Published in final edited form as:
Gait Posture. 2009 June ; 29(4): 634–639. doi:10.1016/j.gaitpost.2009.01.006.

Training-related changes in dual-task walking performance of elderly persons with balance impairment: A double-blind, randomized controlled trial

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Abstract

The purpose of this study was to compare the efficiency of three different balance training strategies in an effort to understand the mechanisms underlying training-related changes in dual-task balance performance of older adults with balance impairment. Elderly individuals with balance impairment, age 65 and older, were randomly assigned to one of three individualized training programs: single-task (ST) balance training; dual-task training with fixed-priority (FP) instruction; and dual-task training with variable-priority (VP) instruction. Balance control during gait, under practiced and novel conditions, was assessed by calculating the center of mass and ankle joint center inclination angles in the frontal plane. A smaller angle indicated better balance performance. Other outcomes included gait velocity, stride length, verbal reaction time, and rate of response. All measures were collected at baseline and the end of the 4-week training. Results indicated that all training strategies were equally effective ($P > .05$) at improving balance performance (smaller inclination angle) under single-task contexts. However, the VP training strategy was more effective ($P = .04$) in improving both balance and cognitive performance under dual-task conditions than either the ST or the FP training strategies. Improved dual-task processing skills did not transfer to a novel dual-task condition. Results support Kramer et al.'s proposal that VP training improves both single-task automatization and the development of task-coordination skills.

Keywords

Balance; Gait; Divided attention; Aging; Rehabilitation

1. Introduction

An impaired ability to maintain balance while simultaneously performing cognitive tasks has been associated with adverse outcomes, such as falls [1–4], and physical and cognitive functional decline [5–7] in elderly people. Despite the potential importance of interventions to

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Conflict of interest statement
None.

improve dual-task balance performance [8,9], there have been very few studies [10–12] evaluating the efficacy of strategies to train balance under dual-task conditions. Previous studies have included either a small sample size [11], or have focused on healthy young adults [10] or patients with stroke [12]. None of those studies was directly designed to uncover the mechanisms underlying dual-task balance processing.

It has been suggested that understanding the mechanisms of dual-task processing will lead to the development of an optimal strategy to improve dual-task performance [13,14]. Although the mechanisms underlying changes in dual-task performance in postural control are not known, there is information on dual-task processing using non-balance-related tasks. At least two models have been proposed to account for the training-related changes in dual-task performance [14,15]. The task-automatization model proposes that improved dual-task performance is the result of increased automatization of the individual tasks. This model predicts comparable improvement in dual-task performance with either single-task (ST) or dual-task training. Alternatively, the task-integration model suggests that an efficient integration of the two tasks acquired during dual-task training is crucial for the improvement of dual-task performance. Consequently, improvement in dual-task performance would be observed only following dual-task training, not single-task training.

The ability to modulate attention may also play an important role in the acquisition of dual-task coordination skill. Kramer et al. compared dual-task training under two instructional sets; the variable-priority (VP) group members were required to vary their priorities between the two tasks, whereas the fixed-priority (FP) group members were instructed to equally emphasize both tasks [16]. The two non-postural related tasks trained in their study included a monitoring task in conjunction with an alphabet–arithmetic task. Results showed that the VP group improved (i.e. increased accuracy and decreased response time) significantly more than the FP group and the dual-task processing skills learned during VP training transferred to novel tasks. It is not known, however, whether similar training effects would be observed when training balance under dual-task conditions.

Thus, the purpose of this study was to compare the efficiency of three different training strategies in an effort to understand the mechanisms underlying changes in dual-task balance performance of older adults with balance impairment. Specifically, the effect of training on dual-task balance performance and the generalizability of dual-task processing skills to novel tasks were examined. In accordance with the task-automatization hypothesis, we predicted equivalent training benefits in dual-task balance performance from both single-task and dual-task training groups. Alternatively, based on the task-integration hypothesis, it was expected that there would be improvement in dual-task balance performance only following dual-task training. In addition, it was predicted that dual-task training using VP strategy would be superior to training using FP and ST strategies, and the dual-task processing skills acquired during VP training would generalize to novel dual-task balance conditions.

