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Motor Dual-Task Effect on Gait and Task of Upper Limbs in Older Adults under Specific Task Prioritization: Pilot Study

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Abstract

Background and Aims—Performing multiple tasks simultaneously may result in reduced performance of subtasks (dual-task cost) particularly among old individuals. Subtask performance during dual-tasking is also known to be affected by task prioritization. However, it has not been well studied how the performance of subtasks is affected during motor dual-task in old adults compared to young when instructed to prioritize one task over the other. This study aims to investigate the dual-task effect on subtasks during motor dual-tasking under specific instruction of task prioritization in old compared to young adults.

Methods—Sixteen independent old and 18 young adults performed two single tasks (usual walking, holding a tray as steady as possible while standing) and two dual-tasks (walking while holding a tray focusing attention on keeping tray as steady as possible-WTAT, and walking while holding tray focusing attention on walking -WTAW). Gait parameters [velocity and variability (coefficient of variation; CV) of stride length] and the pitch (forward-backward) and roll (side-to-side) angles of the tray were measured during the four conditions.

Results—During the WTAT compared to single tasks, both young and old groups showed reduced gait velocity ($\beta = -14.0$ for old, -34.3 for young), increased gait variability ($\beta = 0.19$ for old, 0.51 for young), and increased tray tilt ($\beta = 9.4$ for old, 7.9 for young in pitch; $\beta = 8.8$ for old, 5.9 for young in roll). Higher proportion of older individuals showed higher dual-task effect on tray stability, but lower dual-task effect on gait compared to young individuals. During WTAW, there was no difference in dual-task effect between age groups in tray stability or gait performance.

Conclusions—Compared to young, older adults tend to compromise the task involving upper limbs during motor dual-tasking even when instructed to prioritize this task over gait. These findings may have ramifications on developing training strategies to learn or relearn complex motor activities in seniors.

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Keywords

Aged; Task performance and analysis; Attention

INTRODUCTION

The ability to perform more than one task at a time is essential for older adults to maintain functional independence. Walking in home and local neighborhoods often involves simultaneous activities of upper limbs such as carrying bags. The cost of performing multiple tasks simultaneously may result in reduced performance on individual subtasks, particularly among old individuals (1, 2). Deterioration of gait has been reported when walking while performing concurrent upper limb tasks such as buttoning (3) or carrying an object in older adults (2, 4). However, most studies of motor dual-tasking have focused on effects of dual-task on gait but not on upper limb performances (3-5). More importantly these studies have not investigated the relationship between the dual-tasking effects on both subtasks. For a comprehensive understanding of dual-task effects, it is necessary to interpret the dual-task effects on one subtask in relation to the other subtask.

During dual-tasking, the performance of subtasks is also affected by task prioritization (6-9). Yogev-Seligmann reported reduced gait speed during cognitive and motor dual-tasking when priority was given to the cognitive task, however, the effect was less dramatic in older adults (7). It is also reported that dual-task cost on posture or gait under specific instruction of prioritization differs between young and old adults depending on the nature of the secondary cognitive task (i.e. task complexity) (8, 9). However, it has not been well studied whether dual-task effect on subtasks during motor-motor dual tasking differs between old and young adults under specific task prioritization. Deterioration in subtask performance during cognitive dual-tasks has been related to cognitive function, particularly reduced executive attention (10-12). During motor dual-tasks, the association between the dual-task effect on subtasks and cognitive function has not been studied. Understanding the effect of aging on motor dual-tasking with specific task prioritization and the underlying cognitive processes is essential for developing evidence based methods of training complex motor performance. The objective of this study was to investigate motor dual-task effect on gait and a secondary motor task [walking while holding a tray (13)] in young and old adults under specific task prioritization conditions. The secondary objective of the study was to explore the association between the executive attention and dual-task effect on two subtasks (tray stability, gait).

METHODS

Participants

Older participants were recruited from an independent living facility for seniors located in New Rochelle, NY. Inclusion criteria were age 60 and older, mini-mental status examination (MMSE) score of 27 or higher (14, 15), and the ability to walk independently without assistive devices. Exclusion criteria were presence of neurologic disorders (stroke, cervical myelopathy, and Parkinson's disease diagnosed by the study clinician or by self-report),

visual impairment (acuity less than 20/200 on the Snellen chart), depression score of 10 or higher on 30-item geriatric depression scale score (GDS) (16), or requiring personal help for activities of daily living (ADLs). Young participants were recruited from the community by advertisement. Both groups were frequency matched for years of education (± 2 years) and gender. The study protocol was approved by the local Institutional Review Board of Albert Einstein College of Medicine.

