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Dual tasking affects lateral trunk control in healthy younger and older adults

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ABSTRACT

Assessing the effects of attention-demanding tasks on trunk movement provides useful insights into postural control while walking in an attention-split situation, such as occurs in daily life. The coefficient of attenuation of acceleration (CoA) at the trunk is a useful gait index to assess whole trunk movements. We investigated the effect of attention-demanding tasks on CoA to assess the role of attention on trunk control during walking. Thirty healthy, community-dwelling older adults (70.1 ± 5.6 years) and 38 younger adults (22.1 ± 3.4 years) participated in this study. Participants walked 20 m at a self-selected speed (slow, normal, fast) and while performing an attention-demanding cognitive task. Trunk acceleration was measured using triaxial accelerometers attached to the lower (L3 spinous process) and upper (C7 spinous process) trunk and used to compute CoA (the reduction in acceleration from the lower to upper trunk). Results showed that an attention-demanding task significantly decreased CoA in the medio-lateral (ML) direction in both age groups ($p < 0.001$), whereas it did not affect CoA in the vertical (VT) and anterior-posterior (AP) directions. Our findings suggest that the priority of whole trunk control in the ML direction may be higher than in other directions and be strongly associated with attention, whereas whole trunk control in the VT and AP directions may be passively regulated and require minimal attentional control.

1. Introduction

Dual-task methods are frequently used to test the relationship between gait and attention[1, 2]. Attention-demanding tasks affect gait speed, step length and width, gait rhythmicity, and trunk movements[2-5]. These dual-task-related gait changes have been reported to be strongly associated with the risk of falling in older adults and people with Parkinson's disease[6, 7]. Among the dual-task-related gait changes, changes in trunk movements are considered more important to postural control while walking because the trunk plays a critical role in providing a stable support platform for the head by modulating the amplitude and structure of gait-related oscillations[8, 9].

Recently, dual-task-related trunk movements have been investigated with miniature sensors such as an accelerometer or gyro sensor[5, 10]. Instability of the trunk during dual-task movements was mainly reported in the medio-lateral (ML) and anterior-posterior (AP) directions at the lower trunk (e.g., L3 spinous process)[5, 10]. Although whole trunk control should be characterized by comparisons between temporal-spatial data of the lower and upper trunks, there are only a few dual-task-related studies in which temporal-spatial data of the lower and upper trunk movements were measured. Whole trunk control can be assessed by the coefficient of attenuation of acceleration (CoA)[11, 12]. CoA represents the ability to attenuate acceleration at the trunk segment. Greater CoA values mean that oscillation generated by gait movements is attenuated efficiently by whole trunk movement, whereas smaller CoA values mean that oscillation generated by gait movements is attenuated less efficiently.

Because most acceleration-based gait indexes, including CoA, are dependent on gait speed, the influence of gait speed should be minimized or controlled when group- or condition-comparisons are made[11, 13]. In our previous study, we reported that CoA in the vertical (VT) and ML directions was reduced by attention-demanding tasks[5]. However, the influence of gait speed was not fully minimized or controlled; thus the effect of attention-demanding tasks on whole trunk control remains unclear. In this study, we first investigated the effect of gait speed on CoA in three self-selected gait speeds (slow, normal, fast) and subsequently investigated the effect of an attention-demanding task on CoA after adjusting for the effect of gait speed. Furthermore, fluctuation and oscillation of the upper trunk were also computed because these gait variables can be associated with whole trunk control[14]. For these purposes, we used the harmonic ratio (HR) as an index of fluctuation and root mean square (RMS) as an index of oscillation[8, 14]. As reported, both parameters are strongly dependent on gait speed[13]. Thus we also investigated the effect of gait speed on these two parameters, and then investigated the effect of attention-demanding tasks on HR and RMS after adjusting for the effect of gait speed.

Age-related differences in trunk movements exist in a dual-task gait[3, 15-18]. Compared with younger adults, older adults exhibit different trunk control in all directions in a dual-task gait[15, 18]. Older adults walking with an additional task had less smooth movements in the AP direction whereas younger adults had less smooth movements in the AP and ML directions[18]. Importantly, older adults exhibited no dual-task related changes in the center of mass displacement in the ML direction but younger adults did[15]. Additionally, head movement is more strictly controlled in the ML direction than the VT and AP directions in younger adults than in older adults during walking[19, 20]. Taken together, these observations indicate that older adults may exhibit different whole trunk control during a dual-task gait compared with younger adults, especially in the ML direction. However, few studies have investigated age-related differences in whole trunk control and trunk movements during a dual-task gait. Thus, the other objective of this study was to investigate age-related differences of whole trunk control between older and younger subjects during a dual-task gait.

