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Research article

Effects of using assistive devices on the components of the modified instrumented timed up and go test in healthy subjects

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ABSTRACT

Introduction: Evaluation of the changes in gait spatiotemporal parameters and functional mobility with using assistive devices (ADs) would provide useful information and mutual assistance when prescribing such ambulatory devices. This study aimed to investigate the spatiotemporal gait and functional mobility parameters in healthy adults when walking using different ADs.

Methods: A group of healthy subjects participated in the study. The instrumented modified Timed Up and Go test (iTUG) was used to investigate the impact of different types of ADs on spatiotemporal and functional mobility parameters.

Results: Subjects showed a significant difference in the gait task performance ($P = .001$) in stride velocity, stride length, and cadence when walking with and without ADs. A significant difference was also found in the performance of the turn-to-sit task ($P = .001$) in both velocity and duration when walking with and without ADs. The time to complete sit-to-stand was significantly slower when using a walker ($98.3 \pm 22.3°$/sec, $P = .004$) and a cane ($78.2 \pm 21.9°$/sec, $P = .004$) compared to walking without an AD ($78.2 \pm 21.8°$/sec). No significant difference was found between walking with a cane group versus walking with a four-wheeled walker group ($P = .94$).

Conclusion: ADs altered gait and functional mobility parameters differently in healthy subjects. Using a four-wheeled walker showed a tendency to increase stride velocity, cadence, stride length, and slow sit-to-stand velocity compared to using a cane. The findings highlight using more caution clinically when prescribing ADs and providing gait training.

1. Introduction

The use of assistive devices (ADs), especially canes and walkers, is common and has increased since the last decade due to the rise in life expectancy and mobility limitations [1, 2, 3, 4]. More than 1,127,000 of Canadians aged 15 and older use at least one AD [4]. In the United States, 8.5 million use ADs, and this number increases annually [1]. ADs can be used to facilitate mobility and activities in daily life because they help to increase the base of support, preventing falls [5, 6, 7] and reducing the body pressure on irritated weight-bearing joints [6, 8]. Most previous studies have focused on the effects of ADs, particularly single-tip canes and four-wheeled walkers, on gait parameters and whole functional mobility performance [6, 9].

The most commonly studied spatiotemporal gait parameters (STPs) are stride velocity, stride length, and cadence [6, 9, 10, 11]. Existing studies have associated slower stride velocity (gait speed), short stride length, and decreased cadence with poor balance, higher risk of falling, and increased physical efforts measured by O_2 consumption in elderly people and those with neurological conditions [6, 9, 10, 11]. It is therefore important to investigate the effects of ADs on an individual's gait parameters.

Most previous studies that investigated the impact of ADs on functional mobility and spatiotemporal parameters used the Timed Up and Go test (TUG) and the GAITRite system. For example, it was reported that the spatiotemporal gait parameters measured by GAITRite when using a four-wheeled walker were the closest to normal pattern in subjects with Parkinson's disease [10, 11] and Huntington's disease [12]. Additionally, Schülein et al. [13] showed that spatiotemporal gait parameters improved when walking with a four-wheeled walker compared to free walking in hospitalized geriatric subjects with gait impairments. Similarly, Kristensen et al. [14] reported that patients with hip fractures took less time to finish the TUG tasks when using a four-wheeled walker

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compared to crutches. However, the main drawback in the studies that used the TUG test were that it fails to provide enough information to assess functional mobility since it relies only on the time required to accomplish the TUG tasks. Thus, wearable sensors are currently being added (i.e., the instrumented TUG [iTUG] test) to obtain precise measurements for trunk angular movements and spatiotemporal parameters. One of the main advantages of using iTUG is that it provides more detailed information on each mobility component, which will help in the development of specific treatment plans for enhancing an individual's mobility.

