



The effect of text-based math task on dynamic stability control during stair descent (ID: BM-D-20-00079R3)

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ABSTRACT

Stair descent imposes a significant challenge for dynamic stability among young adults. The effect of a concurrent text-based math task on dynamic stability control remains unclear during stair descent when considering the influence of gait velocity. Twenty-six participants performed three successful stair descent trials under TEXTING or NO-TEXTING conditions at their preferred speed. Synchronous kinematics and kinetics were collected by an eight-camera Vicon infrared motion capture system and two force platforms. Repeated measures analysis of covariance and Wilcoxon signed rank test were used to analyze the differences between the two different task conditions with gait velocity as a covariate. The outcomes indicated that under TEXTING condition, sagittal margin of stability increased at right-foot-landing; step cadence, double-support percentage, sagittal and frontal joint moment decreased; and sagittal and frontal joint angles were also modified. It is concluded that concurrent TEXTING impaired sagittal and frontal stability control during stair descent despite slowing down the step cadence. Knee and ankle joint adjustment strategies were mainly adopted in response to stability control in the sagittal plane with the interference of TEXTING, whereas the hip joint adjustment strategy was adopted in the frontal plane. In conclusion, texting behaviors on mobile phones should be minimized during stair descent.

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1. Introduction

Over 1,000,000 stair-related injuries are reported in the US annually and have caused widespread concerns throughout society, especially for young adults in their 20s, who account for approximately 20% (Blazewick et al., 2017). Stair descent is a prevalent but challenging daily activity, given that the requirements for stability (Lee and Chou, 2007; Zachazewski et al., 1993), joint angle (Protopapadaki et al., 2007) and joint moment (Heinlein et al., 2009; Nadeau et al., 2003) in lower extremities are greater in this activity compared with level walking and stair ascent. Stair descent imposes a significant challenge for dynamic stability control among young adults (Hashish et al., 2017).

Engaging in an additional task during stair descent is a routine activity. Evidence suggests that dual-tasks would adversely affect gait patterns (Crowley et al., 2019; Hashish et al., 2017). However, the effect of dual-tasks on dynamic stability remains uncertain. Previous research has demonstrated that certain additional tasks decrease gait stability (Strubhar et al., 2015; Je et al., 2011), whereas another study revealed that additional tasks were associated with slower gait, which increased dynamic stability (Madehkhaksar and Egges, 2016).

A possible reason for the contradictory results is the different variables used to quantify dynamic stability. Center of mass (CoM) displacement (Strubhar et al., 2015), center of pressure (CoP) displacement (Song et al., 2018), and CoM-CoP separation (Zhang et al., 2020) were mainly used in previous studies, but these variables did not consider the influence of velocity on stability. Margin of stability (MoS) can comprehensively quantify the dynamic control of CoM relative to the base of support (BoS) under the influence of gait velocity during locomotion (Hof et al., 2005).

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And MoS has been widely used to assess stability during treadmill walking (Kao et al., 2015) and turning (He et al., 2018). At the instant of foot-landing, dynamic stability is difficult to control given the large forward momentum (Novak et al., 2016). Similarly, dynamic instability typically occurs at the instant of foot-take-off due to the decrease in BoS (Caderby et al., 2014). However, few studies have investigated the instantaneous stability quantified by MoS at these instants during stair descent in a dual-task paradigm.

Different types of dual-tasks could potentially cause inconsistent results for dynamic stability. Capacity-sharing theory posits that a concurrent cognitive task may compete for available attentional resources with a locomotive task (Tombu and Jolicoeur, 2003). Increasing lines of evidence report that a series of gait performance (Smith et al., 2017), kinematics (Qu and Hu, 2014) and joint moments (Vallabhajosula et al., 2015) would be negatively affected by a concurrent cognitive task. Another viewpoint is attentional integration theory with regard to performing a concurrent motor task during locomotion (de Lima et al., 2010). In this case, the concurrent motor task may lead to additional stabilization rather than destabilization. It remains unclear whether attentional competition or integration theory dominates in the cognitive-motor combined task paradigm.

Hence, the text-based math task on mobile phones, simulating real-life situations, was designed to represent the cognitive-motor combined task. Mental math calculations are a purely cognitive task that challenges the cognitive domain, whereas text-based input is a typical motor task. The effect of TEXTING on dynamic stability control should be evident during hazardous locomotion, such as stair descent. Although TEXTING was an additional task explored in Hashish et al.'s study (2017), only gait kinematics were investigated. In addition, given the dual-task paradigm, the influence of gait velocity should be considered in the assessment of dual-task effects (Song et al., 2020), however, it was not considered in Hashish et al.'s study.