2. Methods

2.1 Subjects (Table 1)

Thirty healthy, community-dwelling older adults (17 males and 13 females, age 70.1 ± 5.6 years) and 38 younger adults (19 male and 19 females, age 22.1 ± 3.4 years) were included in this study. Subjects older than 60 years were recruited through a local community center, and subjects younger than 40 years were recruited from a university in Kobe city in Japan. Inclusion criteria for all subjects were the ability to independently perform activities of daily living and absence of self-reported neurological or musculoskeletal conditions that could affect mobility or balance. Exclusion criteria were acute illness or cognitive impairment (frontal assessment battery at bedside score < 13/18)[21]. Current medications were recorded and basic mobility was assessed with the Timed Up & Go test (TUG) in older adults. General cognitive function was assessed with the modified Stroop test in younger and older adults. The study was carried out in accordance with the principles of the Helsinki Declaration. The Research Ethics Committee of the Society of Physical Therapy Science approved the study (Approval No. 20-2), and informed consent was obtained from all subjects prior to participation.

2.2 Apparatus

Three piezo-resistive triaxial accelerometers were used—two for measuring trunk movements and one for detecting initial contact during walking. The accelerometers were defined by a vibration testing system based on the Japanese national standard of the National Metrology Institute of Japan. For trunk acceleration measurements, one accelerometer (MA3-04AC, Microstone Co., Nagano, Japan) was attached over the L3 spinous process (L3) using a Velcro™ belt, and an identical accelerometer was attached over the C7 spinous process (C7) using surgical tape. L3 was selected to represent the lower trunk during walking and C7 to represent the upper geometrical limit of the trunk. Trunk linear accelerations were measured in the VT, AP, and ML directions while subjects walked along a walkway. The third accelerometer (MA3-10AC, Microstone Co.) was attached to the heel using surgical tape to detect the time of initial contact. The acceleration signals from the heel in the VT direction showed the typical sharp peak, indicating the timing of initial contact, which was identified from zero following negative acceleration.

Each accelerometer was connected to a data logger (WP-RF-AC, Microstone Co.) that was fixed to the subject’s waist without restricting movement. Before each measurement, all accelerometers were set on a level surface and were statically calibrated against gravity. All accelerations were sampled at 200 Hz, and all acceleration signals were synchronized. After analog-to-digital conversion, signals were collected in the logger and immediately transferred to a laptop computer (VAIO VGN, Sony Co., Tokyo, Japan) via a Bluetooth personal area network.

2.3 Measurements

Subjects were instructed to walk on a smooth, horizontal, 25-m walkway at self-selected slow, normal, and fast speeds. After the measurements of three gait speed conditions, subjects were instructed to walk while counting down aloud from 100 by 7s (serial 7, dual-task gait). No instructions were given regarding which task to prioritize during the dual-task gait. If subjects did not understand the procedure of the dual-task gait, an examiner demonstrated how to do the dual-task gait until they understood it. The time taken to walk over the central 20 m of the walkway was measured using an electrical stopwatch. Gait speed was calculated by dividing the time taken by 20.

2.4 Signal processing

Signal processing was performed using Matlab Release 2008a (MathWorks, Natick, MA). All acceleration data were low-pass filtered using a dual pass zero lag Butterworth filter with a cut-off frequency set at 20 Hz. All analyses were performed using data from the middle 10 strides of the steady walk of each test. From the 10 stride time data, we first calculated stride time variability (STV), as the percentage standard deviation of the mean, which was used as the index of gait variability. Next, we calculated the RMS acceleration, which provides information on the average magnitude of acceleration at L3 and C7 in each direction. Using the RMS acceleration at L3 and C7, we calculated the CoA for each direction using the following equation. CoA [%] = 100 × (1 – RMS at C7/ RMS at L3)[11]. In addition, we calculated the HR of acceleration signals in three directions at C7[8, 18]. The HR has been used as an index of fluctuation of acceleration patterns. The mathematical derivation of the HR was based on the detailed description provided by Menz et al[8]. Primary outcomes of the study were gait speed, STV, CoA in three directions, and HR and RMS acceleration in three directions at C7.

