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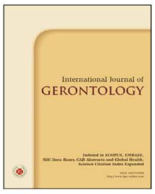

Original Article

Gait Performance and Brain Activities during Cognitive and Motor Dual Task in Prefrail Elderly

Shih-Jung Cheng [a], Wen-Chi Hsu [b], Yea-Ru Yang [c], Yan-Ci Liu [d], Hsiang-Tsen Kuo [e], Ray-Yau Wang [c] *

[a] Department of Neurology, Mackay Memorial Hospital, Taipei, Taiwan, [b] Department of Physical Medicine and Rehabilitation, Kaohsiung Municipal United Hospital, Kaohsiung, Taiwan, [c] Physical Therapy and Assistive Technology, National Yang-Ming University, Taipei, Taiwan, [d] School and Graduate Institute of Physical Therapy, National Taiwan University, Taipei, Taiwan, [e] Department of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital, Taoyuan, Taiwan

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SUMMARY

Background: Dual tasking is a performance when people execute two tasks simultaneously. Both motor and cognitive task during walking are required in daily living. Prefrailty is a common physical de-condition in elder people. This study investigated the gait performance and brain activities during dual task in prefrail elderly.

Methods: This crossed-sectional study included 27 prefrail subjects to perform single walking (SW), cognitive dual task walking (WCT), and motor dual task walking (WMT). The gait parameters of interest included speed, cadence, stride time, stride length, swing cycle, spatial variability, temporal variability, and dual task cost (DTC). Brain activities in prefrontal cortex (PFC), premotor cortex (PMC), and supplementary motor areas (SMAs) were measured by functional near-infrared spectroscopy (fNIRS) during each walking condition. One-way ANOVA with repeated measures with post-hoc test was used for statistical analysis.

Results: The results showed significant decrease in speed, cadence, stride length and swing cycle, and increase in stride time and spatial variability during WCT compared with SW condition. There was also significant decrease in speed, stride length and swing cycle, and increase in stride time during WMT compared with SW condition. The DTC during WCT was more than during WMT. The brain activities did not change significantly during WCT or WMT as compared with SW.

Conclusion: Dual task exerted difficult in prefrail elderly during walking and WCT is even more difficult than WMT. The insignificant change in brain activities during dual task walking may result in negative impact of secondary task on gait in prefrail elderly.

1. Introduction

"Frailty" is a symptom when functions of multiple organs decline to a certain level during aging.[1] Fried's defines five components of physical frailty phenotype which include unintentional weight loss, muscle weakness, exhaustion, slow walking speed, and low physical activity, and presence of one or two components are described as prefrail status.[2] According to a systematic review, the prevalence of prefrailty in community-dwelling older persons ranged from 35%–50%.[3]

Dual tasking is a performance when people do two things simultaneously. Comparing to single task, dual tasking requires more attentional resources and induces higher brain activities.[6] Motor dual task walking refers to performing motor tasks such as carrying a tray while walking, and cognitive dual task walking performing cognitive tasks such as calculation during walking.[4] Both types of dual task walking are functional and essential for daily life. It has been shown that 80% of older adults who stopped walking to answer a simple question would fall in the following six months.[5] Therefore, dual task walking performance may indicate a marker for fall.

Previous studies demonstrated the gait performance deteriorated during dual task walking due to additional demands.[6] In healthy adults, decreased gait speed and cadence and increased stride time and stride time variability under both motor and cognitive dual task walking were documented.[6,7] The decreased cadence and speed were also noted in community-dwelling healthy older adults.[8] It is known that the poor postural control ability contributes to frailty, and thus may have impact on dual task walking for people with prefrailty. However, the dual task walking performance has not yet been established in prefrail elderly.[9] Regarding the brain activity during dual task walking, Mirelman et al.[10] reported that dual task walking is associated with frontal lobe activity in young healthy adults and the activity level changes along with dual task complexity. According to our previous study in healthy young adults, elevated cerebral oxygenation was found in prefrontal cortices (PFC), premotor cortices (PMC), and supplementary motor area (SMA) in parallel with a decline in gait performance under cognitive dual task walking.[6] Nevertheless, SMA and especially PMC were crucial in cognitive and motor dual task walking after stroke.[11] How the brain responds to fulfill the

