The Effect Of Visual Dual-Tasking Interference On Walking In Healthy Young Adults.

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ABSTRACT

Background

Visual dual-task skills are essential for stable ambulation in everyday life such as walking while reading text. Gait analysis in a virtual environment can provide insight into altered walking performance while visual dual-tasking.

Research question

How visual dual-tasking including cognitive load of reading text and altered optical flow influences walking speed and stability in healthy adults? Also, is there a relationship between the mediolateral centre of mass(CoM) displacement and mediolateral trunk movement?

Methods

Nineteen able-bodied young adults performed self-selected walking on a treadmill in a virtual environment under the following three conditions; single-task walking, walking while viewing scrolling lines, and walking while reading text scrolling on the screen. Three-dimensional motion analysis was used to measure the effect of dual-tasking on gait velocity, step length, mediolateral CoM displacement, and mediolateral thorax inclination.

Results

The effect of visual dual-tasking showed significantly increased walking speed and longer step length compared to single-tasking. The cognitive load of reading text while walking had a significant impact on reduced step length variability and greater mediolateral CoM displacement. This was related to the mediolateral thorax inclination.

Significance

A visual dual-task influences gait through altered optical flow and a cognitive load effect. Altered optical flow increased walking speed whilst the visual attention to read text affected foot placement and upright trunk posture, together with greater mediolateral CoM displacement. Thus, dual-tasking of reading text in a virtual environment substantially affected walking stability in healthy young people. This paradigm is therefore useful for assessment of walking stability in daily life and in the clinical setting.

Keywords: Visual Dual-task; Virtual reality; Gait stability; Center of mass; Trunk movement

1. Introduction

Dual-tasks while using concurrent visual input play an important role in the safety of locomotion in everyday life[1]. The paradigm of dual-tasking is defined as performing two tasks simultaneously such as motor and cognitive tasks[2]. Gait movement control is normally suggested to be automatic[3] whereas dual-tasking requires attention to be divided between motor and cognitive components[4]. A number of studies have suggested the impact of dual-tasking on overground walking such as decreased walking speed, step length[5], and increased variability[6] in healthy adults. More recent research has highlighted the need to investigate visual dual-tasking by mobile phone use during walking[7]. Key issues reported were unstable walking and distracted visual attention to road navigation.

Impaired walking performance as observed in individuals with neurological disease may be more affected by a simultaneous cognitive task[8] due to the reliance on visual input to compensate for unstable posture[9]. Generally, visual input during walking provides information regarding the estimation of foot placement[10] and helps to regulate head and trunk movement providing a reference frame in the central vertical axis[11]. Visual dual-tasking of reading text may interfere with the regulation of head and trunk movements that could affect stable posture. Individuals with neurological disease may face difficulties performing those functions for stable walking while visual dual-tasking[12], leading to a risk of falling[3]. To date, the standard assessment for the influence of visual dual-tasking on gait stability has not been sufficiently explored and validated in the clinical setting. Thus, the use of virtual reality(VR) can provide a controllable and safe environment to assess gait stability.

Gait stability is defined as maintaining the position of the body's centre of mass(CoM) within the supporting surface without falling[11]. We defined gait stability as the ability to maintain mediolateral(ML) CoM displacement within a limited, dynamic trajectory whilst maintaining upright posture, so increasing ML COM reflects less stable gait while dual-tasking[13,14,15]. Previous studies investigating the effect of dual-task costs on the ML CoM displacement[13] and the ML trunk displacement[14] during walking showed significant increases in healthy adults. However, other studies contradicted these results depending on the task[15] or the prioritisation between motor and cognitive task[8]. Despite these biomechanical assessments in dual-task interference, it is unclear how disturbed visual input influences gait. Thus, research to explore visual dual-task interference needs to provide normative gait parameters. The assessment in able-bodied adults helps to give insight into walking stability while visual dual-tasking and to develop a clinical assessment tool.

Furthermore, considering the prevention of falling, it is essential to maintain stable trunk posture. Biomechanically, only nine degrees of trunk leaning can cause the CoM displacement outside of the supporting surface[16] as approximately 50% of body weight is accounted for within body posture[17]. The trunk movement has an essential role providing a reference for controlling posture during walking[18]. Therefore, theoretically the ML trunk displacement can have a significant impact on the displacement of the ML CoM. Since the CoM is an invisible parameter it is difficult for clinicians to evaluate it. However, trunk movement can be observed. Therefore, by referring to trunk displacement during walking in patients with neurological diseases this could serve as an indicator of gait stability.