2. Methods

2.1. Participants

Elderly persons were recruited through flyers in the surrounding communities. Inclusion criteria included age ≥65, able to walk 10 m, no neurological or musculoskeletal diagnosis, met the criteria of balance impairment, and scored >24 on the mini mental state examination [17]. Balance impairment was determined using the berg balance scale (BBS) [18,19], and self-selected gait speed [20,21], previously shown to correlate with balance during stance [19] and gait [22,23]. Persons were eligible for the study if they scored <52 on BBS, and/or walked with a self-selected gait speed of ≤1.1 m/s. Written informed consent, in accordance with the Human

Subjects Compliance Committee of the University of Oregon, was obtained from all participants.

2.2. Interventions

All participants received 45-min individualized training sessions, three times a week for 4 weeks. Participants were randomly assigned to one of three training groups: (1) single-task balance training; (2)dual-task training with fixed-priorityinstructions; and (3) dual-task training with variable-priority instructions. Participants in the ST group received 12 balance training sessions under single-task conditions, using a task-oriented approach. This approach emphasized improving movement strategies within a given environment in order to achieve a desired functional task [24]. Examples of balance tasks included tandem standing, transferring from one chair to another chair, and walking with a reduced base of support.

The participants in the FP group practiced the same set of balance tasks as the ST group, while simultaneously performing cognitive tasks. Examples of cognitive tasks included counting backward, naming objects, and spelling words backward. Individuals in this group were instructed to always pay attention to both balance and cognitive tasks. Lastly, the participants in the VP group participated in the same set of activities as the FP group, but under a different instructional set. During each session, half of the training was done with a focus on postural task performance, and half was done with a focus on cognitive task performance [11].

To examine the effect of single-task automatization, a paradigm using a practiced task (trained in every session) was used. A narrow base walk was used as the practiced task, with no additional task for the single-task training group, and while counting backward by threes for the dual-task training groups. Obstacle crossing in conjunction with the auditory Stroop task was used to test whether the dual-task processing skills generalized to a novel task (never been trained). This study was a double-blind, randomized controlled trial in which both the participants and the persons who administered the tests were blinded from group assignments and from the randomization procedure.

2.3. Procedures

Before and after 12 training sessions, each participant was instructed to walk at their preferred pace 6 m under two single-task (narrow walking, and obstacle crossing) and two dual-task (narrow walking while counting backward by 3 s, and obstacle crossing with an auditory Stroop task) conditions. For the narrow walking task, participants were asked to walk between two strips of tape, normalized to each participant as 50% of their ASIS width. For the obstacle crossing task, individuals were instructed to step over an obstacle (10% body height), which was placed at the 3-m mark.

For the narrow walking while counting backward by threes task, the participants were asked to perform narrow walking while simultaneously counting backward by threes from varying starting numbers. For the obstacle crossing with auditory Stroop task, the words ‘high’and ‘low’ (spoken at a high or a low pitch) were presented continuously while walking over an obstacle. The participants were instructed to report the pitch of the voice while ignoring the meaning of the word. All participants were required to complete five trials for each condition.

An eight-camera motion analysis system (Motion Analysis Corp., Santa Rosa, CA) with a set of 29 reflective markers were used to capture whole-body motion. Three-dimensional marker trajectory data were collected at 60 Hz, and filtered using a fourth-order Butterworth low-pass filter with a cutoff frequency of 8 Hz. Reflective markers were placed bilaterally on bony landmarks of each participant, which has been described in detail elsewhere [25]. The 13-link biomechanical model was used to compute segmental center of mass (COM) locations.

The primary outcome measure was the average frontal plane center of mass position and ankle joint center (AJC) inclination angle. This angle is formed by the intersection of the line connecting the COM and AJC with a verticalline through the AJC, and was computed throughout the single stance phase of gait (Fig. 1). For the obstacle crossing task, the angle was calculated during the crossing stride. The inclination angle was chosen as an outcome measure because research by Lee and Chou [23] and Chen and Chou [26]demonstrated that it was a sensitive measure of balance control during gait, with a smaller angle indicating better balance performance.