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* Corresponding author. Physical Therapy and Assistive Technology, National Yang-Ming University, No. 155, Sec. 2, Linong Street, Taipei, 112, Taiwan.
E-mail address: rywang@ym.edu.tw (R.-Y. Wang)

dual task demand has not yet been established understood in elderly with pre-frailty. Therefore, this study aimed to investigate the influence of cognitive and motor dual task on gait performance and brain activity in prefrail elderly.

2. Methods

2.1. Participants

Participants were recruited from the communities and daycare centers for the elderly in Taiwan. The inclusion criteria were: (1) age $\geq$ 65 years old, (2) the presence of one or two characteristics of the five following physical characteristics defined by Fried:[2] unintentional body weight loss, exhaustion, weakness, slow gait speed, and low physical activity level, (3) ability to walk 10 meters independently without an assistive device, (4) ability to use upper extremity to hold a tray for motor dual task assessment, and (5) Mini-Mental State Examination (MMSE) scores $\geq$ 24. The exclusion criteria included any disease that may interfere with participation in the experiment. All participants signed the written consent form. The study protocol was approved by the Institutional Review Board of National Yang-Ming University.

2.2. Study design

This was a cross-sectional study. A total of 27 individuals with prefrailty were included in this study. The characteristic data, such as age, gender, MMSE scores, Falls Efficacy Scale-International (FES-I),[12] and the characteristics of frailty were obtained before the measurement. Participants were asked to walk on a walkway back and forth for 60 seconds under three walking conditions described below.

1. Single walking (SW): Participants were asked to walk at their comfortable speed.
2. Walking while performing cognitive task (WCT): Participants were asked to walk while subtracting three from a three-digit number serially.
3. Walking while performing motor task (WMT): Participants were asked to walk while carrying a tray with a cup of water with both hands.

Each walking condition was repeated two times (a total of six walking blocks) in a random order, and there was a 60-second resting block before each walking condition. Participants were asked to stand quietly in their comfortable way for at least 15 seconds during each resting condition to stabilize the hemodynamic response. Gait performance and brain activation were recorded simultaneously during all the walking conditions, and the average of the two trials was used for data analysis.

2.3. Gait performance

Gait performance was measured using the wearable GaitUP (Physiolg 5, GaitUp system, Lausanne, Switzerland), which has been shown to be the reliable and valid gait measurement.[13] The wearable motion sensors were clipped to the top of the right and left shoe. The gait parameters included: speed (cm/s), cadence (steps/min), stride length (cm), stride time (s), swing cycle (% of the gait cycle), temporal and spatial variability. Temporal variability was calculated as the coefficient of variation (standard deviation / mean × 100%) of the stride time. Spatial variability was calculated as the coefficient of variation (standard deviation / mean × 100%) of the stride length. Dual task cost of walking speed (DTC) was calculated using the following formula: (dual task walking speed – single walking speed) / single walking speed × 100%. The calculation of DTC was to quantify the interference of dual tasking on walking.[6]

2.4. Brain activation

A multichannel wearable functional near-infrared spectroscopy (fNIRS) imaging system (NIRSport, NIRx Medical Technologies LLC, Glen Head, NY, USA) was used to detect the hemodynamics of the bilateral PFC, PMC, SMA, as previously reported.[6,11] The 14 source-detector channels were arranged (Figure 1) to detect changes in local blood oxygenation with a sample rate of 7.81 Hz. The locations of the fNIRS channels have been validated by structural T1-weighted magnetic resonance (MR) image in the previous study.[6] The fNIRS control box and a connected laptop computer for data acquisition were placed in a backpack worn by participants.