A feature of the VR environment, unlike normal laboratory settings, is that it provides a wide range of visual cognitive tasks including optical flow and conflicting visual information to assess locomotor behaviour[19]. The optical flow refers to the visual perception of self-motion between an observer and the scene[20]. During walking, an observer receives a typical pattern of moving light that provides information regarding walking speed and the direction through the environment[21]. The effect of altered optical flow in a VR environment showed that reduced optical flow speed led to increased walking speed and stride length, and vice versa in healthy adults[22]. Salinas et al.[23] examined whether optical flow affects stepping regulation and concluded that the presence of optical flow influenced reduced stepping variability, contributing to more constant walking speed. Moreover, dual-tasking of shopping in a VR environment showed faster walking speed compared to single-task in healthy adults[19]. Malcolm et al.[24] investigated the influence of optical flow on dual-task walking, suggesting that adding a cognitive task diminished the effect of simultaneous optical flow on walking performance in older adults. Thus, the alteration of visual input in VR would offer different characteristics of walking pattern[25]. Previous VR studies have not established how visual dual-tasking affects gait stability and walking performance. Hence, the purpose of this study was to investigate the effect of visual dual-tasking on gait velocity and stability under three conditions: single-task walking; walking whilst viewing lines scrolling across the screen; and walking whilst reading text scrolling on the screen in abled-bodied adults in a VR environment. The secondary purpose was to investigate the relationship between the CoM displacement and trunk inclination in the ML direction. We hypothesised that visual cognitive load will influence gait velocity and stability compared to single-task walking. Also, we hypothesised that there will be a positive correlation between the CoM displacement and trunk inclination.

2. Methods

2.1. Participants

Nineteen healthy young adults were recruited from university students(Table1). The sample size was determined by a power calculation using G*Power[26] which showed a minimum total of 17 subjects was required with 80% power, medium to large effect size at 0.65. However, based on past experience we chose a larger sample size than indicated by this estimation of 19 participants involved in all conditions. Participants aged between 18 to 44 years old were included since the physical influence of age over 45 years old on gait were reported[27]. Participants were excluded if they had any neurological, musculoskeletal, vestibular, orthopaedic, cardio-vascular diseases, impaired normal vision, or took any medications that may affected the execution of this study. Ethical approval was obtained from the Research Ethics Committee of School of Healthcare Science, Cardiff University. All participants signed an informed consent form.

2.2. Experimental Procedure

The Cardiff Gait Real-time Analysis Interactive Lab system (GRAIL; Motekforce Link Amsterdam, the Netherlands) was used to assess gait. The system contains an instrumented dual-belt treadmill with force platform, a 12-camera VICON optical infrared tracking system (Oxford Metrics, UK; sampling frequency at 100 Hz) and synchronised VR environments (Figure 1). The instrumented dual-belt treadmill system is self-propelling and is capable of adapting to each participant's current walking speed. The VICON system for motion analysis was used to measure the gait parameters. A total of 47 retro-reflective markers for motion capture were placed according to the VICON Plug-in-Gait marker placement protocol (Oxford Metrics, UK). The accuracy of marker positions was ensured by two experienced physiotherapists. A VR scene of a road was projected onto a semi-cylindrical screen located in front of participants for all tasks, so the occurrence of optical flow was provided in all conditions within the field-of-view. Each participant wore a safety harness and two emergency stop buttons were set in case of adverse events such as falls. Participants had a familiarisation walking trial for three minutes prior to data collection. A resting time was given to participants between the tasks for a minute.