The secondary outcomes included gait temporal-distance measurements (e.g., gait speed and stride length normalized to height) for all walking tasks, the number of missteps (stepping onto or outside either strip of tape) for the narrow walking task, the rate of response and the response accuracy for the counting backward by threes task, and the verbal reaction time (VRT) and the congruency effect (VRT difference between the congruent and incongruent conditions) for the auditory Stroop task. In the congruent condition, the meaning and pitch of the word were similar.

2.4. Sample size

The sample size was determined based on our pilot study, using G*Power3 [27]. A priori, repeated-measure ANOVA indicated that a total sample size of 18 was needed to achieve 80% power to detect the interaction effect size of 0.34 at the .05 level of significance. With a potential 20% attrition rate, a total of 24 participants were targeted for this study.

2.5. Analysis

An intention-to-treat analysis was performed using SPSS version 15.0 (SPSS Inc., Chicago, IL). Baseline characteristics were compared among groups using a one-way ANOVA for quantitative variables and the chi-square test for qualitative variables. The intervention effects on all outcome measures, except VRT, were determined using a three-way mixed-effects repeated measures ANOVA with group (ST, FP, VP) as a between-subjects factor and time (pre-training, post-training) and testing condition (single-task, dual-task) as within-subjects factors. The intervention effect on VRT data was performed using a four-way repeated measures ANOVA with group as a between-subjects factor and time, testing condition, and congruency effect (congruent, incongruent) as within-subject factors. Partial Eta squared values were reported as measures of effect size.

3. Results

Fifty older adults were recruited for the study, 17 did not meet the inclusion criteria and 10 declined to participate (Fig. 2). Twenty-three eligible older adults were randomly assigned to one of three training groups; 21 completed the training program. There were no significant group differences in any baseline characteristics ($P > .05$). In addition, no training effect was found for gait temporal-distance measurements in any condition (Table 1).

3.1. Narrow walking and obstacle crossing under single-task conditions

The group × time interaction was not significant for the COM–AJC inclination angle, for either the narrow walking ($P = .25$, effect size = 0.15) or obstacle crossing conditions ($P = .86$, effect size 003D 0.02). However, the main effects of time were significant ($P = .04$, effect size = 0.2 for narrow walking and $P = .03$, effect size = 0.23 for obstacle crossing), indicating that participants in all groups demonstrated a significantly smaller angle after training when performing narrow walking and obstacle crossing without additional cognitive tasks.

3.2. Counting backward by threes task while sitting

There was a significant group × time interaction effect on the rate of response when the participants performed the counting backward by threes task while sitting (*P* = .04, effect size = 0.29). Participants who received dual-task training (regardless of instructional set) demonstrated significant improvement on the cognitive task (i.e. counted faster) after training (FP: *P* = .003, effect size = 0.49, and VP: *P* = .02, effect size = 0.36). However, no significant improvement was found for the ST group (*P* = .72, effect size = 0.01).

3.3. Auditory Stroop task while sitting

There was a significant group × time interaction effect (*P* = .02, effect size = 0.37), indicating that the amount of improvement in VRT was different across training groups regardless of the congruency effect. Follow-up analyses revealed that the participants in the FP and VP groups responded significantly faster after training (*P* = .003, effect size = 0.54, and *P* = .01, effect size = 0.41, respectively). However, there was no significant change after training for the ST group (*P* = .75, effect size = 0.01).

3.4. Narrow walking while counting backward by 3 s (a practiced dual-task condition)

A significant group × time interaction was found for the COM–AJC inclination angle under this condition (*P* = .04, effect size = 0.31) (Table 2). This interaction indicated that, although the angle reduction was significant for all groups after training, it was greater for the VP group than for the ST and FP groups (*P* = .02 and *P* = .03, respectively) (Fig. 3).

Participants in all groups significantly reduced the number of missteps after training (*P* < .001, effect size = 0.60). However, only the VP group significantly counted backward by 3 s faster during narrow walking after training (*P* = .04, effect size = 0.28). The number of errors participants made on the counting backward task was comparable across groups (*P* = .36, effect size = 0.11).

