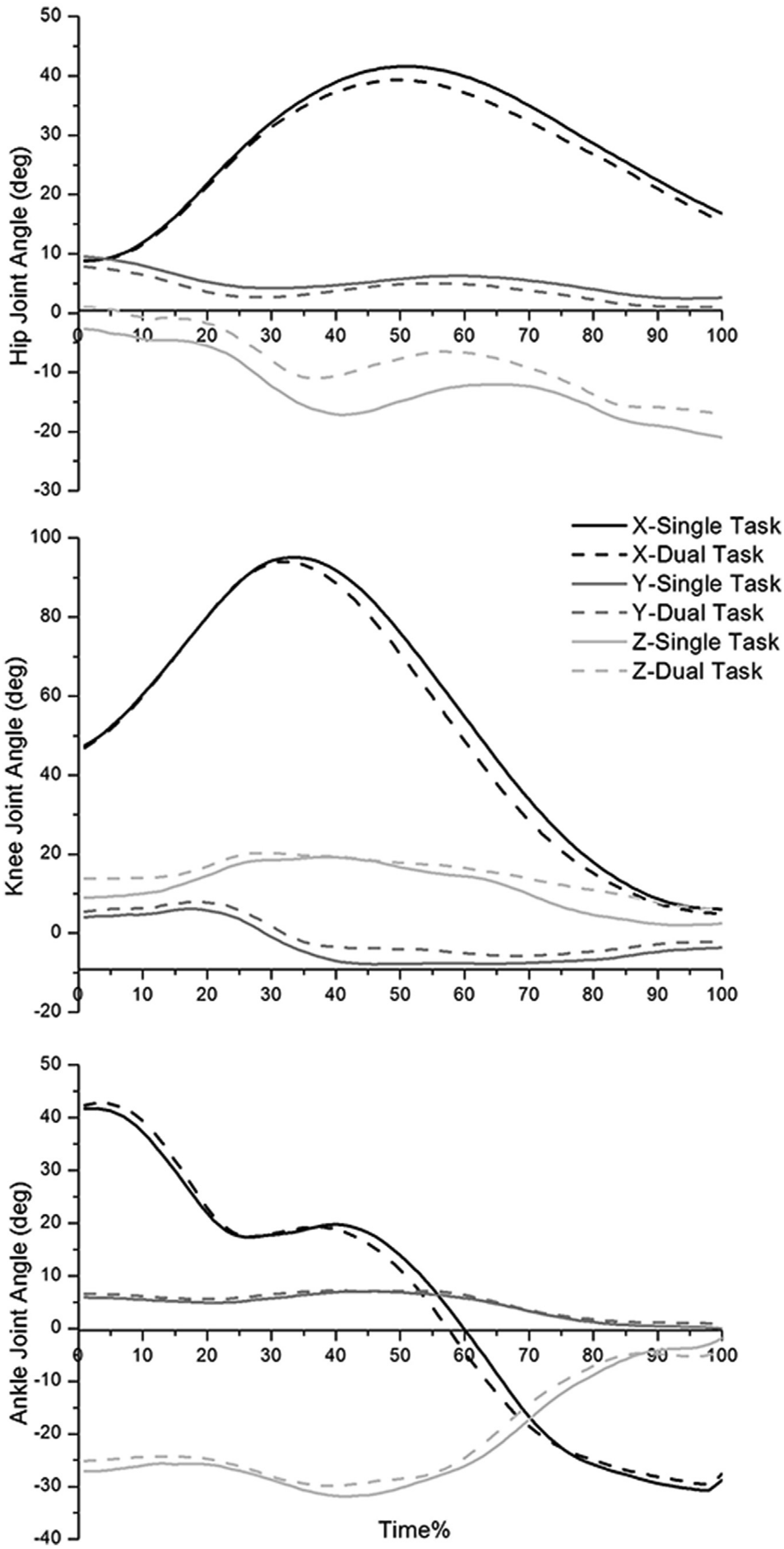

Fig. 4. Swing leg joint angle in a step cycle at single task and dual task conditions. x represents hip joint flexion/extension, knee joint flexion/extension, ankle joint plantar/dorsal flexion. y represents hip joint abduction/abduction, knee joint valgus/varus, ankle joint inversion/eversion. z represents hip joint, knee joint and ankle joint internal/external rotation.