The present study attempted to fill in the above research gaps and aimed to examine the effect of texting on dynamic stability and identify the underlying mechanism of stability control during stair descent considering the influence of gait velocity. Furthermore, the 6-riser staircase used in our study enables a more complete exploration of stair gait than the 2-riser obstacle in Hashish's research. Thus, this study might provide new insights into attentional competition or integration theory while performing a cognitive-motor combined task on stairs. We hypothesized that sagittal and frontal dynamic stability would decrease during TEXTING; specifically, sagittal and frontal MoS would increase. We also hypothesized that several compensatory strategies in gait performance, joint angle and joint moment would be adopted in response to the compromised stability during TEXTING; specifically, gait cadence, step length, joint moment and frontal joint angle would decrease, whereas the step width, double-support percentage and sagittal joint angle would increase.

2. Methods

2.1. Participants

Twenty-six young healthy adults (thirteen females, thirteen males, age: 22.0 ± 2.1 years, height: 170.2 ± 10.2 cm, body mass: 62.2 ± 12.1 kg, BMI: 21.3 ± 2.6) were recruited from Shandong Sport University. A prior power analysis (G*Power Version 3.1) indicated that a minimum of 16 participants are needed to obtain an alpha level of 0.05 and beta level of 0.80 based on a previous report (Zhang et al., 2020). The inclusion criteria included possession of a smartphone with a 5.5- to 6.0-in. touchscreen over

3 months and texting with a QWERTY keyboard. The exclusion criteria included diagnosis of any neuromusculoskeletal and cardiovascular diseases that lead to gait and balance dysfunction. All participants voluntarily signed a written informed consent. This study was approved by the internal review board of Shandong Sport University and conducted in accordance with the Declaration of Helsinki.

2.2. Equipment and data collection

A cast iron simulating staircase with six steps and a platform on the top (Fig. 1) was customized for data collection. The step dimensions were 17 cm (riser) $\times$ 29 cm (tread) with approximately 30° inclination in compliance with Chinese housing standards (Song et al., 2018). Two force platforms (Kistler, 9287BA and 9281CA, Switzerland) were embedded in the third and fourth steps of the staircase from the bottom. Forty-one retroreflective markers were affixed on the bone landmarks according to the Vicon plug-in-gait set (Fig. 2). Three-dimensional kinematics were recorded by an eight-camera Vicon infrared motion capture system (Vicon, Oxford Metrics Ltd., UK) at 100 Hz synchronized with force platforms collecting kinetics at 1000 Hz (Song et al., 2018).

2.3. Procedures

All participants were required to wear tight-fitting suits and uniform shoes (Fig. 2). Prior to the formal test, each participant was required to perform a 5-min warm-up (e.g., stretching and walking around the laboratory and the staircase) to familiarize themselves with the laboratory facilities. All participants were tested to have right foot dominance, which was determined as the preferred leg for kicking a soccer ball (Gribble et al., 2007). The start point was 15 cm (Vallabhajosula et al., 2015) from the sixth riser. Upon hearing an instruction "go", participants stepped on the fifth step with their right foot and descended in a step-over-step manner without pausing until the terminal point, which is 1 m from the first riser.

Under NO-TEXTING condition, participants were required to descend stairs at a self-selected velocity with their arms in a natural position. Under TEXTING condition, individuals performed a mental calculation and text-based input with both hands concurrently while descending stairs. A random computer-generated double-digit number ranging from 50 to 99 was sent to WeChat (a widely used communication app in Mainland China) prior to the trial. Then participants iteratively subtracted 7 from the double-digit number and sent every result back to the experimenter until completing the trial. For example, if the participant received the number "67", then he would perform the calculations "67-7 = 60, 60-7 = 53, and 53-7 = 46" and text "60", "53" and "46", respectively, back to the experimenter.

A successful trial required participants to descend stairs from the top to the terminal point without pausing. Any pause or double-stance on the same step or starting trials without receiving the text would be considered a failure. Participants needed to rerun the trial until three successful trials were guaranteed under each condition. A one-minute break was given every two trials.