3.5. Obstacle crossing with auditory Stroop task (a novel dual-task condition)

Neither the interaction nor main effects on the COM–AJC inclination angle were significant under the novel dual-task condition (*P* > .05). Similarly, a group × time × congruency interaction for VRT was not significant (*P* = .42, effect size = 0.10). The only significance found for VRT data under this condition was the congruency main effect (*P* < .001, effect size = 0.59), indicating that the VRT was longer in incongruent conditions than in congruent conditions.

4. Discussion

The goal of this study was to compare the effects of three types of training on balance performance in single- and dual- (practiced and novel) task conditions among older adults with impaired balance. Results indicated that type and magnitude of benefits vary by training type. Dual-task training with VP instruction was more effective in improving both balance and cognitive performance under a dual-task condition than either the ST or the FP training strategies.

Participants in all groups demonstrated significant improvement on balance performance under a practiced dual-task cond00ition, with the greatest improvement found in the VP group. The average angle reduction was 1° for the VP group (56% reduction in body sway), compared to 0.4° for the ST and FP groups (30% reduction in body sway). In the Lee and Chou study, a smaller angle indicated better balance, with the angle not affected by the gait speed. Elderly patients with balance disorders demonstrated 1.8° and 1.5° greater angles (or 45% and 37%

larger body sway) than did healthy elderly under single-task level walking and obstacle crossing conditions, respectively [23].

In addition to dual-task *balance* performance, the VP training strategy was also more effective at improving dual-task *cognitive* performance. Although both FP and VP groups demonstrated equivalent training benefits on single-task cognitive performance, only the VP group showed significant improvement in cognitive performance under a dual-task condition. They significantly improved on the counting backward by threes task (i.e. increased rate of responses) during narrow walking after training. Thus, the data from this study supported the findings from Kramer et al. [16] that the VP training strategy offers a greater advantage over ST and FP training strategies on improving dual-task performance.

There was a significant improvement on dual-task balance performance following both single-task and dual-task training. This finding was consistent with the prediction of the task-automatization model. Based on this model, the narrow walking task became automatized after practicing either under the single-task (practicing this task separately) or dual-task conditions (practicing this task together with additional cognitive tasks) [14,15]. As a result, both the single- and dual-task training led to improved balance under dual-task conditions. This finding did not support the task-integration model, which proposed that dual-task training is necessary for efficient integration of the two tasks, and thus a critical factor in improving dual-task performance.

The improvement in dual-task balance performance after single-task balance training could not be accounted for, in its entirety, by automatization of the single task. If task-automatization was the only mechanism underlying the improvement in dual-task balance performance, the magnitude of training benefits should be comparable across training groups. Although participants in all groups spent the same amount of time in training, the actual number of narrow walking trials practiced by the ST group exceeded that of the dual-task training group, because adding a secondary task slowed gait speed resulting in fewer practice trials in the equivalent amount of time. Despite fewer practice trials, the VP training group improved to a greater extent than the ST group. Thus, results suggest that improvement on dual-task performance might be the result of both automatization of an individual task and the development of task-coordination skills. Participants in the VP group may have learned to efficiently coordinate performance between the two tasks (task integration) as they improved performance on each task (task automatization) [16].

To assess the generalizability of dual-task processing skills, the participants were asked to perform a novel dual task before and after training. Unlike Kramer et al. [16] and Silsupadol et al. [11], we did not find that dual-task processing skills acquired during training transferred to a novel dual task. While all groups improved performance on the narrow walking task while counting backward by 3 s, none improved on the novel obstacle crossing with auditory Stroop task. One possible explanation for this lack of transfer was that the walking tasks used for the practiced (narrow walking) and the novel task (obstacle crossing) were quite different. Specifically, only one perturbation/obstacle was used for the obstacle crossing task whereas continuous perturbations were employed for the narrow walking task.

While no changes were observed for gait speed and stride length after training, there was a training effect on the inclination angle. This suggests that even with the same walking pattern (same speed and stride length), the body sway decreased after the training. It might also suggest that the inclination angle is more sensitive to detect the training effect than the gait temporal-distance parameters.