Assessment of medical history and clinical evaluation

Medical history including hypertension, diabetes, angina, myocardial infarction, congestive heart failure, chronic obstructive pulmonary disease, depression, arthritis was used to calculate an illness index score as previously described (17, 18). History of falls during the past one year and fear of falling was recorded. Short physical performance battery (SPPB) (19) and Community Healthy Activities Model Program for Seniors (CHAMPS) Physical Activities questionnaire (20) was administered by a trained study clinician to assess physical function. The Trail Making Test (TMT forms A and B) (21) was used to assess executive attention. Scores of TMT form A were subtracted from those of TMT Test form B (TMT B-A) to provide a measure of “switching cost of attention” (22).

Experiment protocol and equipment

Gait performance was assessed quantitatively in all participants using the GAITRite system (CIR systems Inc, Havertown, PA, USA), a computerized walkway (457×90.2×0.64 cm). We a priori selected two gait parameters; velocity (cm/sec) and stride-to-stride variability (coefficient of variation; CV of stride length) based on associations with adverse outcomes including falls and disability (23-25). The GAITRite system is widely used in clinical and research settings with high validity (26) and test-retest reliability (27).

A wooden tray (50.0×35.0×5.0 cm, 1.30 kg) was used for the upper limb task. Tray stability was measured using a GAITRite inclinometer (6.7×2.2×4.5 cm, 85 g) positioned in the center on the bottom surface of the tray. No objects were placed on top of the tray to avoid creating additional task priorities in this experiment and to minimize anxiety or stress effects. The inclinometer measures a total span of 60 degrees from the horizontal plane (the plane perpendicular to the true vertical) in sagittal (forward-backward tilt; pitch angle) and coronal (side-to-side tilt; roll angle) planes with a sampling rate of 60 Hz. A positive value in the pitch or roll angles indicated that the tray was tipped forward or to the left respectively. Peak to peak pitch and roll angles were utilized as parameters for tray stability. Inclinometer measures were validated by concurrently measuring euler angles during tray tilts using Motion Monitor (Motion Monitor; Innovative Sports Training, Inc, Chicago, IL, USA), an electromagnetic motion analysis system. The measures showed excellent correlations across all four directions (Pearson's $r = 0.92$ for forward, $r = 0.93$ backward, $r = 0.94$ right, and $r = 0.93$ left).

Each individual participated in total of four conditions of the following.

- Two baseline conditions
 - walking at preferred pace

- holding a tray as steady as possible during quiet stance for 10 seconds
- two dual-task conditions
 - walking while holding a tray with instructions to focus attention on keeping the tray as steady as possible (WTAT)
 - walking while holding a tray focusing attention on walking at preferred pace (WTAW)

The two baseline tasks were performed first, followed by the dual-tasks in random order to minimize series effects. Two trials were performed for each of the four experimental conditions. Each participant established the self-balance position of holding the tray with elbows flexed at 90 degrees without leaning the tray against the torso prior to the task. To promote focus of attention to the tray stability, each participant was shown the inclinometer placed under the tray and demonstrated change in tray tilt angles occurring with movements of the tray before performing the experiment. All tests were conducted by a single tester. Recording of steady state gait performance was consistent with previously described guidelines (28). All participants wore comfortable footwear avoiding slippers or high heeled shoes.

Statistical analysis

Gait parameters of usual walking and tray stability of standing position were compared between age groups using student t-test. Linear mixed effects models (29) were used to assess effect of the dual-task on gait parameters and tray stability in young and old groups since this model takes the correlation of data obtained from a same individual into account. Task conditions (single versus dual task) were the factors for repeated measurement and the outcomes were the two gait parameters, and the pitch and roll angles of the tray. Stride length variability was calculated as Coefficient of Variation [$CV = (\text{standard deviation} / \text{mean}) \times 100$]. It was log transformed to ensure normal distribution. All models were adjusted for gender. The interaction between group status (young versus old) and task condition (single versus dual-task) was used to determine whether the effect of dual-tasking on gait performance and tray stability was influenced by age.

The dual-task cost on velocity, pitch and roll angles of tray was calculated as the difference in each of these parameters between the dual (WTAT or WTAW) and single task (usual walking or holding tray in standing). To assess the relationship between dual task cost on gait velocity and tray stability, these dual-task costs were dichotomized at the mean value to define relatively 'high cost' and 'low cost' categories for velocity and tray stability. Fisher's exact test was used to compare the proportions of participants who had high and low costs on the tray stability and gait velocity between the young and old groups.