2.5 Statistical analysis

The student t test was used to identify differences in demographic data between age groups, except the female to male ratio. Pearson's chi square test was used to identify differences in the female to male ratio between age groups. Two-way repeated measures analysis of variance (ANOVA) was used to evaluate the effects of gait speed (slow, normal, fast) and age group (younger or older) on STV, CoA, RMS at C7, and HR at C7. Next, we fit a mixed linear model using the JMP MIXD procedure with each gait parameter as the response variable; age group, walking condition, and age group × walking condition interaction as fixed effects of interest; and a participant random effect to account for the same participants performing under multiple conditions and gait speed as a covariate effect to the models. After significant effects of age group and walking condition were identified, a series of pair-wise comparisons was performed using Bonferroni-adjusted t tests to assess differences between age groups and walking conditions. To ensure the soundness of our statistical approach, we examined the residuals from the mixed models and constructed normal probability plots to determine if they were normally distributed. For all models, the residuals showed approximate normality. A p value < 0.05 was considered statistically significant for the student t tests, Pearson's chi square tests, and two-way repeated measures ANOVA. A p value < 0.0125 was considered statistically significant for Bonferroni-adjusted t tests. All statistical analyses were performed using JMP 7.0J software (SAS Institute Japan, Tokyo, Japan).

3. Results

3.1 Effect of gait speed and age on STV, CoA, RMS at C7, and HR at C7 (Table 2, Figure 1)

Gait speed had a significant effect on STV, on CoA in the VT and AP directions, on RMS at C7 in all directions, and on HR at C7 in the ML and AP directions. Age groups also had a significant effect on STV, on CoA in the VT and ML directions, and on RMS at C7 in the ML and AP directions. Interaction of age groups and gait speed had a significant effect on RMS at C7 in the VT and ML directions.

3.2 Effect of task conditions and age on gait speed, STV, CoA, RMS at C7, and HR at C7 adjusting for gait speed (Table 3, Figure 2)

Task conditions had a significant effect on STV, on CoA in the ML and AP directions, on RMS at C7 in the VT and AP directions, and on HR at C7 in the VT direction. Age groups had a significant effect on CoA in the ML direction, RMS at C7 in the ML and AP directions, and HR at C7 in the ML direction. Interaction of age groups and task conditions had a significant effect on CoA and RMS at C7 in the VT direction.

Younger adults walked with greater STV ($p = 0.006$) and older adults walked more slowly ($p < 0.001$) in the dual-task gait than the single-task gait. Older adults walked more slowly than younger adults in the dual-task gait ($p < 0.001$). Younger and older adults exhibited reduced CoA in the ML direction ($p < 0.001$) in the dual-task gait compared with the single-task gait. Younger adults exhibited reduced RMS at C7 in the VT direction ($p < 0.001$) and increased RMS at C7 in the ML direction ($p < 0.001$) in the dual-task gait compared with the single-task gait. Older adults exhibited greater RMS at C7 in the ML and AP directions in both task conditions compared with younger adults (single-task gait: ML, $p < 0.001$; AP, $p = 0.003$; dual-task gait: ML, $p < 0.001$, AP, $p = 0.008$). Younger adults exhibited reduced HR at C7 in the AP direction in the dual-task gait compared with the single task gait ($p = 0.010$).

4. Discussion

4.1 Effect of gait speed and age on STV, CoA, RMS at C7, and HR at C7

Several studies show significant effects of gait speed on RMS and HR at the head and L3[8, 13]. Our results added to these findings by showing significant effects of gate speed on STV and CoA in the VT and AP directions. On the other hand, CoA in the ML direction and HR at C7 in the VT direction were less affected by gait speed in the current study. The range of gait speed observed in the current study might not be wide enough to compare with other studies (gait speed: 1.0-1.7 [m/s] vs. 0.5-2.1 [m/s])[11]. Taken together, our findings and those from other studies indicate that acceleration-based gait variables may strongly depend on gait speed and may need to be adjusted or controlled for gait speed when group- or condition-comparisons are implemented. Additionally, CoA in the ML direction and HR at C7 in the VT direction may be used for group- or condition-comparisons when the measured gait speed is not widely distributed.