Although this study provided some interesting data regarding the efficacy of dual-task training in balance control, a number of unanswered questions remain. First, the extent to which the participants would benefit from practicing a cognitive task in isolation is not known. Second, further research is needed to evaluate the relative efficacy of different intensities and durations of training. Finally, even though Lee and Chou [23] demonstrated that the inclination angle is sensitive to identify elderly fallers, there are no data in the literature linking these laboratory measures to actual fall risk. In addition, a minimal detectable change (MDC: minimal amount of change that is not due to measurement errors) and a minimal clinically important difference (MCID: the smallest change that is considered to be important to an individual) have not been reported in the literature for this measurement.

5. Conclusions

This is the first study to examine the mechanisms underlying training-related changes in dual-task balance performance of older adults with impaired balance. The results suggested that a VP training strategy was more effective in improving both balance and cognitive performance under a dual-task condition than the ST and FP training strategies. However, the dual-task balance processing skills acquired during training did not generalize to a novel dual-task condition. Finally, the overall data do not completely support either the task-automatization or the task-integration models in isolation. Rather, as suggested by Kramer and colleagues, results indicated that the benefits acquired during VP training were the result of both automatization of the walking task and the development of task-integration skills.

Acknowledgements

This study was funded by a grant from the National Institutes of Health (AG-021598) to M. Woollacott. We thank Cooper Boydston for assistance with data collection. We acknowledge Charlene Halterman, Teresa Hawkes, Chu-jui Chen, and Sujitra Boonyong for their assistance with training sessions.

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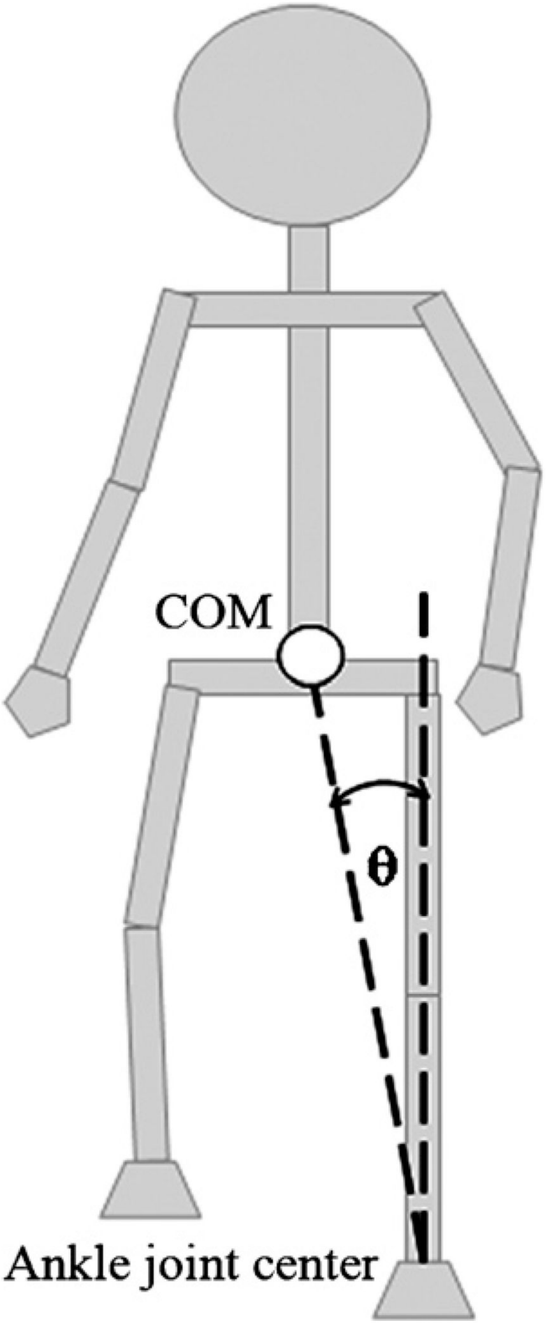

Fig. 1.
An illustration of the center of mass (COM)–ankle joint center inclination angle in the frontal plane.