Univariate linear regression analysis was performed to examine association between dual-task effect and attentional flexibility (TMT B-A). Assumptions of linear regression analysis were satisfied. All analysis was performed with STATA version 10.1 (College Station, TX, USA).

RESULTS

Sixteen older individuals with mean ($\pm$ SD) age of 74.5 ($\pm$ 6.4) years and 18 young individuals with mean age ($\pm$ SD) of 19.2 ($\pm$ 2.7) years participated in the study. Demographic and clinical characteristics are summarized in Table 1. Geriatric depression scale, SPPB, CHAMPS questionnaire score were not relevant for younger population and only described for older participants.

The mean SPPB score among old participants was 10.9 ($\pm$ 1.1) and CHAMPS questionnaire frequency scores of all exercise-related activities was 19.2 ($\pm$ 3.1) indicating relatively high physical function (19, 20). Among the 16 older participants three reported fall during the previous year and 31% reported fear of falling. Gait parameters, the pitch and roll angles of tray in the single and dual-task conditions are presented in Table 2. During the single task of usual walking, gait performance was worse among the old compared to the young group ($p = 0.008$). There were no significant differences between age groups in tray stability during single task ($p = 0.249$ for pitch, $p = 0.082$ for roll angle).

Dual-task effect on gait and tray stability during WTAT and WTAW

Linear mixed effects models revealed significant dual-task effect on gait parameters during WTAT [reduced velocity, β (estimate of change from usual walking condition); -34.3, 95% confidence interval (CI) -40.8 to -27.7, increased stride variability; β of 0.51, 95% CI 0.16 to 0.86) in the young group (in Table 3). Among the old, there was significant reduction in gait velocity (estimate of change in gait velocity, 14.0 cm/sec) but no significant change in stride variability. Dual-task effect on gait performance was more pronounced in the young for velocity ($p < 0.001$) compared to old group but not for stride length variability. In terms of tray stability, significant increase in roll and pitch angles were shown during WTAT compared to single task in both age groups (Table 3). The increase in roll angle during WTAT was significantly more among the old compared to the young ($p = 0.004$ for interaction between age group and task condition). Similarly, the increase in pitch angle was more among the old compared to the young, however, the difference was not significant ($p = 0.156$).

During WTAW, there was no significant dual task effect on gait parameters compared to usual walking in both young and old groups. Dual task effect on tray stability was significant for both age groups, however, there was no interaction between age group and dual task effect on tray stability during WTAW.

Relationship between the dual task cost on gait velocity and tray stability

The dual-task cost on gait velocity and tray pitch angle during WTAT is plotted in figure 1(a). The dual-task cost was dichotomized to relatively high and low cost categories for velocity (x-axis) and pitch angle (y-axis) at the mean value of the entire sample. The largest proportion (56.3%, $n=9$) of old individuals was in the category of relatively low cost (better performance) on velocity and relatively high cost (worse performance) on tray stability compared to 16.7% ($n=3$) of the young ($p=0.03$). On the other hand, the highest proportion (55.5%, $n=10$) of the young was in the category of relatively high cost (worse performance)

on velocity and low cost (better performance) on tray stability compared to 12.5% ($n=2$) of the old ($p = 0.03$). Similar pattern of distribution was also noted for dual-task cost on velocity and the roll angle of the tray.

During WTAW, the proportion of individuals in relatively low cost on velocity and high cost on tray stability in pitch angle was 12.5% ($n=2$) in old and 33.3% ($n=6$) in young. The proportion of those in relatively high cost on velocity and low cost on tray stability was 25% ($n=4$) in old and 33.3% ($n=6$) in young participants. However, the difference in these proportions was not statistically significant ($p = 0.156$ for pitch angle, $p = 0.346$ for roll angle) [Figure 1(b)].

Association between executive attention and dual-task cost

Univariate linear regression analysis of overall sample showed that a superior score (low switching cost of attention) on TMT B-A was associated with lower dual-task cost (better performance) on tray stability (pitch angle) and higher dual-task cost (worse performance) on velocity and during WTAT; β of TMT B-A for cost of pitch angle = 0.020, 95% CI (0.006, 0.035), β of TMT B-A for cost of velocity = -0.108, 95% CI (-0.020, -0.001). In separate analysis for each age group, significant association between superior score on TMT B-A and lower dual-task cost (better performance) on tray stability (pitch angle) in the older group [β of TMT B-A for cost of pitch angle = 0.02, 95% CI (0.001, 0.04)]. However, no association was shown between TMT B-A and dual-task cost on tray stability among the younger group ($p = 0.756$). No significant correlation was noted between TMT B-A score and the cost on roll angle ($p = 0.220$) although the direction of association was similar to the result of pitch angle.