2.4. Data processing

Three-dimensional data extracted as c3d files were imported into Visual 3D software (C-Motion, Inc) for further processing. Kinematic and kinetic data were filtered by a fourth-order Butterworth low-pass digital filter at cut-off frequencies of 6 Hz (Qu and Hu, 2014) and 10 Hz (Dixon et al., 2014), respectively. Kinematics was used to calculate gait parameters, joint angle, MoS and its

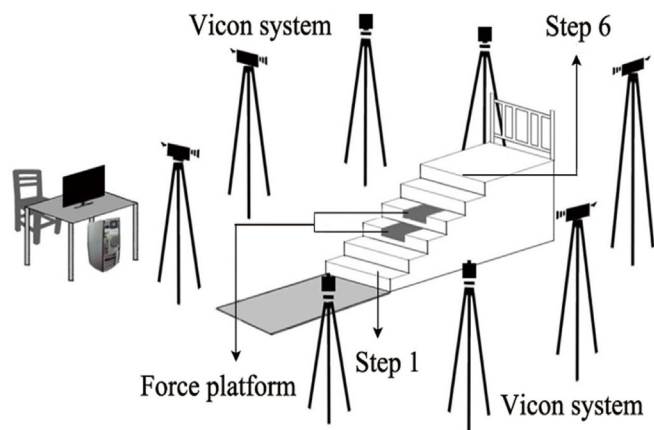


Fig. 1. Staircase and schematic diagram for experimental setup.



Fig. 2. 41 markers on participants with tight-fitting suits and uniform shoes.

components. Kinetics was used to calculate joint moment and determine gait phase.

2.5. Outcome variables

2.5.1. Kinematics and kinetics

The gait kinematics and lower limb kinetics are symmetric between the left foot and right foot (Hamil et al., 1984; Hannah et al., 1984). Thus, the instants of right-foot-landing and left-foot-take-off were selected for analysis in this study. Right-foot-landing and left-foot-take-off were defined as the instants of right foot landing on the third step and left foot take-off the fourth step, respectively.

Gait cycle was defined as the duration from right foot landing on the third step to right foot landing on the first step.

Double-support percentage (%) was calculated as the percentage of double-support phase in the entire gait cycle. Double-support phase was defined as the duration from right foot landing on the third step to left toe-off the fourth step and from left foot landing on the second step to right toe-off the third step.

Step length and step width (m), normalized to body height, were calculated as the anterior–posterior and medial–lateral horizontal distance between right and left heels at right-foot-landing.

Step cadence (steps/min) was calculated as steps per minute.

Joint angle (°) was defined as the Euler angle between adjacent segments in a local coordinate system. The joint angle of lower

extremity in the anatomical position was defined as zero degrees. Positive values denote hip flexion, knee extension, and ankle dorsiflexion in the sagittal plane, whereas positive values represent hip abduction, knee abduction, and ankle adduction in the frontal plane.

Internal joint moment (Nm/kg) in lower extremities was calculated using the inverse kinetic method (Hof, 1992). A positive value represents hip flexion, knee extension, and ankle dorsiflexion moment in the sagittal plane, whereas a positive value represents hip abduction, knee abduction, and ankle adduction moment in the frontal plane. All kinetics were normalized to body mass.

2.5.2. Dynamic stability

Dynamic stability was quantified by MoS using an inverted pendulum model. MoS is presented as the difference between the maximum boundary of BoS (BoS_m) and the position of extrapolated CoM in the sagittal and frontal planes. The equations are as follows (Hof et al., 2005):

$$MoS = BoS_m - CM$$

$$CM = pCoM + \frac{vCoM}{\sqrt{g/l}}$$

where BoS_m is represented by CoP in our study (van Hof et al., 2007). CM refers to the dynamic position of extrapolated CoM. pCoM refers to the anterior–posterior or medial–lateral component of the vertical projection of CoM to the ground. vCoM represents anterior–posterior or medial–lateral velocity of CoM. Here, g denotes the acceleration of gravity with a magnitude of 9.8 m/s^2 , and l denotes the distance between CoM and the center of ankle joint.

A positive value indicates the posterior or lateral velocity of CoM, and CoP is in a posterior or lateral position of the extrapolated CoM. A negative value indicates the anterior or medial velocity of CoM, and CoP is in an anterior or medial position of the extrapolated CoM (Fig. 3). The greater the magnitude of MoS, the larger the distance between CoP and extrapolated CoM, and the worse the stability.

2.6. Statistical analysis

Data from three successful trials were averaged for statistical analysis under each task condition. The normality of all outcome variables was tested using the Shapiro-Wilk test. If the data met the assumptions of normality, repeated measures analysis of