Each participant was instructed to walk at a self-selected speed on the treadmill while performing three different tasks for each three minutes; walk through a road as a single-task (ST), viewing horizontal lines moving across the screen (DTL), and reading text silently regarding general information moving across the screen (DTT). The moving horizontal lines in DTL and text in DTT were fixed at the same speed, and 10 lines or text per minute appeared on the screen. The speed of those tasks was independent from the treadmill's velocity and was not adapted to participant's walking speed. The content of the text was general information regarding Wales that demands attention and cognitive load to read and memorise. The tasks were in fixed order of ST, DTL, and DTT to prevent the effect of altered gait performance on the baseline of ST. Because the majority of studies conducting dual-tasking have suggested the influence of cognitive load on the concurrent motor performance[28], which may alter the baseline. The ST was used as baseline to compare the effect of visual dual-task to single-task. The DTL was used to explore confounding and as a control of DTT to differentiate the effect of reading text as cognitive load from the effect of viewing scrolling lines on perceived optical flow. The following instructions were given to participants for each task; "Please walk at your comfortable speed" for ST, "Please walk at your comfortable speed while looking forwards", or "while silently reading a text coming up on the screen" for DTL or DTT, respectively. To ensure that participants read text during DTT, participants knew that four questions regarding the contents of the text were asked after the trial.

2.3.Data Processing and Analysis

Recorded data were processed using VICON Nexus software (Oxford Metrics, UK) to provide the kinetic and kinematic gait parameters. All data were low-pass filtered using a Butterworth filter with a cut-off frequency of 10 Hz using a MATLAB programme (MathWorks, Natick, Massachusetts). The middle one minute from each three-minute trial was used to calculate gait parameters. The average of gait velocity, the average of step length (SL_{ave}) for the left side, and the variability of step length (SL_{var}) for the left side were calculated. The right side of the SL_{ave} and SL_{var} were omitted from this report since those results were identical. The SL_{ave} and SL_{var} were normalised to each individual's height. The coefficient of variation was used as the SL_{var}. The location of the whole-body CoM was determined by the weighted average of each body segment CoM. The difference of peak values between both sides of the ML CoM displacement during gait was calculated as the range of ML CoM displacement. The vertical axis of the thorax segment was defined by the midpoints between spinous process of 7th cervical vertebrae, jugular notch where the clavicles meets the sternum, and between spinous process of 10th thoracic vertebrae, and xiphoid process of the sternum. The difference of peak values between both sides of the ML thorax rotation angles were calculated in degrees, and the range of ML thorax inclination was determined as trunk displacement in this study.

2.4.Statistical Analysis

The statistical analysis was conducted by IBM SPSS Statistics version 25 software. A one-way repeated measures analysis of variance (RM ANOVA) was applied to assess the changes of variables between ST, DTL, and DTT and the significance level was set at 0.05. When the normal assumptions did not hold, a non-parametric Friedman test was applied. For the Bonferroni post-hoc tests the significance level was adjusted to 0.017. The effect size for significant results were determined, in which Kendall's W for Friedman test and partial-eta squared (η_p^2) for a one-way RM-ANOVA were applied. Furthermore, Pearson product-moment correlation coefficient or Spearman's rank correlation coefficient was applied to determine the linear relationship between the ML CoM and the ML thorax inclination, and between gait velocity and step length in all conditions.

3. Results

All participants completed the experiment and were included in the analysis. Eight participants answered all questions correctly and the average percentage of correct answers were 78.9%.

3.1. Comparison of Gait Parameters Between ST, DTL, and DTT.

Friedman test showed that the average of gait velocity significantly differed between three conditions (chi-squared=12.74, p=0.002). The post-hoc tests showed a significant increase in DTL compared to ST (Z=-3.1, W=0.62, p=0.002)(Figure 2A; Table 2). The SL_{ave} showed a statistically significant difference among the conditions (F=12.04, p<0.001) in which there were significant increases in DTL (η_p^2=0.57, p=0.001) and in DTT (η_p^2=0.57, p=0.003) compared to ST (Figure 2B;Table 2). A one-way RM ANOVA showed a statistically significant difference between three conditions in the SL_{var} (F=9.01, p=0.001). The post-hoc tests revealed that those in DTT were significantly reduced compared to ST (η_p^2=0.6, p<0.001) and compared to DTL (η_p^2=0.6, p=0.033) for which the significance level of 0.05 was applied (Figure 2C; Table 2).

The ML CoM significantly differed between the conditions (F=4.01, p=0.027) (Figure 2D; Table 2). The post-hoc tests showed that the ML CoM was significantly increased in DTT compared to DTL (η_p^2=0.37, p=0.017), which the significance level of 0.05 was applied. No significant difference was found in the ML thorax inclination among the three conditions (Figure 2E; Table 2).

3.2. Correlation Between CoM Displacement and Thorax Inclination in Mediolateral Direction, and Between Gait Velocity and Step Length.