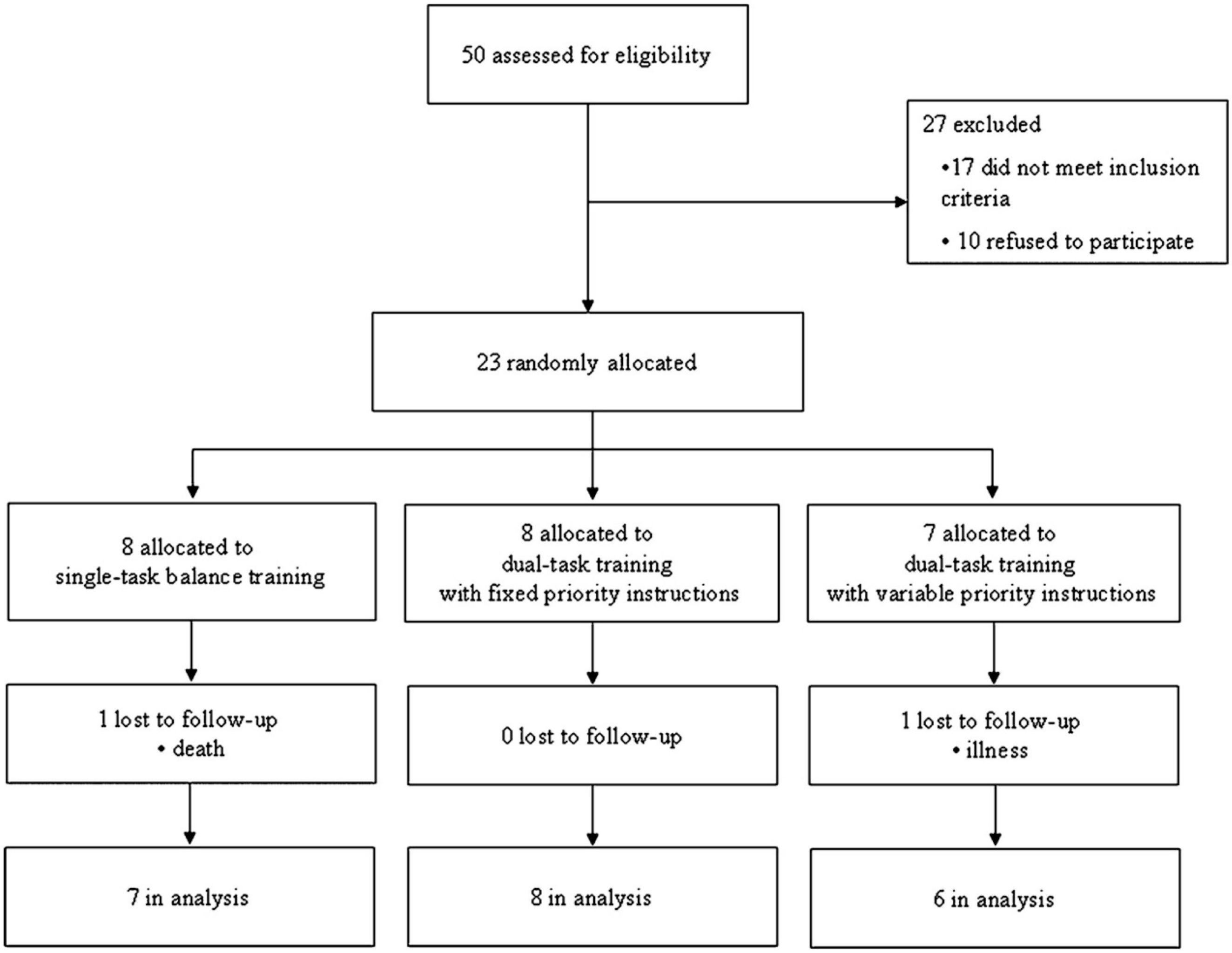

Fig. 2.
Diagram showing the flow of participants through the study.