The fNIRS signals were bandpass-filtered (low-cut frequency of 0.005 Hz and high-cut frequency of 0.03 Hz) to eliminate the effects of heartbeat, respiration, and low-frequency signal drifts for each wavelength. The HOMER2 fNIRS processing package was used to preprocess the signals, including filtering, artifact removal and conversion for further analysis.[6,11] The index of hemoglobin differential (Hbdiff = HbO – HbR; HbO: oxygenated hemoglobin, HbR: deoxygenated hemoglobin) was used to evaluate the brain activation changes in this study.[6,11] A 60-second block period was used to investigate brain activation in this study.

2.5. Statistics analysis

The one-way repeated measures ANOVA was used to analyze the differences in the gait performance and brain activation between three different walking conditions. Post hoc test with Bonferroni correction was to determine the significant differences in pairwise comparisons (SW and WCT, SW and WMT, WCT and WMT). The statistical power of our data was calculated by G*Power software. Despite the small sample size, the statistical power was 0.99 indicating that the possibility of a Type 2 error was very low. The significance level was set at $p < 0.05$.

3. Results

A total of 27 individuals (22 male, 5 female) with prefrailty participated and received a single session of assessment in this study. The mean age was 78.5 ± 5.4 years old with the mean MMSE score of 28.3 ± 1.5. Among these 27 participants, 22 demonstrated the weak-

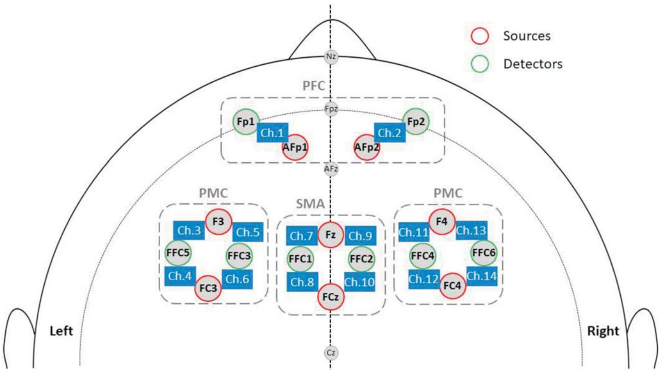

Figure 1. Arrangement of fNIRS optodes – Locations of eight sources and eight detectors based on the international 10–5 system. Abbreviations: PFC, prefrontal cortex; SMA, supplementary area; PMC, premotor cortex.

ness, five demonstrated slow gait speed, three demonstrated unintentional body weight loss, and one demonstrated exhaustion according to Fried's criteria. The characteristic data of all participants are shown in Table 1. There was no unexpected event during all walking tasks, and no adverse effect using the fNIRS imaging system.

3.1. Gait performances

The gait performances under three difference walking conditions are shown in Table 2. Participants walked more slowly, with shorter stride length, and longer stride time during both cognitive and motor dual task walking conditions as compared to single walking (p < 0.05). In addition, adding the cognitive dual task during walking resulted in significantly decreased cadence and swing cycle and increased spatial variability (p < 0.05). As for the comparison between cognitive and motor dual task walking, participants with prefrailty walked slower with less steps and longer stride time and greater spatial and temporal variability during WCT than during WMT. The higher dual task cost was also noted during cognitive dual task walking than during motor dual task walking.

3.2. Brain activation

There was no significant increase in any channel during cognitive and motor dual task as compared with single walking (Table 3, Figure 2(A) and (B)). The pairwise comparisons of hemodynamic responses during different walking conditions are shown in Figure 2(C) and Table 3. The activation of right and left SMA were increased significantly more during cognitive dual task walking as compared with motor dual task walking (p < 0.05).

4. Discussion

This study is the first study to compare the different impacts between cognitive and motor dual task on walking performance and brain activation in prefrail elderly. We found that adding the secondary task, motor or cognitive task, during walking increased the difficulty as demonstrated by decreased the walking speed and stride length and increased stride time. Therefore, dual task activities adversely affect gait in prefrail older people. However, the secondary cognitive task exerted more negative impact on walking than motor dual task in prefrail elderly.