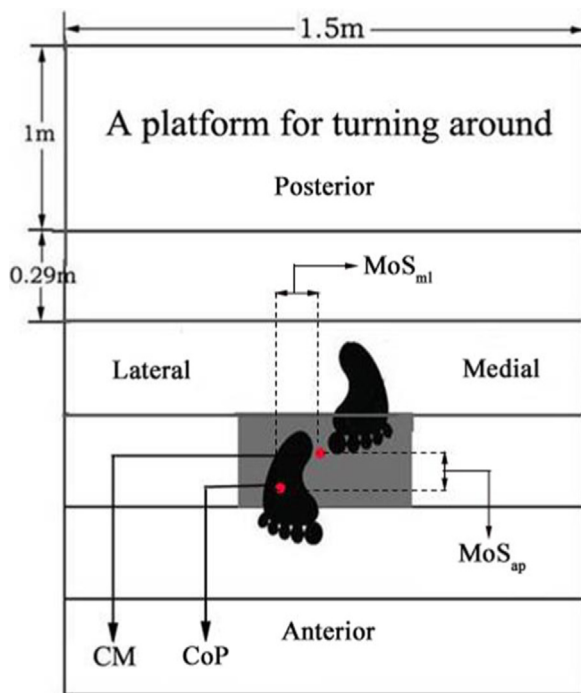


Fig. 3. Schematic diagram for MoS. Note: MoS_{ap} = anterior–posterior MoS; MoS_{ml} = medial–lateral MoS; CM = extrapolated CoM; CoP = center of pressure.

covariance (ANCOVA) was used, with gait velocity as a covariate. Otherwise, the Wilcoxon signed rank test was used. All analyses were conducted in R 3.5.0. Significance was set at $P < 0.05$, and a tendency was defined as $0.05 \leq P \leq 0.09$ (Bosse et al., 2012).

3. Results

The Shapiro–Wilk tests revealed that most of the outcome variables met the assumptions of normality ($P > 0.05$), whereas the variables pCoM_{ml}, sagittal hip joint angle, ankle plantarflexion moment, hip adduction moment at right-foot-landing and sagittal hip joint angle at left-foot-take-off did not. The Wilcoxon signed rank test was used for these variables.

3.1. Gait parameters

Compared with NO-TEXTING, step cadence ($P < 0.001$) and double-support percentage ($P < 0.001$) decreased during TEXTING. No significant difference in step length and step width was detected between the two different conditions (Table 1).

3.2. Sagittal dynamic stability control

At right-foot-landing, decreased anterior velocity of CoM ($P < 0.001$), more posterior position of CoM ($P < 0.001$) and extrapolated CoM ($P < 0.001$), and increased sagittal MoS ($P < 0.001$) were observed during TEXTING compared with NO-TEXTING (Table 2).

Table 1
Gait parameters during NO-TEXTING and TEXTING (mean $\pm$ SD).

	NO-TEXTING	TEXTING	$F_{(1,25)}$	P
Step cadence (steps/min)	116.38 $\pm$ 10.53	75.42 $\pm$ 10.94	202.277	< 0.001
Step length (m)	0.31 $\pm$ 0.01	0.31 $\pm$ 0.02	0.130	0.726
Step width (m)	0.08 $\pm$ 0.04	0.09 $\pm$ 0.05	0.312	0.588
Double-support percentage (%)	28.00 $\pm$ 3.15	21.72 $\pm$ 3.65	141.878	< 0.001

The hip flexion moment increased ($P < 0.001$; Fig. 4A) and the knee flexion moment decreased ($P < 0.001$; Fig. 4B) at right-foot-landing during TEXTING (Table 4). No significant difference in sagittal joint angle and ankle plantarflexion moment was observed between the two tasks (Table 4, Fig. 4C).

Compared with NO-TEXTING, young adults exhibited a decreased sagittal velocity of CoM ($P < 0.001$), a more posterior position of CoM ($P < 0.001$) and extrapolated CoM ($P < 0.001$), and a smaller sagittal MoS ($P < 0.001$) at left-foot-take-off during TEXTING (Table 2). Furthermore, knee flexion angle decreased ($P = 0.013$), whereas the ankle plantarflexion angle increased ($P = 0.024$) at this instant during TEXTING (Table 3). Decreased knee extension moment ($P = 0.005$) and ankle plantarflexion moment ($P = 0.009$) were also observed at this instant during TEXTING (Table 4, Fig. 4).

3.3. Frontal dynamic stability control

No significant difference in medial–lateral MoS was noted between the two different task conditions at right-foot-landing ($P = 0.616$) and left-foot-take-off ($P = 0.141$). Frontal velocity of CoM increased at right-foot-landing ($P < 0.001$) and left-foot-take-off ($P < 0.001$) during TEXTING. Frontal extrapolated CoM tended to be more lateral ($P = 0.059$) at right-foot-landing, and it was more lateral ($P = 0.019$) during TEXTING than that during NO-TEXTING at left-foot-take-off (Table 2).

An increased tendency in hip adduction ($P = 0.053$) and ankle abduction ($P = 0.086$) angle at right-foot-landing was observed during TEXTING (Table 3). Compared with NO-TEXTING, hip abduction angle ($P = 0.009$) and hip abduction moment ($P < 0.001$) decreased at left-foot-take-off during TEXTING (Table 3, Fig. 4).