The gait velocity was significantly correlated with the SL_{ave} in ST (r=0.83, p<0.001), in DTL (r=0.86, p<0.001), and in DTT (r=0.86, p<0.001).

The ML CoM displacement showed a significant positive correlation with ML thorax inclination range only in DTT (r=0.66, p=0.002)(Figure 3).

4. Discussion

The purpose of this study was to investigate the effect of visual dual-tasking on gait velocity and stability in the VR environment, and to examine the relationship between the ML CoM and the ML thorax displacements in abled-bodied adults. We found that the visual dual-task had a significant impact on gait velocity and stability through changes in optical flow and in cognitive loading dividing attention between task components.

4.1. The Effect of Visual Factors on Gait during Dual-Tasks

Gait velocity showed a significant increase in DTL compared to ST. Corresponding to the gait velocity changes, average step length demonstrated significant increases in both dual-tasks compared to ST. Those findings are not in agreement with major findings from previous studies that demonstrated reduced gait velocity and step length while dual-tasking compared to a single-task[5]. Kelly et al.[29] showed increased walking speed when attention was focused on walking over cognitive task. However, our study did not provide any instruction to prioritise a task component. Kizony et al.[19] demonstrated increased gait velocity while shopping and walking in a virtual environment. They implicated that diminished attention to walking might affect more automatic walking, resulting in increased gait speed. This may explain our results. Another possible explanation is that the appearance of lines and text on the screen might interfere with the optical flow of the general scene in ST and diminish the perception of optical flow speed since line movement was in the opposite direction. Previous studies suggested that reduced optical flow speed led to faster walking speed[22]. Because the treadmill used was self-propelled, decreased perception of self-motion speed would conversely result in increasing walking speed. The DTL condition was not a dual-task and therefore gait speed changes seem to be based exclusively on altered optical flow. Moreover, gait velocity in DTT was slightly attenuated compared to DTL. This phenomenon could be due to the trade-off between the attention effect of cognitive loading and the optical flow effect. Malcolm et al.[24] indicated that adding a cognitive task diminished the effects of simultaneous optical flow on walking performance in healthy adults. The cognitive load of reading and memorising content might reduce the effect of optical flow on gait velocity in healthy adults through divided attention.

4.2.The Effect of Cognitive Load through Reading Text on Gait during Dual-Task

The assessment of gait stability while dual-tasking showed that reading text had a significant impact on the ML CoM displacement compared to DTL. This result was supported by a previous study that demonstrated increased ML pelvis displacement while using a mobile phone[7]. In addition, the relationship between the ML CoM displacement and the ML thorax movement was significant only in DTT. A possible explanation for the increased CoM displacement is that reading text might distract attention from controlling posture. Furthermore, visual input helps to regulate head and trunk movements in space[11], whilst visual input during reading text may interfere with this regulation, causing increased COM displacement. Thus, reading text while walking can contribute to greater instability, which could relate to increased trunk displacement. These findings suggested that increasing ML trunk displacement can be used to indicate changes in walking stability, which would help clinicians to use observational assessment in the clinical setting.

The step length variability was significantly reduced in DTT compared to ST and DTL. The findings were contrary to previous studies that showed increased step length variability while dual-tasking affecting working memory in healthy adults[6]. A possible explanation is that reading text might challenge the planning and adjustment of next foot placement during walking[11], causing a more automated execution of walking. Generally, visual input is used to specify foot placement, which is a strategy to maintain stable ML CoM movement during walking[11]. However, a visual attentional demand of reading text might challenge the ability to guide the precision in foot placement[30] and promote a more constrained gait pattern, resulting in decreased step length variability. Consequently, diminished control of foot placement might lead to increased ML CoM displacement. Thus, reduced walking stability while visual dual-tasking would be due to the distraction from precise foot placement making the control the ML CoM displacement less effective.

The clinical implication is that firstly visual dual-tasking in a VR environment can offer altered walking speed and stability which can be utilised to assess the capability of stability in a safe environment. Secondly, the cognitive load of reading text substantially altered gait stability presumably due to the distraction from foot placement control. Especially, individuals with neurological disease can be increasingly reliant on visual input to manage unstable walking. Thus, the assessment of gait stability while dual-tasking in a safe environment can be useful to detect problems at an early stage. Finally, greater ML CoM displacement in DTT appeared to be influenced by increasing ML trunk movement that theoretically has a substantial impact on postural control. Hence, gait observational analysis in the clinical setting referring to trunk movement seems a useful approach to assess walking stability.