4.2 Effects of dual tasking and age on STV, CoA, RMS at C7, and HR at C7

We showed that an attention-demanding task significantly decreased CoA in the ML direction in both age groups, whereas it did not affect CoA in the VT and AP directions. Our findings suggest that the priority of whole trunk control in the ML direction may be higher than in other directions and be strongly associated with attention. Other studies support our findings. Lateral trunk movements have previously been suggested to be of importance for balance control during standing and walking and to be more strictly controlled compared with the other two directions[19, 20, 22]. Conversely, instability of lateral control was associated with an increased risk of falling in the attention-split condition[23, 24]. Thus, balance control in the ML direction may be more important than in the other two directions for safe walking. It may be necessary to allocate the appropriate attention resource to ML direction control, while whole trunk control in the VT and AP directions may be passively regulated and require minimal attentional control.

Compared with results of CoA in the ML direction, the attention-demanding task significantly increased RMS in the ML direction only in younger adults. It has been reported that both center of mass displacement and step width increase when performing an additional task in younger adults, but center of mass displacement in the ML direction is not affected by an additional cognitive task in older adults[3, 15]. Similar to other studies, our results suggest that younger adults exhibited signs of frontal plane dynamic instability during the dual-task gait, but older adults maintained dynamic stability in the ML direction, in agreement with the reported “posture-first” strategy[25]. On the other hand, age groups and task conditions did not affect HR in the ML direction. The HR has previously been used to assess the smoothness of acceleration signals, with higher HR values representing a smoother walking pattern[18]. Our results are consistent with other studies and indicate that upper trunk movements may be strictly controlled even in a dual-task gait to ensure head stability regardless of age and task conditions, although upper trunk oscillation increased with an attention-demanding task[8.]

Older adults had greater RMS values at C7 in the ML and AP directions compared with younger adults in both task conditions, so their attenuation of acceleration by the trunk may be insufficient and their upper trunk (C7) may be exposed to larger oscillation than younger adults. These results may be due to age-related changes in trunk rigidity[26, 27]. Movements of the pelvis and trunk in the ML and AP directions are reported to be synchronized and controlled to enhance trunk rigidity in older adults compared with younger adults when both groups walk at a similar speed[27]. In the current study, trunk oscillation RMS adjusted statistically with gait speed was comparable between age groups. Thus, increases in trunk rigidity may result in increased upper trunk oscillations in the ML and AP directions in older adults.

One limitation of the current study is that it did not assess the effects of different types of additional tasks on gait[10, 28]. Dual-task-related gait changes have been reported to be dependent on the type of additional task. Our results only show the effects one type of additional task on gait, and further study is needed to assess postural control with different types of additional tasks.

In conclusion, this study provides important information on the role of attention on whole trunk control. Whole trunk control in the ML direction is higher than in the other two directions and is strongly associated with attention. In addition, age-related differences exist in upper trunk movements when walking. Increases in trunk rigidity result in increased upper trunk oscillations in the ML and AP directions in older adults, regardless of the task condition.

5. Conflict of interest statement

The authors have no conflicts of interests to declare.

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Table 1
Subject demographics (n=68)

Characteristics	Older adults (n=30)	Younger adults (n=38)	p value
Age (y)	70.1 ± 5.6	22.1 ± 3.4	**< 0.001**
Sex, Men/Women (n)	17/13	19/19	ns
Height (cm)	158.0 ± 7.5	165.5 ± 9.2	**< 0.001**
Weight (kg)	58.8 ± 9.9	57.2 ± 8.5	ns
Number of medications per day	2.0 ± 2.4	-	-
TUG (s)	8.5 ± 2.0	-	-
FAB	15.4 ± 1.4	-	-
Modified Stroop-congruent test (s)	19.6 ± 4.6	13.1 ± 2.3	**< 0.001**
Modified Stroop-incongruent test (s)	34.7 ± 9.4	15.9 ± 2.2	**< 0.001**
⊿ modified Stroop test (s)	15.2 ± 8.3	2.8 ± 2.5	**< 0.001**

Values are mean ± standard deviation. TUG, Timed Up and Go test; FAB, frontal assessment battery at bedside score; ⊿ modified Stroop test, time difference between the modified Stroop-incongruent test and the modified Stroop-congruent test; ns, not significant.