The decrease in walking speed observed in prefrail elderly was also observed in healthy adults during cognitive dual task walking as compared with single walking.[6,14] Previously, we found the gait speed decreased by 8.5% during WCT and by 7.3% during WMT in healthy adults.[6] In present study, the gait speed decreased by 16.8% while performing WCT and by 9.4% while performing WMT in participants with prefrailty. The magnitude of dual task interference seems to be evident especially the WCT. It has also been reported that the walking speed decreased by 13.2% during cognitive dual task as compared with single walking in community-dwelling older adults,[8] which was comparable to our results. The decrease in stride

Table 1
Basic data of participants (n = 27).

Variable	Values
Age (years)	78.5 ± 5.4
Gender (male/female)	5/22
MMSE score (0–30)	28.3 ± 1.5
FES-I score (16–64)	37.1 ± 12.9
Frailty characteristics (number of participants)	
Unintentional body weight loss	3 (11%)
Exhaustion	1 (4%)
Low physical activity level	0 (0%)
Slow gait speed	5 (18%)
Weakness	22 (81%)

Values are mean ± SD or frequency.
Abbreviations: MMSE, mini-mental state examination; FES-I, Fall Efficacy Scale-International.

Table 2
Gait performance under three different walking conditions (n = 27).

	SW	WCT	WMT
Speed (m/s)	0.83 ± 0.18	0.69 ± 0.17*	0.78 ± 0.17*†
Cadence (steps/min)	106.24 ± 2.12	95.61 ± 2.96*	105.44 ± 2.26†
Stride time (s)	1.15 ± 0.13	1.27 ± 0.18*	1.16 ± 0.14*†
Stride length (m)	0.92 ± 0.14	0.82 ± 0.16*	0.87 ± 0.13*
Swing cycle (%)	37.97 ± 2.73	36.46 ± 3.28*	37.21 ± 2.9
Spatial variability (%)	7.4 ± 3.43	9.85 ± 4.69*	7.83 ± 3.75†
Temporal variability (%)	6.28 ± 6.72	9.92 ± 2.64	5.60 ± 4.96†
Dual task cost (%)		-17.36 ± 10.71	-8.27 ± 5.67†

Values are mean ± SD.
Abbreviations: SW, single walking; WCT, walking while performing cognitive task; WMT, walking while performing motor task.
* p < 0.05 as compared with SW; † p < 0.05 as compared with WCT.

Table 3
Brain activation indicated by HbDiff in different channels under three different walking conditions (n = 27).

Brain area	SW	WCT	WMT
PFC of left hemisphere (Ch.1)	29.28 ± 62.65	20.35 ± 42.80	14.45 ± 59.99
PFC of right hemisphere (Ch.2)	12.51 ± 37.19	20.79 ± 46.63	18.67 ± 53.37
PMC of left hemisphere (Ch.3)	9.18 ± 31.88	9.80 ± 39.68	7.14 ± 44.12
PMC of left hemisphere (Ch.4)	7.22 ± 33.77	16.35 ± 33.85	4.58 ± 46.30
PMC of left hemisphere (Ch.5)	9.49 ± 35.67	21.05 ± 36.21	14.49 ± 37.40
PMC of left hemisphere (Ch.6)	7.94 ± 35.08	12.86 ± 46.07	2.80 ± 46.55
PMC of right hemisphere (Ch.11)	6.12 ± 27.87	11.14 ± 32.29	5.17 ± 33.17
PMC of right hemisphere (Ch.12)	8.63 ± 23.43	8.97 ± 30.63	2.05 ± 32.51
PMC of right hemisphere (Ch.13)	7.92 ± 6.20	21.72 ± 7.52	5.40 ± 8.26
PMC of right hemisphere (Ch.14)	9.14 ± 25.25	14.44 ± 26.10	7.33 ± 15.09
SMA of left hemisphere (Ch.7)	15.16 ± 40.46	14.17 ± 40.43	7.31 ± 53.80
SMA of left hemisphere (Ch.8)	12.99 ± 54.90	11.12 ± 57.90	3.06 ± 72.71†
SMA of right hemisphere (Ch.9)	8.07 ± 37.92	19.92 ± 47.99	14.34 ± 41.77
SMA of right hemisphere (Ch.10)	14.14 ± 48.35	22.60 ± 65.44	10.37 ± 56.36†