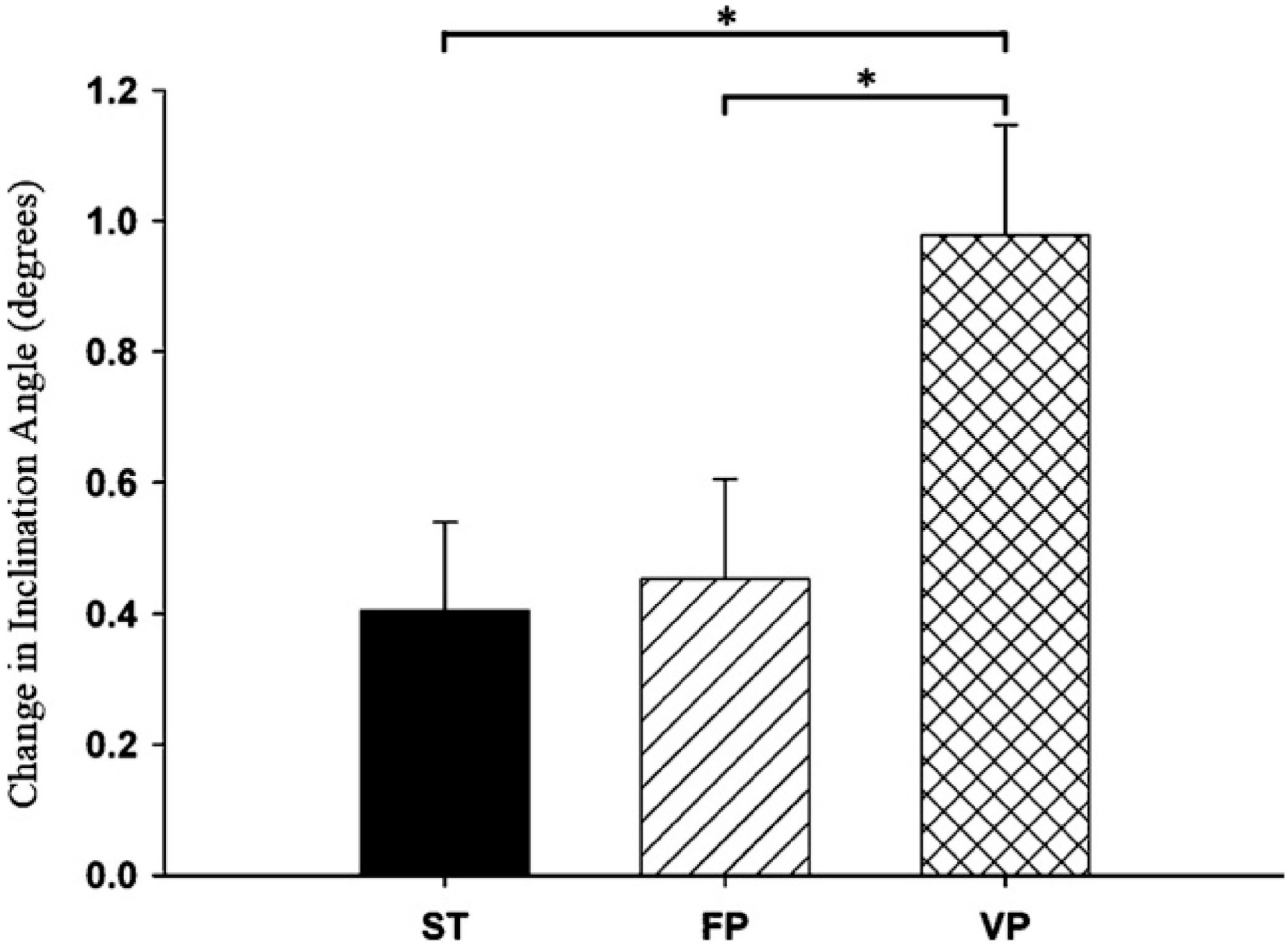

Fig. 3.

Bar graph of change (pre-testing–post-testing) on center of mass–ankle joint center inclination angle under a practiced dual-task condition (narrow walking while counting backward by 3 s). Solid bar represents single-task (ST) balance training group; lined bar represented dual-task training with fixed-priority (FP) instructions; hatched bar represents dual-task training with variable-priority (VP) instructions.