Table 2
Gait speed, STV, CoA, RMS at C7 and HR at C7 in three self-selected gait speeds in younger and older adults.

	Self-selected gait speed			p value		
	Fast	Normal	Slow	Age	Speed	Age*Speed
Gait speed (m/s)						
Younger adults	1.7 (0.2)	1.3 (0.1)	1.0 (0.1)	ns	**< 0.001**	ns
Older adults	1.7 (0.2)	1.3 (0.2)	1.2 (0.1)			
STV (%)						
Younger adults	1.7 (0.6)	1.5 (0.6)	2.1 (1.0)	**0.011**	**< 0.001**	ns
Older adults	2.0 (0.9)	1.7 (0.6)	2.7 (1.6)			
CoA (%)						
VT						
Younger adults	19.4 (12.2)	14.3 (13.7)	11.8 (13.5)	**0.005**	**< 0.001**	ns
Older adults	28.7 (12.8)	22.2 (10.5)	19.3 (10.8)			
ML						
Younger adults	44.4 (12.5)	42.9 (12.5)	45.8 (11.0)	**0.012**	ns	ns
Older adults	38.1 (12.3)	35.8 (14.2)	37.0 (16.0)			
AP						
Younger adults	36.0 (13.5)	40.0 (12.4)	46.3 (12.4)	ns	**< 0.001**	ns
Older adults	31.2 (18.5)	35.5 (15.0)	38.4 (13.0)			
RMS at C7 (m/s^2)						
VT						
Younger adults	2.9 (0.5)	2.2 (0.4)	1.6 (0.3)	ns	**< 0.001**	**0.001**
Older adults	3.0 (0.4)	2.2 (0.3)	1.9 (0.3)			
ML						
Younger adults	1.3 (0.3)	0.9 (0.2)	0.7 (0.1)	**< 0.001**	**< 0.001**	**0.048**
Older adults	1.6 (0.4)	1.1 (0.2)	0.9 (0.2)			
AP						
Younger adults	1.9 (0.5)	1.3 (0.3)	0.9 (0.3)	**0.003**	**< 0.001**	ns
Older adults	2.2 (0.6)	1.5 (0.4)	1.2 (0.3)			
HR at C7						
VT						
Younger adults	3.6 (0.9)	3.7 (0.7)	3.6 (0.7)	ns	ns	ns
Older adults	3.5 (0.7)	3.5 (0.6)	3.4 (0.8)			
ML						
Younger adults	2.6 (0.8)	2.5 (0.7)	2.4 (0.6)	ns	**0.002**	ns
Older adults	2.8 (0.8)	2.9 (0.8)	2.5 (0.7)			
AP						
Younger adults	3.5 (0.9)	3.4 (0.6)	2.9 (0.6)	ns	**< 0.001**	ns
Older adults	3.6 (0.8)	3.1 (0.9)	2.8 (0.7)			

Values are mean (standard deviation). A p value resulting from the repeated measures two-way ANOVA performed on Gait speed, STV, CoA, RMS at C7 and HR at C7 in three self-selected gait speeds (fast, normal, slow) in two subject groups (younger adults or older adults). STV, stride time variability; CoA, coefficient of attenuation; RMS, root mean square; HR, harmonic ratio; VT, vertical; ML, medio-lateral; AP, anterior–posterior.

Table 3
Gait speed, STV, CoA, RMS at C7 and HR at C7 in single-task (walking alone) and dual-task (walking while counting down aloud from 100 by 7 s) gaits.