4. Discussion

The present study is the first to investigate the effect of a text-based math task on dynamic stability control in sagittal and frontal planes during stair descent considering the influence of gait velocity. Our results showed the following: 1) during TEXTING, sagittal MoS increased at right-foot-landing, but no difference in frontal MoS was detected, which partially supported our first hypothesis; 2) step cadence, double-support percentage, joint moment and frontal joint angle decreased, whereas no difference in step length and step width between the two task conditions was detected, which partially supported our second hypothesis.

Sagittal stability was compromised at right-foot-landing during TEXTING, but increased at left-foot-take-off. Je et al. (2011) demonstrated an adverse effect of concurrent cognitive tasks on sagittal stability, whereas another work reported a positive one (Madhkhaksar and Egges, 2016). This discrepancy might be explained by the different variables representing dynamic stability. MoS was used in our study, whereas CoP and CoM displacements were used in their studies. Essentially, the difference depends on whether the influence of gait velocity was considered. The influence of gait velocity should be considered in the assessment of dual-task effects (Song et al., 2020). In addition, CoP and CoM dis-

Table 2MoS and its components in the sagittal and frontal planes at right-foot-landing and left-foot-take-off during NO-TEXTING and TEXTING while descending stairs (mean $\pm$ SD).

	NO-TEXTING	TEXTING	$F_{(1,25)}$	P
Right-foot-landing				
MoS _{ap} (m)	-0.02 ± 0.01	-0.06 ± 0.01	31.390	<0.001
MoS _{ml} (m)	0.08 ± 0.02	0.08 ± 0.02	0.266	0.616
CM _{ap} (m)	0.02 ± 0.02	0.10 ± 0.03	68.239	<0.001
CM _{ml} (m)	0.34 ± 0.02	0.37 ± 0.04	4.430	0.059
vCoM _{ap} (m/s)	-0.61 ± 0.04	-0.46 ± 0.06	105.219	<0.001
vCoM _{ml} (m/s)	0.11 ± 0.05	0.18 ± 0.07	47.454	<0.001
pCoM _{ap} (m)	0.22 ± 0.02	0.25 ± 0.02	24.019	<0.001
pCoM _{ml} (m)	0.31 ± 0.02	0.31 ± 0.04	0.049	0.893*
Left-foot-take-off				
MoS _{ap} (m)	0.12 ± 0.03	0.02 ± 0.02	180.138	<0.001
MoS _{ml} (m)	0.05 ± 0.01	0.04 ± 0.01	2.513	0.141
CM _{ap} (m)	-0.04 ± 0.03	0.07 ± 0.03	98.268	<0.001
CM _{ml} (m)	0.35 ± 0.02	0.38 ± 0.05	7.574	0.019
vCoM _{ap} (m/s)	-0.62 ± 0.07	-0.44 ± 0.09	57.655	<0.001
vCoM _{ml} (m/s)	0.08 ± 0.04	0.17 ± 0.06	86.535	<0.001
pCoM _{ap} (m)	0.15 ± 0.02	0.20 ± 0.02	87.545	<0.001
pCoM _{ml} (m)	0.32 ± 0.02	0.33 ± 0.05	0.209	0.657

MoS_{ap}: anterior–posterior MoS; MoS_{ml}: medial–lateral MoS.CM_{ap}: anterior–posterior position of extrapolated CoM; CM_{ml}: medial–lateral position of extrapolated CoM.vCoM_{ap}: anterior–posterior velocity of CoM; vCoM_{ml}: medial–lateral velocity of CoM.pCoM_{ap}: anterior–posterior position of CoM; pCoM_{ml}: medial–lateral position of CoM.

Wilcoxon signed rank test was labeled with * in the table.