the base of support increases[18]; the projection of the center of mass should stay in the base of support for stability. However, the anterior–posterior movement is limited by the tread of a staircase. Increasing the step width is the only means to increase the base of support. Therefore, healthy older adults adopted a strategy of increasing the lateral base of support to maintain stability. However, the results of this study still showed that the single support time of the healthy older adults did not significantly decrease in the dual-task condition relative to that in the single-task condition during stair descent. Posture sway increases at a single leg stance, especially for older adults with a decline in posture balance.[19] Therefore, the second cognitive task did not disturb the single leg support of the healthy older adults during stair descent. These results, when combined together, suggest that older adults have a slower gait speed and wider support compensation for enhancing body stability in the dual-task condition relative to that in the single-task condition during stair descent.

This result is consistent with those of previous research in different participants and different dual task conditions. Madehkhaksar et al.[14] discovered that the gait speed of younger adults decreases under dual-task conditions relative to that in single-task conditions during stair ascent and descent. Taylor et al.[20] found that step width increases and the single support time of older adults does not decrease under functional and cognitive dual-task conditions relative to the situation in single-task conditions during walking. De Lima et al.[17] revealed that dual-task conditions provide additional stabilization rather than posture perturbation. However, the result of this study is inconsistent with those of several previous studies. For example, Hausdorff et al.[21] revealed that the body stability of older adults might be attenuated under dual-task condition.

The results of this study partially support our second hypothesis that healthy older adults would perform less foot clearance, greater pelvic and thorax movement, and less joint flexion of the swing leg under dual-task conditions than under single-task conditions during stair descent. The results of this study showed that foot clearance significantly decreased among the healthy older adults, which indicates that the slipping risk encountered by healthy old adults increases under dual-task conditions during stair descent because the smaller the foot clearance is, the larger the slipping ratio is.[22] The results of this study also showed that hip flexion at cross significantly decreased, indicating that the older adults stood erect, and lower extremity mobility was disturbed by the second cognitive task. According to parallel information processing theory, the brain's processing speed decreases under dual-task conditions.[23] The second cognitive tasks might occupy the brain sources of the primary task and influence the performance of the primary task. Body control would slacken because the executive function shares a network of brain regions in the frontal and parietal cortex.[24] Combination of these two results indicates that the support and swing leg control of the healthy older adults during stair descent were disturbed by the second cognitive task, and the fall risk was increased. The results of this study still showed that the pelvis rotation range of motion did not significantly increase, which indicated that pelvis movement was limited by the size of the staircase. The results of this study even showed that the thorax rotation range of motion did not significantly increase, but the thorax appears to exhibited a growing trend in rotation and tile, which indicated that upper trunk rotation and inclination were used to compensate for the limitation of pelvis movement, although the statistical power was low. Trunk movement was a common stability control strategy, and the lower extremity was limited by the environment.[25] These two results suggest that healthy older adults tend to use an upper trunk compensation strategy to enhance their body stability under dual-task conditions relative to the situation in single-task conditions during stair descent.

The results of this study are consistent with those of previous research. Vallabhajosula et al.[26] discovered that the kinematic movement of the lower extremity does not change under dual- and single-task conditions during stair ascent. Madehkhaksar et al.[14] and Song et al.[10] reported that body movement was disturbed by the second cognitive task during stair descent due to the increased medial–lateral body center of mass displacement, body inclination angle, and other factors.

A limitation of this study is that only the cognitive task was included. The second cognitive task and second motor task are common in daily activities and may exert different disturbances on the gait and posture of healthy older adults during stair descent due to the different occupations of the brain resources. Future studies should analyze the performance of older adults in the second motor task during stair walking to determine the effect of allocation of attention resources. Another limitation of this study is that kinematic variables were analyzed in a step cycle. More characteristics of gait and body control could be observed in multiple steps. Future studies should increase the step numbers of staircases for stride or multi-step analysis of stair walking.

Conclusion

The following conclusions were obtained from the results. First, the second cognitive task provides additional stabilization and posture perturbation to healthy older female adults during stair descent. Second, healthy older adults apply a gait and trunk compensation strategy to enhance their body stability under dual-task conditions relative to the situation in single-task conditions during stair descent.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jesf.2018.09.001.

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