Values are mean ± SD.
Abbreviations: Hbdiff, index of hemoglobin differential (Hbdiff = HbO – HbR); SW, single walking; WCT, walking while performing cognitive task; WMT, walking while performing motor task; PFC, prefrontal cortex; PMC, premotor cortex; SMA, supplementary area.
† p < 0.05 as compared with WCT.

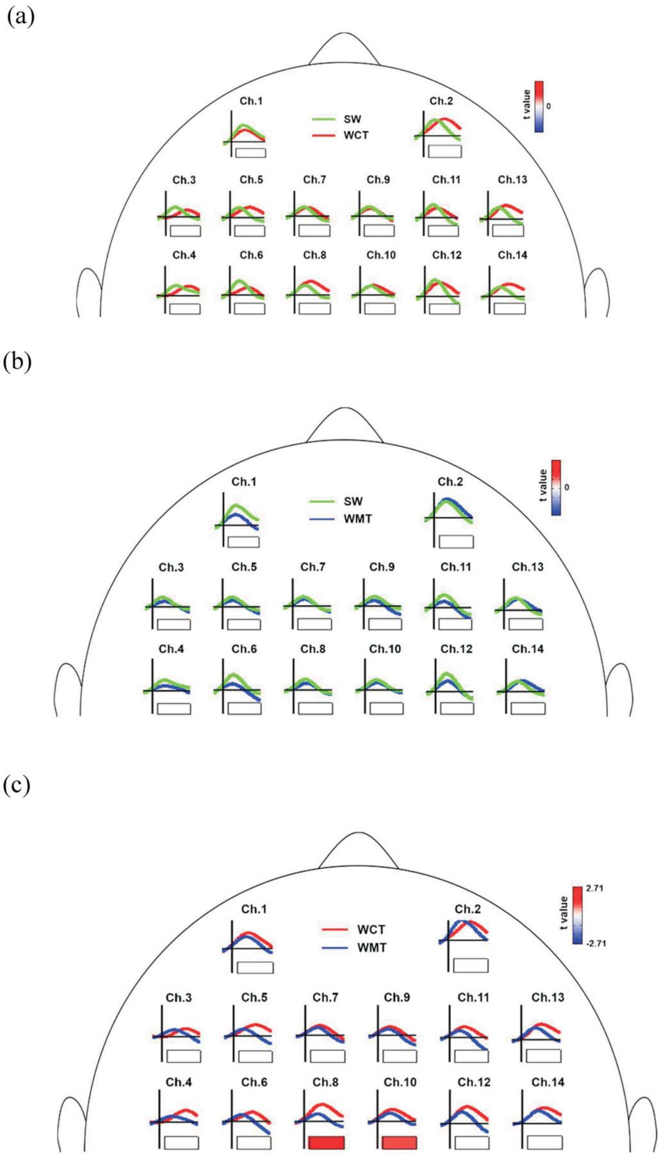

Figure 2. Illustrations of brain activation level. (a) During WCT and during SW, (b) During WMT and during SW, and (c) During WCT and WMT. Abbreviations: WCT, cognitive dual task walking; SW, single walking; WMT, motor dual task walking.