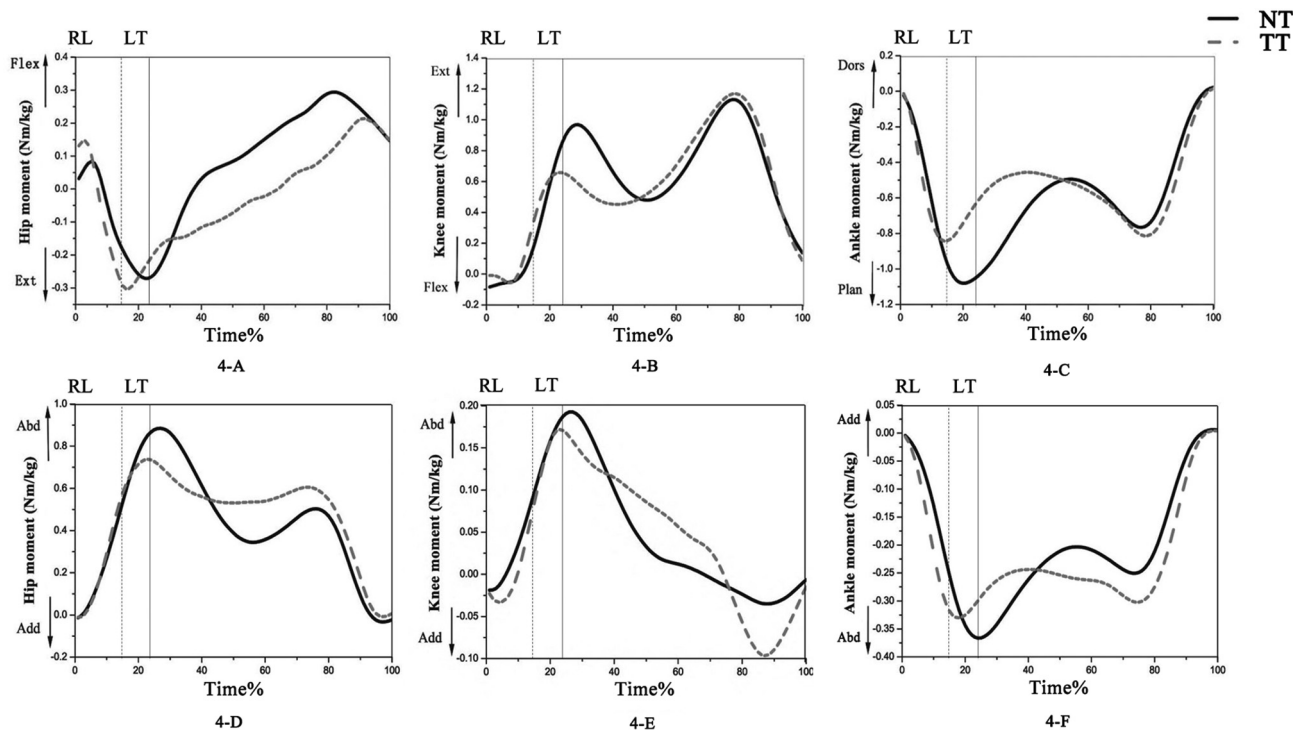


Fig. 4. Variation of mean sagittal and frontal moment during stance phase of right leg under two different task conditions. Figures (A)–(C) denotes the sagittal hip, knee and ankle joint moment, respectively. Figures (D)–(F) denotes the frontal hip, knee and ankle joint moment, respectively. The vertical solid and dash lines denote the instant of left-foot-take-off under NT and TT conditions, respectively. NT = NO-TEXTING task; TT = TEXTING task; RL = right-foot-landing; LT = left-foot-take-off; Flex = Flexion; Ext = Extension; Dors = Dorsiflexion; Plan = Plantarflexion; Abd = Abduction; Add = Adduction.

placements can reflect stability changes only during a certain period. However, falls typically occur at an instant. Thus, MoS is more convincing than other variables to clarify the instantaneous instability under a dual-task condition.

The step length decreases when sagittal instability occurs (Parr et al., 2014). However, no difference in step length was noted between the two conditions, which was consistent with previous work (Hashish et al., 2017). The inherent dimension of stairs might restrict the modification in step length. Consequently, a more pos-

terior extrapolated CoM at right-foot-landing during TEXTING, which is caused by reduced CoM velocity and more posterior CoM, led to a 4-cm increase in sagittal MoS compared with that during NO-TEXTING. Zhang et al. (2020) reported a magnitude of 15 cm in sagittal MoS while retaining stability at left-foot-take-off, and the result was 12 cm at this instant in our study. The magnitude of sagittal MoS between our study and Zhang et al.'s was similar, and a 4-cm difference between NO-TEXTING and TEXTING was approximately 27% and 33% of the absolute MoS in Zhang

Table 3Sagittal and frontal joint angle at right-foot-landing and left-foot-take-off under NO-TEXTING and TEXTING task conditions (mean $\pm$ SD).