Limitation

The main limitation of this study is that reading text might have been relatively easy for healthy young adults. The current study investigated only mediolateral directions of CoM displacement and thorax inclination movement. Hence, further research needs to explore the other direction, combined with using more complex cognitive tasks or different types of cognitive load.

5. Conclusion

The analysis of visual dual-tasking while walking in a VR environment revealed that the cognitive load of reading text had a significant impact on walking stability even in able-bodied adults. The increased ML CoM displacement could be related to ML trunk displacement. The reduced step length variability presumably was due to the distraction of precise foot placement. Thus, the assessment of visual dual-task interference in a VR environment can provide insight into walking stability and performance which will be useful for clinical assessment.

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Declarations of Interest: None

Conflict of Interest Statement

We hereby declare that we have no financial or business relationships with other people or organisations that could influence our research study.

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Highlights

1. Visual dual-task affects walking speed and stability in a virtual environment.

2. The optical flow predominantly altered walking speed.

3. Visual attention to read text affected foot placement and upright trunk posture.

4. This led to unstable walking with greater mediolateral CoM displacement.

5. This paradigm is useful for clinical assessment of walking stability.

Figure 1: The Cardiff Gait Real-time Analysis Interactive Lab system (GRAIL; Motek force Link Amsterdam, the Netherlands) including VR environment.

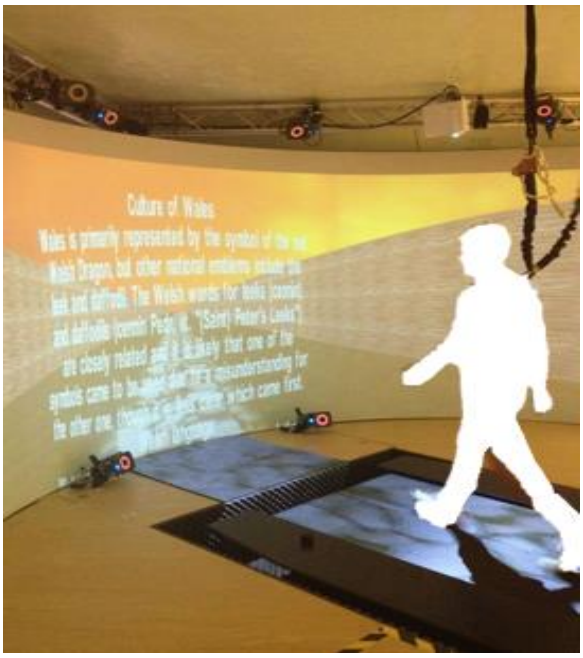

Figure 2: Comparison of Variables Between Single-Task (ST), Dual-Task with Viewing Lines (DTL), and Dual-Task with Reading Text (DTT). Representation of the comparison between the tasks in the average of gait velocity (A), the average of step length (B), the variability of step length (C), the range of ML CoM displacement (D), and the range of ML thorax inclination (E). Error bar indicates standard deviation for each variable. Abbreviations: CoM, centre of mass; ML. mediolateral. (**p*>0.017).