		Task condition		ANOVA adjusted for gait speed p value		
		Single-task	Dual-task	Age	Task	Age*task
Gait speed (m/s)						
	Younger adults	1.3 (0.1)	1.3 (0.2)	-	-	-
	Older adults	1.3 (0.2)	1.0 (0.1)	-	-	-
STV (%)						
	Younger adults	1.5 (0.6)	2.2 (1.3)	ns	**< 0.001**	ns
	Older adults	1.7 (0.6)	3.1 (1.6)			
CoA (%)						
VT	Younger adults	14.3 (13.7)	16.1 (12.7)	ns	ns	**0.020**
	Older adults	22.2 (10.5)	16.3 (14.5)			
ML	Younger adults	42.9 (12.5)	35.2 (14.4)	**0.029**	**< 0.001**	ns
	Older adults	35.8 (14.2)	25.7 (16.8)			
AP	Younger adults	40.0 (12.4)	38.2 (14.9)	ns	**0.002**	ns
	Older adults	35.5 (15.0)	37.3 (12.5)			
RMS at C7 (m/s2)						
VT	Younger adults	2.2 (0.4)	2.0 (0.4)	ns	**0.047**	**0.034**
	Older adults	2.2 (0.3)	1.7 (0.3)			
ML	Younger adults	0.9 (0.2)	0.9 (0.2)	**< 0.001**	**< 0.001**	ns
	Older adults	1.1 (0.2)	1.0 (0.2)			
AP	Younger adults	1.3 (0.3)	1.3 (0.4)	**0.002**	ns	ns
	Older adults	1.5 (0.4)	1.1 (0.2)			
HR at C7						
VT	Younger adults	3.7 (0.7)	3.5 (0.7)	ns	**0.024**	ns
	Older adults	3.5 (0.6)	2.9 (0.6)			
ML	Younger adults	2.5 (0.7)	2.5 (0.7)	**0.025**	ns	ns
	Older adults	2.9 (0.8)	2.6 (0.7)			
AP	Younger adults	3.4 (0.6)	3.0 (0.7)	ns	ns	ns
	Older adults	3.1 (0.9)	2.4 (0.6)			

Values are mean (standard deviation). A p value resulting from the repeated measures two-way ANOVA performed on STV, CoA, RMS at C7 and HR at C7 in two subject groups (younger adults or older adults) in two task conditions (single-task gait or dual-task gait) with or without adjusting for gait speed. STV, stride time variability; CoA, coefficient of attenuation; VT, vertical; ML, medio-lateral; AP, anterior–posterior.

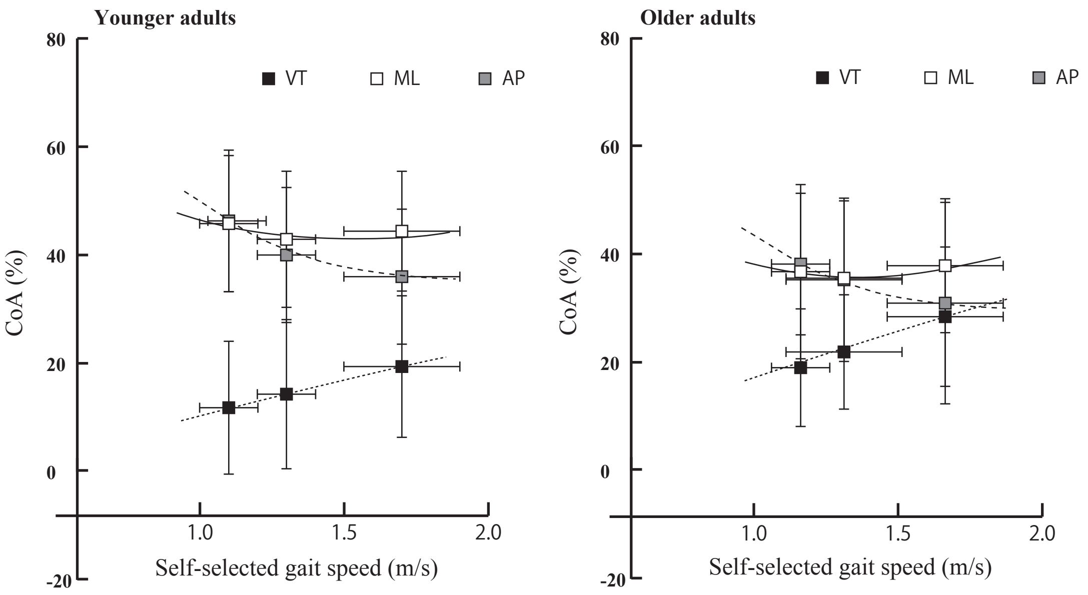

Figure 1

Coefficient of attenuation of acceleration (CoA) at the trunk in three different speed conditions in younger and older adults. VT, vertical; ML, medio-lateral; AP, anterior-posterior