	NO-TEXTING	TEXTING	$F_{(1,25)}$	P
Right-foot-landing				
Sagittal hip joint angle (deg)	35.95 $\pm$ 6.18	35.26 $\pm$ 5.17	0.745	0.455*
Sagittal knee joint angle (deg)	-14.87 $\pm$ 4.73	-13.80 $\pm$ 5.10	0.946	0.352
Sagittal ankle joint angle (deg)	-41.82 $\pm$ 5.34	-43.47 $\pm$ 6.62	1.587	0.234
Frontal hip joint angle (deg)	-1.90 $\pm$ 2.86	-3.29 $\pm$ 2.74	4.687	0.053
Frontal knee joint angle (deg)	-1.54 $\pm$ 2.14	-2.17 $\pm$ 2.81	1.527	0.242
Frontal ankle joint angle (deg)	-1.73 $\pm$ 4.22	-3.53 $\pm$ 5.55	3.557	0.086
Left-foot-take-off				
Sagittal hip joint angle (deg)	32.86 $\pm$ 5.88	32.46 $\pm$ 5.30	0.871	0.414*
Sagittal knee joint angle (deg)	-29.40 $\pm$ 6.33	-24.50 $\pm$ 6.95	8.798	0.013
Sagittal ankle joint angle (deg)	-5.59 $\pm$ 6.89	-12.06 $\pm$ 9.03	6.863	0.024
Frontal hip joint angle (deg)	2.74 $\pm$ 2.71	0.60 $\pm$ 2.65	10.187	0.009
Frontal knee joint angle (deg)	0.29 $\pm$ 3.76	0.32 $\pm$ 3.03	0.001	0.972
Frontal ankle joint angle (deg)	-7.26 $\pm$ 6.37	-7.99 $\pm$ 6.89	0.631	0.444

Wilcoxon signed rank test was labeled with * in the table.

Table 4Internal sagittal and frontal joint moments of right lower extremity at right-foot-landing and left-foot-take-off during NO-TEXTING and TEXTING (mean $\pm$ SD).

	NO-TEXTING	TEXTING	$F_{(1,25)}$	P
Right-foot-landing				
Hip flexion moment (Nm/kg)	0.03 $\pm$ 0.06	0.13 $\pm$ 0.05	71.893	<0.001
Knee flexion moment (Nm/kg)	0.08 $\pm$ 0.04	0.01 $\pm$ 0.02	62.967	<0.001
Ankle plantarflexion moment (Nm/kg)	0.02 $\pm$ 0.02	0.02 $\pm$ 0.02	1.302	0.305*
Hip adduction moment (Nm/kg)	0.01 $\pm$ 0.03	0.01 $\pm$ 0.03	0.081	0.839*
Knee adduction moment (Nm/kg)	0.02 $\pm$ 0.02	0.02 $\pm$ 0.01	0.303	0.593
Ankle abduction moment (Nm/kg)	0.01 $\pm$ 0.01	0.01 $\pm$ 0.01	2.164	0.169
Left-foot-take-off				
Hip extension moment (Nm/kg)	0.26 $\pm$ 0.17	0.23 $\pm$ 0.14	0.172	0.687
Knee extension moment (Nm/kg)	0.60 $\pm$ 0.44	0.27 $\pm$ 0.39	12.200	0.005
Ankle plantarflexion moment (Nm/kg)	1.07 $\pm$ 0.22	0.79 $\pm$ 0.23	9.666	0.009
Hip abduction moment (Nm/kg)	0.76 $\pm$ 0.16	0.49 $\pm$ 0.17	25.002	<0.001
Knee abduction moment (Nm/kg)	0.15 $\pm$ 0.12	0.08 $\pm$ 0.09	2.656	0.131
Ankle abduction moment (Nm/kg)	0.33 $\pm$ 0.15	0.28 $\pm$ 0.11	2.974	0.113

Wilcoxon signed rank test was labeled with * in the table.

et al.'s and our study, respectively, at that instant. Similarly, Bosse et al. (2012) reported that a 4.4-cm difference in MoS between the two groups led to an increased risk of falls for older adults during stair descent. In this regard, a 4-cm difference was crucial and could result in increased potential for instability at right-foot-landing. In addition, the instant of right-foot-landing is the commencement of the weight-acceptance phase (McFadyen and Winter, 1988), and knee flexor eccentric contraction was used to control knee extension during this phase. However, concurrent TEXTING decreased the knee flexion moment and weakened knee control. Compared with that during NO-TEXTING, an increased hip flexion moment during TEXTING might prevent the CoM from moving forward at this instant; as such, the extrapolated CoM was more posterior relative to CoP. Therefore, sagittal stability control was impaired by TEXTING at right-foot-landing.