Table 1

Findings on gait temporal-distance measurements at pre-training (pre), and the end of training (post) by intervention group.

Measure	**Single-task (ST) balance training (*N* = 7)**		**Dual-task training: fixed priority (FP) (*N* = 8)**		**Dual-task training: variable priority (VP) (*N* = 6)**		P^a
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	
Gait speed (m/s)							
Narrow walk	0.96 ± 0.19	0.97 ± 0.15	0.80 ± 0.26	0.88 ± 0.19	0.82 ± 0.27	0.77 ± 0.24	.39
Narrow walk + count	0.87 ± 0.17	0.87 ± 0.17	0.69 ± 0.20	0.71 ± 0.13	0.74 ± 0.32	0.63 ± 0.24	.37
Obstacle	0.76 ± 0.16	0.80 ± 0.12	0.75 ± 0.15	0.77 ± 0.16	0.73 ± 0.23	0.76 ± 0.22	.90
Obstacle + Stroop	0.74 ± 0.11	0.78 ± 0.13	0.73 ± 0.19	0.76 ± 0.15	0.72 ± 0.18	0.76 ± 0.18	.97
Normalized stride length							
Narrow walk	0.63 ± 0.09	0.65 ± 0.07	0.58 ± 0.16	0.64 ± 0.10	0.58 ± 0.11	0.58 ± 0.11	.44
Narrow walk + count	0.61 ± 0.10	0.61 ± 0.09	0.56 ± 0.13	0.59 ± 0.07	0.57 ± 0.14	0.56 ± 0.10	.53
Obstacle	0.67 ± 0.10	0.69 ± 0.06	0.67 ± 0.08	0.70 ± 0.07	0.64 ± 0.08	0.65 ± 0.07	.77
zObstacle + Stroop	0.66 ± 0.08	0.67 ± 0.07	0.63 ± 0.12	0.66 ± 0.09	0.63 ± 0.05	0.63 ± 0.06	.33

[a] Group × time interaction effect.

Table 2

Findings on outcome measures at pre-training (pre), and the end of training (post) by intervention group.

Measure	**Single-task (ST) balance training (*N* = 7)**		**Dual-task training: fixed priority (FP) (*N* = 8)**		**Dual-task training: variable priority (VP) (*N* = 6)**		P^a
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	
Angle (°)							
Narrow walk	1.11 ± 0.62	0.99 ± 0.13	1.47 ± 0.65	1.38 ± 4.60	1.66 ± 0.49	1.09 ± 0.56	.25
Narrow walk + count	1.36 ± 0.54	0.95 ± 0.33	1.49 ± 0.62	1.04 ± 0.67	1.74 ± 0.49	0.76 ± 0.38	.04
Obstacle	2.07 ± 0.91	1.74 ± 0.69	1.84 ± 0.66	1.64 ± 0.32	2.56 ± 0.78	2.20 ± 0.66	.86
Obstacle + Stroop	2.12 ± 0.61	1.85 ± 0.51	2.14 ± 0.47	2.09 ± 0.75	2.71 ± 0.50	2.33 ± 0.82	.54
Rate of response							
Sit + count	36.57 ± 9.98	37.43 ± 6.08	33.75 ± 8.84	42.69 ± 7.29	43.00 ± 18.96	51.00 ± 19.54	.04
Narrow walk + count	34.00 ± 10.78	32.57 ± 6.40	30.60 ± 7.43	36.75 ± 6.32	39.67 ± 17.95	51.80 ± 20.55	.04
VRT (ms)							
Sit + Stroop	939.54 ± 49.01	952.05 ± 66.64	1104.18 ± 38.75	974.48 ± 52.68	1021.96 ± 44.74	906.95 ± 60.83	.02
Obstacle + Stroop	936.51 ± 60.66	982.06 ± 56.05	1026.83 ± 47.96	1022.20 ± 44.31	963.53 ± 55.38	938.29 ± 51.16	.21

[a] Group × time interaction effect.