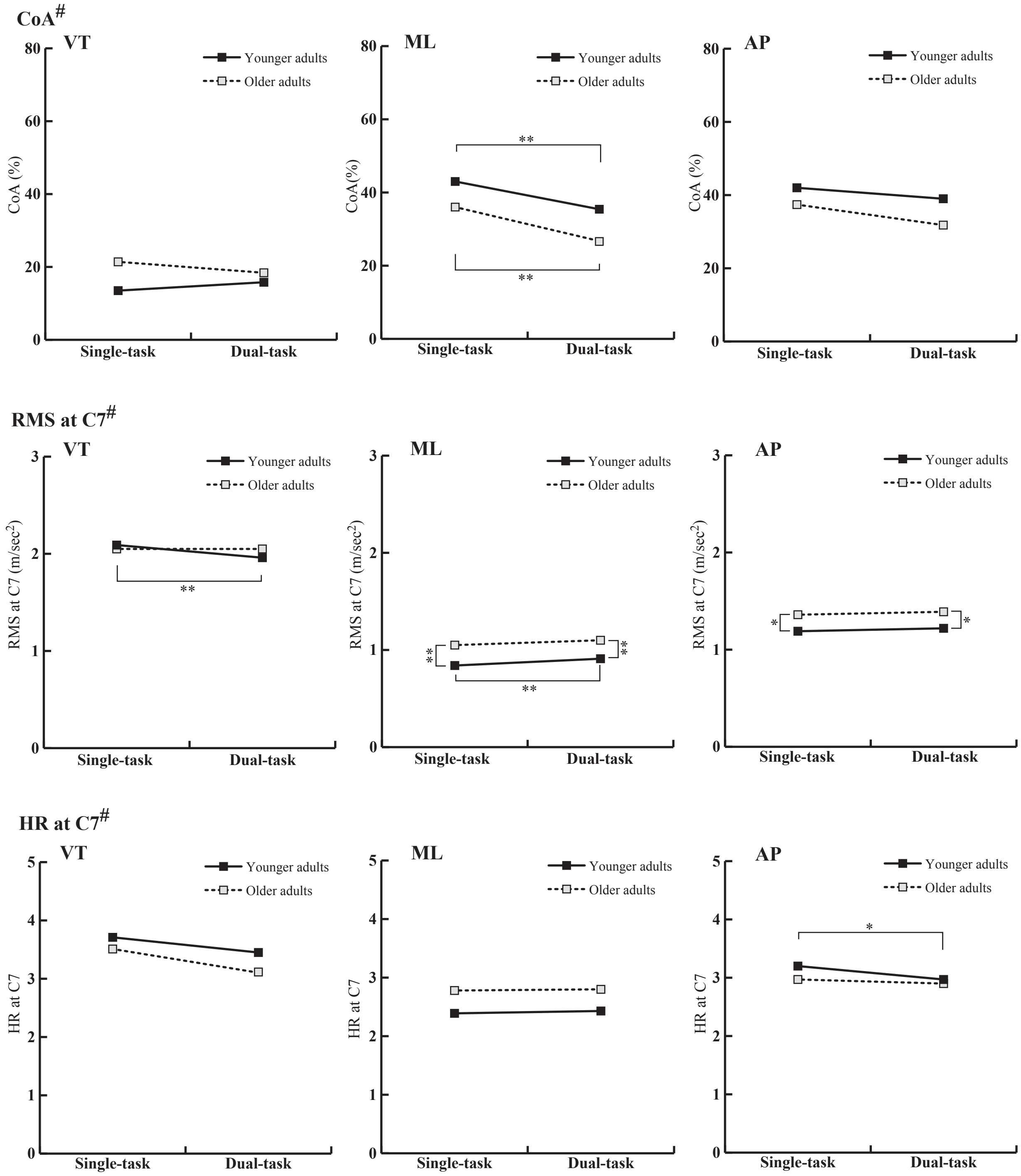

Figure 2

Coefficient of attenuation of acceleration (CoA) at the trunk (top), root mean square (RMS) at C7 (middle), and harmonic ratio (HR) at C7 (bottom) in the single-task and dual-task conditions.

#: All values (CoA, RMS, and HR) were adjusted statistically by gait speed. VT, vertical; ML, medio-lateral; AP, anterior-posterior. Single-task = walking alone; dual-task = walking while counting down aloud from 100 by 7s. *$p < 0.0125$, **$p < 0.001$.