During WTAW, there was no significant association between TMT B-A score and dual-task cost on velocity in both age groups ($p = 0.518$ for young, 0.578 for old). Similarly, no association was shown between TMT B-A score and dual-task cost on tray stability ($p = 0.850$ for young, 0.486 for old in pitch angle; $p = 0.550$ for young, 0.722 for old in roll angle).

DISCUSSION

Tasks that simultaneously involve upper limbs and walking are common in daily life. To our knowledge, this is the first study to report the motor dual-task effect on the performance of task involving upper limbs and gait under specific task prioritization in young and old adults. We also reported the relationship between the dual-task effects of each subtask in both age groups. Our results showed that while focusing attention on tray (WTAT), gait performance and tray stability were compromised during dual-task compared to single tasks. More overall older individuals demonstrated more deterioration in tray stability but are less affected in gait compared to young individuals. Simultaneous performance of a secondary motor task (holding sticks) during walking has shown to reduce gait velocity and increase stride-to-stride variability (2). Performance of the upper limbs during the dual task was not evaluated in this study. Similarly, we found that reduction in gait velocity and increased in stride-to-stride variability during WTAT relative to usual walking in both young and old individuals. However, dual task cost on gait during WTAT was more pronounced in the

younger group. Among older adults, larger reduction of gait velocity during dual-task has been reported to increase risk of falls (30). Gait variability is perceived as a marker reflecting automaticity of the gait (31) and increased variability was also reported to predict falls in older adults (23). However, the reduced gait velocity and increased gait variability among the younger participants during dual-task in our study needs to be interpreted in relationship to the other subtask involving upper limbs. Our results showed that the tray stability during WTAT was superior in younger participants compared to the older participants. We hypothesize that when an individual shifts attention to the upper limb during a complex movement, motor planning and execution resources need to be reallocated to achieve the intended goal of keeping the tray stable (32). This may result in reduced velocity and automaticity in gait pattern (increased variability) within the physiologic range of postural control in younger individuals. During WTAW, gait parameters did not change significantly compared to usual walking in either age group. We hypothesize that during complex motor movement, the “default” priority may be on the postural control of gait when no instructions are provided. Therefore, further shifting of attention to walking may not result in significant changes in gait.

A higher proportion of older individuals in our study had relatively higher dual-task cost (worse) on tray stability and lower dual-task cost on velocity during WTAT compared to the young. These results support the “posture first strategy” concept (33, 34) and the decreased ability to prioritize the upper limb task over walking in older individuals despite explicit instruction to do so. On the other hand, younger individuals showed low dual-task cost on tray stability and high dual-task cost on velocity during WTAT, which supports more efficient motor planning, execution, and resource reallocation in the young compared to the old.

Motivation may also influence the performance on WTAT. We included procedures to motivate participants to prioritize holding the tray as steady as possible. Older individuals might be less motivated to focus attention to the tray compared to young, preferring to focus on walking. Placing a glass of water on the tray may promote increased stability efforts; however, this procedure may trigger performance anxiety as well as introduce additional task priorities.

Task prioritization during walking while carrying a tray may be a cognitively mediated activity as supported by the positive correlation between dual-task cost on tray stability during WTAT and the switching cost of attention (TMT B-A) in old group. However, this association needs to be examined in a larger sample in the future.

Training of ADLs and mobility in rehabilitation settings in older adults often involves complex movements of upper and lower limbs. Clinical staffs need to be aware of the reduced ability of older individuals to prioritize tasks involving upper limbs while walking, and the training process may need to be modified to account for this phenomenon. A recent study involving a cognitive-balance dual-task reported that explicit instruction regarding attentional focus was an important factor for the rate of learning and the retention of the dual-task training effect (35).

The main limitation of this study is the relatively small sample size. We cannot exclude the possibility that difference in dual-task cost on pitch angle between age groups during WTAT may have been underestimated due to lack of power. Although all older participants were independent in ADLs and ambulation with relatively high physical function, they were recruited from an independent living facility and the results of this study may not be generalized to the community residing older population. Strengths of the study include use of validated measures of gait and tray stability, and a single evaluator reducing variability in test procedures. The dual-task paradigm used in this study also enhances ecological validity.