The instant of left-foot-take-off occurs during the weight-acceptance phase for right limbs, and extensor moment is the main supporting moment against gravity during this period (McFadyen and Winter, 1988). However, concurrent TEXTING weakened knee extension and ankle plantarflexion moment output at this instant. Sufficient joint moment output in lower limbs is necessary to maintain dynamic stability during stair descent (Bosse et al., 2012). Thus, sagittal stability control was impaired by TEXTING. At left-foot-take-off, knee flexion angle decreased during TEXTING, which was consistent with the previous study (Qu and Hu, 2014). Increased knee flexion angle was considered as a safe weight-acceptance strategy when stepping toward the next stairstep (Mian et al., 2007). Thus, the decreased knee flexion angle at this instant might indicate an adoption of worse weight-acceptance

strategy during TEXTING. In addition, the greater ankle plantarflexion angle observed at left-foot-take-off during TEXTING might suggest a reduced BoS and the adoption of a forefoot weight-bearing strategy (Mian et al., 2007), which was less safe, as it allows a shorter periods to remain the flat foot position. Consequently, knee and ankle joint adjustment strategies were used in response to sagittal stability control during TEXTING while descending stairs.

TEXTING did not appear to significantly affect the frontal dynamic stability in the current study. These results are inconsistent with a previous study (Zhang et al., 2020), which demonstrated increased frontal stability quantified by MoS while performing a cognitive task during stair descent. A possible explanation for the inconsistent results is that a pure cognitive task in the previous study had less effect on frontal stability compared with TEXTING in the present study. An increase in step width would have a positive impact on frontal stability (McAndrew and Dingwell, 2012). However, no significant difference in step width was detected between the two different task conditions in our study. Hip musculature plays a crucial role in frontal stability control (Winter, 1995) during single-support phase. Reduced hip abduction moment observed at left-foot-take-off might indicate worse frontal control with TEXTING interference. Compared with NO-TEXTING, a tendency of hip adduction angle to increase at right-foot-landing together with decreased hip abduction angle at left-foot-take-off might suggest that a hip joint strategy was adopted to limit the medial-lateral CoM sway during TEXTING. Compared with NO-TEXTING, knee flexion angle decreased at left-foot-take-off during TEXTING, which was related to insuffi-

cient medial-lateral hip control (Mian et al., 2007). Consequently, concurrent TEXTING might weaken medial-lateral motor control, and further affect sagittal stability control during stair descent. The relationship between sagittal and frontal stability control merits further investigation.

Under the influence of additional TEXTING, the step cadence and double-support percentage decreased, which was consistent with a previous study (Simoni et al., 2013). Gait is not an automatic motor activity but demands increased attentional resources during stair descent (Madehkhaksar and Egges, 2016). This phenomenon might help clarify why gait performance was adversely affected by TEXTING according to attentional competition theory. A reduction in double-support percentage indicated dynamic instability (Martini et al., 2011). Thus, a conservative strategy of decreasing step cadence might compensate for the decreased attentional demands during TEXTING (Parr et al., 2014).

In terms of arguments on attentional competition or integration, our results tended to support the former. TEXTING is a type of cognitive-motor combined task. Motor tasks and gait tasks belong to motor-domain tasks, indicating that attentional integration might be achieved as a single unit between them (Yogev-Seligmann et al., 2008). However, achieving attentional integration among gait, cognitive and motor tasks seems difficult, since cognitive tasks employ non-motor domain resources. The ability to retain dynamic stability was thus impaired due to limited attentional resources (Tombu and Jolicoeur, 2003). Consequently, attentional competition theory might better explain the impaired dynamic stability control under the influence of TEXTING during stair descent.

This study has several limitations. First, we only evaluated the effect of cognitive-motor combined task on instantaneous dynamic stability at right-foot-landing and left-foot-take-off. Two typical instants analyzed in this study were based on the symmetry of lower extremity. Further studies might investigate the stability at other instants including left-foot-landing and right-foot-take-off to verify the assumption. Second, investigating the effect of cognitive-motor combined tasks on the stability control of different populations, such as elderly individuals or those who have experienced falls, might be significant because these individuals are more likely to fall. However, ensuring safety during stair descent while performing a texting task is difficult. Third, the absence of electromyography could not reflect the central control mechanism well and might be included in future research. Finally, a significant impact of different step dimensions on dynamic stability control was reported (Novak et al., 2016). Only one type of step dimension (Chinese housing standards) was used in our study. Thus, further dual-task studies involving different step dimensions should be performed to code requirements in other countries.

5. Conclusions

This study concluded that a concurrent text-based math task impaired sagittal and frontal stability control during stair descent despite slowing down the step cadence among young adults. Different adjustment strategies were adopted for sagittal and frontal stability control during TEXTING. Knee and ankle joint strategies were mainly used in the sagittal plane, whereas the hip joint strategy was used in the frontal plane. Our findings suggest that individuals should avoid texting and the associated consequences for dynamic stability during stair descent. Consequently, one possible explanation is that attentional competition theory dominates in dynamic stability control during stair descent while performing a concurrent cognitive-motor combined task.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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