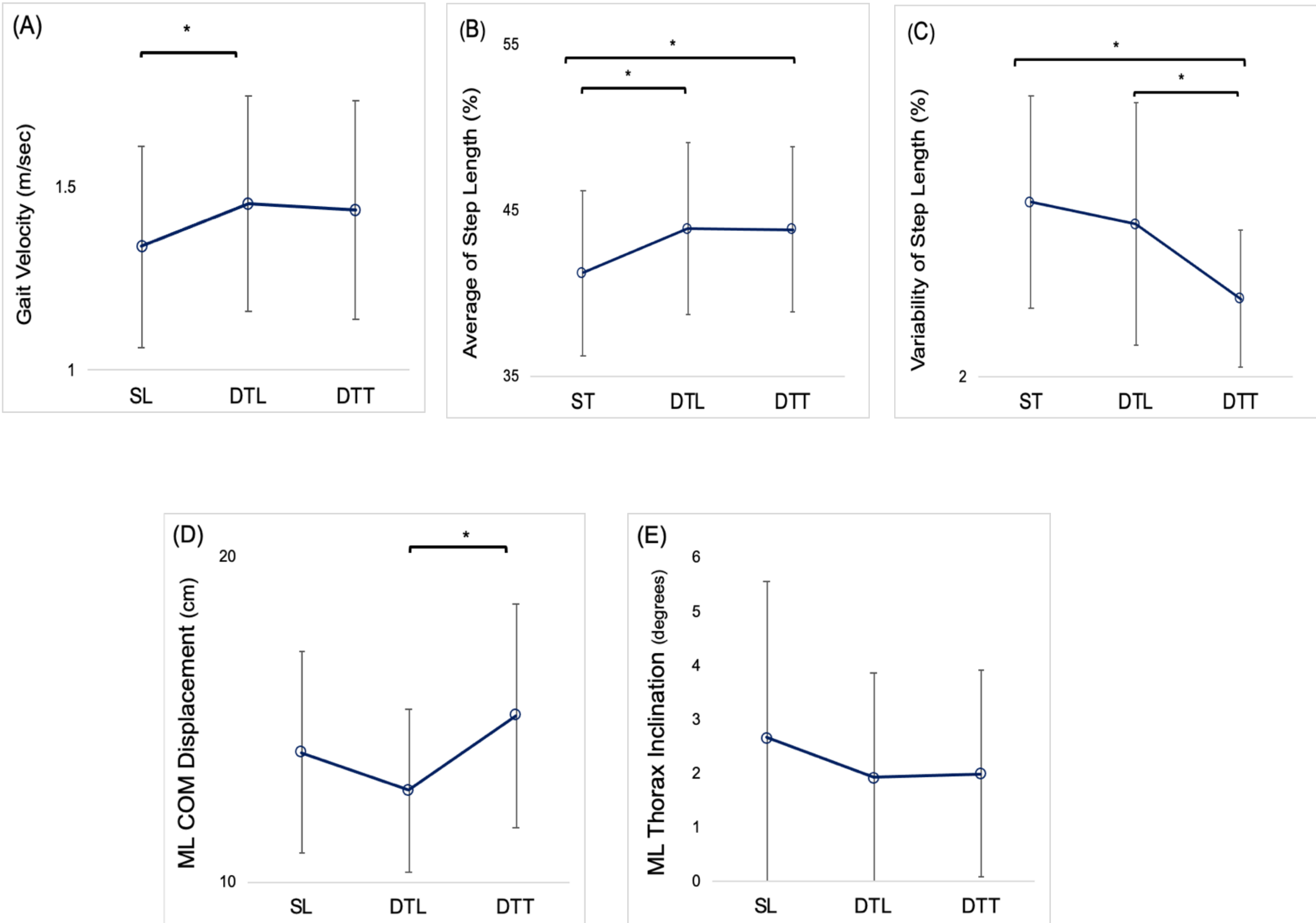

Figure 3: Correlation Between ML CoM Displacement and ML Thorax Inclination in Single-Task (ST)(A), Dual-Task with Viewing Lines (DTL)(B), and Dual-Task with Reading Text (DTT)(C). Abbreviations: CoM, centre of mass; ML. mediolateral.