length and swing cycle and increase in stride time may contribute to the decreased speed according to our results. Previous study suggested that dual-task tests might add the value for fall prediction than single-task tests.[15] However, Taylor noted there was no additional benefit to add secondary cognitive task to discriminate the fallers from non-fallers with cognitive impairment.[16] Among these gait parameters measured in present study, the decrease of swing cycle duration during cognitive dual task walking was found to correlate significantly with the FES-I score (Pearson correlation $r = 0.489$, $p = 0.019$). Thus, the more the prefrail elderly concerned about falling, the less swing duration they demonstrated. Such decreased swing duration may be the strategy for balance control when dealing with secondary challenging cognitive task during walking in prefrail elderly. We further noted that the spatial and temporal variability were both higher during cognitive dual task walking than during motor dual task walking. Studies showed that the temporal and spatial variabilities were able to predict fall risk,[17] and the higher variability indicates the less stability during gait.[18] Taking together, dual task has a prominent influence on the gait performance, and the secondary cognitive task exerts even greater impact on prefrail elderly than motor dual task. This important message should be advised for people with prefrailty since most activities of daily living require the simultaneous performance of two or more tasks. Also, as single walking task provides a measure of the motor function, the cognitive dual task walking may provide a possible measure of fall related balance and gait control.

On the other hand, the secondary motor task also exerted impact on walking indicated by decreased gait speed and stride length and increased stride time in prefrail elderly. But such impact was not as much as the cognitive task. The dual task cost was 17.36% for adding cognitive task as compared with 8.27% for the motor task in our prefrail elderly. It is suggested that performing the cognitive task may require greater cognitive and executive functions to result in higher interference on walking than motor task.[9,19] To explain the interference of performance in dual tasking, models and theories have been developed. The results observed in our study may be explained by the cross-talk theory which states it could be easier to perform two tasks concurrently when they involve similar inputs.[20] Therefore, the motor dual task walking was less challenging than the cognitive dual task walking for the prefrail elderly. However, the brain activities indicated by fNIRS did not differ significantly in the prefrontal areas between cognitive dual task walking and motor dual task walking in our prefrail elderly participants. Only the SMA, known as to adapt walking speed and posture,[21] activated more during cognitive dual task walking than motor dual task walking. In normal elderly, there was no difference between the cognitive and motor dual task cost, but the brain activated more in the prefrontal cortex, PMC, and SMA during cognitive dual task walking than during motor dual task walking.[22] The similar brain activation patterns were also observed in healthy adults as the healthy elderly to result in insignificant difference between cognitive and motor dual task gait performance.[6] Therefore, the limited activated areas during cognitive dual task observed in prefrail elderly may magnify the cognitive challenge during walking. The possible reasons for limited activated areas during cognitive dual task walking is not known and need further elucidation.

Atsumori et al.[23] described increased activation of the PFC when walking and balancing a ping pong ball on a small card in healthy young adults. Lu et al.[6] also found the PFC activated more during the cognitive dual task walking in healthy adults as compared with the single walking. However, the aging effect on reducing the bilateral PFC activations was observed during walking while talking[24] and walking while performing subtractions.[25] In line with previous studies on aging effect, our results also found no significant increase in brain activation during cognitive or motor dual task walking as compared with single walking. We speculate that the aged brain may not be able to activate certain brain areas sufficiently to deal with the dual task. The elderly including our prefrail elderly, then walked slowly with increased stride time and decreased stride length for the balance and safety during the dual task walking.

This study compared the gait performance and brain activation during cognitive and motor dual task walking. There are some limitations of this study should be noted. First, the sample size of present study was relatively small and a larger sample size is needed to validate our findings. Second, this study may provide thorough information about dual task effects on frailty if this study included not only the prefrail elderly but also the frail elderly. Third, the performance of cognitive or motor task during walking should also be measured, in addition to walking performance, to provide better understanding of quality of the dual task performance.

In conclusion, this study demonstrated both cognitive and motor task exerted negative impact on walking, and the cognitive task even exerted more impact on walking performance than motor task. The brain activities measured in this study did not differ significantly during both dual task walking as compared with single walking. The insignificant change in brain activities may result in negative impact of secondary task on gait in prefrail elderly.

Acknowledgments

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Conflict of interest

The manuscript has not been submitted elsewhere nor published elsewhere in whole or in part. None of the authors have any financial or non-financial competing interests to declare.

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