CONCLUSION

This study showed that the effect of task prioritization on upper limb performance and walking during a complex motor task differs between age groups. The limited ability to prioritize upper limb tasks over walking in old compared to young individuals should be considered during training of ADLs or other complex motor performance in rehabilitation settings. Further studies are needed to investigate how best to improve dual-tasking abilities in older adults.

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FIGURE 1. Dual-task cost on gait velocity and pitch angle of tray during WTAT (a) and WTAW (b). Vertical and horizontal reference lines indicate the mean value of dual-task cost on gait velocity and tray pitch angle respectively.

Table 1

Demographic and clinical characteristics of participants.

Characteristics	Old (n=16)	Young (n=18)
Age (years)	74.5±6.4	19.2±2.7
Education (years)	12.6±2.1	13.0±1.7
Female (%)	10 (62.5)	11 (61.1)
Illness summary index (0-8)	1.0±0.6	none
History of falls during past 1 year (%)	3 (18.8)	none
Reporting fear of falling (%)	5 (31.3)	none
Mini-mental status examination (0-30)	28.7±1.5	29.7±0.5
Trail Making Test form A (sec)	55.7±4.5	24.1±2.1
Trail Making Test form B (sec)	162.1±21.7	53.1±5.6
Geriatric depression scale score (0-30)	4.5±3.4	
SPPB score (0-12)	10.9±1.1	
CHAMPS questionnaire score (0-196)*	19.2±3.1	

Abbreviations: SPPB, short physical performance battery. CHAMPS questionnaire, community healthy activities model program for seniors questionnaire
* (Sum of frequency scores/week of all exercise-related activities). Values are presented as mean± standard deviation.

Table 2
Gait parameters, pitch and roll angle of tray during single and dual tasking by age groups

Gait Parameters	Old			Young		
	Normal walking	WTAT	WTAW	Normal walking	WTAT	WTAW
Velocity (cm/s)	123.6±20.6	109.6±20.1	120.7±21.5	142.8±18.7	108.5±22.0	139±18.7
CV of Stride length (%)	2.6±1.2	3.3±1.6	2.4±1.4	1.6±0.8	2.5±1.2	1.7±1.1
Tray tilt (degrees)	Standing	WTAT	WTAW	Standing	WTAT	WTAW
Peak to peak pitch angle	1.1±0.6	10.5±2.2	12.6±3.5	1.2±1.4	9.1±1.6	14.4±3.9
Peak to peak roll angle	0.9±0.8	9.7±3.6	12.2±3.5	0.6±0.6	6.5±1.4	10.3±3.1

Abbreviations: WTAT, walking while holding a tray focusing attention on keeping the tray as steady as possible; WTAW, walking while holding a tray focusing attention on walking at preferred pace; CV, coefficient of variation.

Table 3
Estimates of changes of gait parameters and tray stability during dual task conditions from single task condition.

	<u>Estimates of Change (95% CI) during WTAT</u>		<i>P</i> for interaction [§]	<u>Estimates of Change (95% CI) during WTAW</u>		<i>P</i> for interaction [§]
	Old	Young		Old	Young	
Gait Parameters (reference single task-usual walking)						
Velocity (cm/sec)	-14.0 (-21.0, -7.08) [†]	-34.3 (-40.8, -27.7) [†]	<0.001	-2.9 (-9.8, 4.1)	-3.7 (-10.3, 2.8)	0.862
CV of Stride length [*]	0.19 (-0.18, 0.56)	0.51 (0.16, 0.86) [†]	0.222	-0.01 (-0.37, 0.37)	0.01 (-0.34, 0.36)	0.970
Tray tilt (reference single task-holding tray in standing)						
Pitch angle	9.4 (7.9, 11.0) [†]	7.9 (6.5, 9.4) [†]	0.156	11.5 (10.0, 13.1) [†]	13.2 (11.8, 14.7) [†]	0.119
Roll angle	8.8 (7.3, 10.2) [†]	5.9 (4.5, 7.2) [†]	0.004	11.2 (9.8, 12.7) [†]	9.7 (8.3, 11.1) [†]	0.137

Abbreviation: CV, coefficient of variation.

^{*} log transformed value of CV,

[†] significant change from single condition (*p* value <0.05).

[§] interaction between age-groups × estimated changes on each gait parameters (or pitch and roll angle of tray) during dual-task conditions.