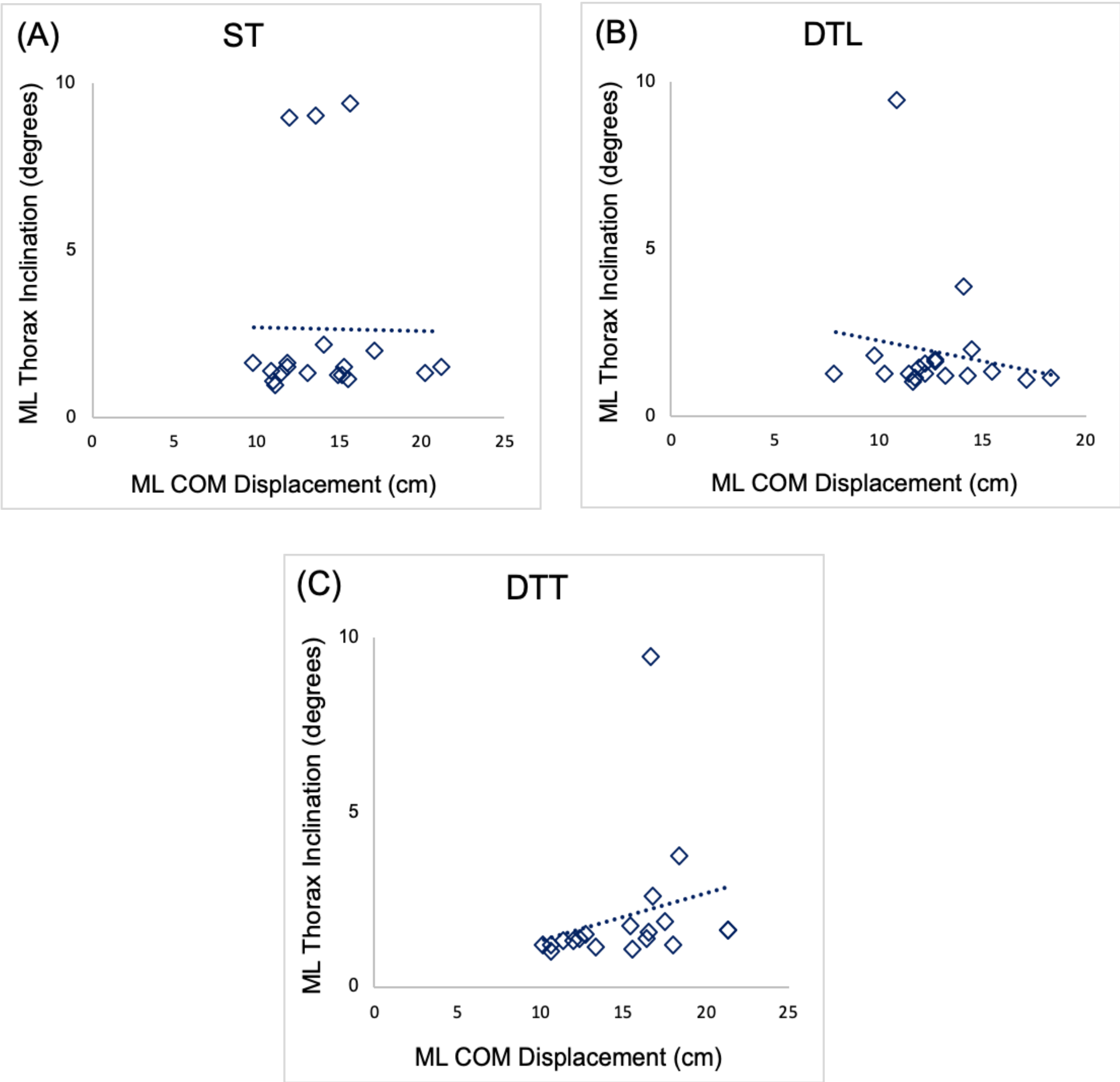

Table 1: Demographic Data of Participants.

Age (years)	27.5 ± 5.2
Gender (male / female)	13 / 6
Height (cm)	171.8 ± 7.8
Body weight (kg)	70.3 ± 11.8
Body mass index	23.7 ± 3.3

Notes: Values are mean ± SD.

Table 2: Comparison of Variables Between Single-Task (ST), Dual-Task with Viewing Lines (DTL), and Dual-Task with Reading Text (DTT).

	ST	DTL	DTT
Gait Velocity (m/sec)	1.34 ± 0.28†	1.45 ± 0.29†	1.44 ± 0.3
ML COM (cm)	13.98 ± 3.10	12.81 ± 2.50⁑	15.10 ± 3.46⁑
ML Thorax Inclination (degrees)	2.66 ± 2.9	1.92 ± 1.93	2.00 ± 1.91
Average Step length (%)	41.21 ± 4.96†‡	43.90 ± 5.17†	43.86 ± 4.98‡
Variability Step length (%)	3.58 ± 0.97‡	3.39 ± 1.1⁑	2.71 ± 0.62‡⁑

Notes: Values are mean ± SD. Abbreviations: ML COM, the range of mediolateral centre of mass; ML, mediolateral; ST, single-task of walking; DTL, dual-task of walking while viewing moving lines; DTT, dual-task of walking while reading text.

Significant level at $p<0.017$.

†Significant difference between ST and DTL

‡Significant difference between ST and DTT

⁑Significant difference between DTL and DTT