Most current studies that investigated the impact of different types of ADs on spatiotemporal parameters were conducted on different populations with diseases in which gait abnormalities are a hallmark and significant contributors to falling [13, 15, 16]. These parameters were found to be affected by the presence of such profound factors. Thus, a deep understanding of the spatiotemporal parameters with AD use in adult healthy subjects will shed light on the type of gait training healthcare professionals should provide to help patients use the ADs effectively and properly. It would also be beneficial to identify which ADs lead to gait parameters that are most consistent with the normal gait pattern. Thus, this study investigates the effects of using different types of ADs on the components of the modified iTUG in a healthy adult population.

2. Participants and methods

2.1. Study design

This study used a within-subjects design in which the AD, with three levels, was considered an independent variable.

2.2. Participants

Twenty healthy subjects (14 women and 6 men; with a mean and standard deviation (SD) age of 22.8 (4.42) years, and body mass index of 22.89 (2.54) kg/m^2) were included in the study. All participants had no history of musculoskeletal or neurological problems and were able to understand and follow commands. All participants signed informed consent forms before commencing the experiment, which was approved by the Institute Review Board at Texas Woman's University, Texas, USA (lRB# 19620).

2.3. Instrumentation

The multi-sensor based Mobility Lab System (APDM Inc., Portland, OR, USA) consists of multiple sensors, an accessing point, a docking station, and a laptop. Each part of the Mobility Lab System has a specific function. The Mobility Lab system uses radio-frequency communication for wireless data capturing, processing, transmission and synchronization of the multiple OPAL wearable sensors via an access point connected to a host laptop. Each OPAL sensor houses a 3-dimensional gyroscope, allowing to measure the rotational trunk velocity in three planes: coronal, sagittal, and axial planes. Moreover, the sensors have a tri-axial accelerometer that measure the linear acceleration in the vertical, lateral and sagittal directions (Spain et al., 2012). The OPAL wearable sensors (55 × 40.2 × 12.5 mm, <25 g) include gyroscope (range: ±2000°/s, resolution: 12 bits), two tri-axial accelerometers (range: ±16 g and ±200 g, resolution: 14 and 17.5 bits), and magnetometer (range: ±8 Gauss, resolution 12 bits) with recording at a sampling frequency of 128 Hz. The accessing point, as a wireless communication hub between OPAL wearable sensors and the host laptop, detects the sensors' signals and sends them to the laptop to be analysed by the installed software. The docking station is used to calibrate, configure and charge the sensors, and download any logged data from the sensors.

Prior to testing, six sensors with straps were used and attached on the participant's' body parts as follow. One sensor was positioned 4 cm above each lateral malleolus and one on the dorsal aspect of each wrist between the ulnar and radial styloid process. Additionally, one sensor was placed on the sternum 2 cm below the sternal notch and the last sensor was placed at the midline on the lumbar spine at L5. The Mobility Lab System exhibits strong psychometric properties including good reliability and validity in evaluating different mobility tasks [17, 18, 19, 20, 21].

2.4. Procedure

Data were collected during one session for each participant. The sessions were conducted in a room with tile flooring and no distractions. A standardized chair with a foam back and seat cushion and plastic armrests was used for all testing. An adjustable single tip aluminium cane and aluminium a four-wheeled walker were used for testing.

Each participant was allocated randomly to perform three different tasks (walking without ADs, with a single tip cane, with four-wheeled walker) before starting the data collection. All sensors were attached and positioned based on protocols from previous studies, which were found to be valid procedures for collecting spatiotemporal data [20, 22]. Similarly, the ADs were adjusted using standardized procedures as described by Fairchild, O'Shea, and Washington [23].

Prior to the data collection, all participants received standardized instructions about the modified iTUG procedure and were allowed to practice twice. All participants performed three trials for each condition with a pause to reset the computer between individual trials. There was a one-minute pause between each modified iTUG condition (without ADs, with a single tip cane, and with a four-wheeled walker). To perform the modified iTUG test, the participants were asked to stand up from a chair with armrests, walk at their comfortable own pace for seven meters, turn 180^o, walk back the same distance and return to the starting point. The distance was modified from three to seven meters to allow more gait cycles for gait parameter capture. Next, the mean of the three trials was calculated for each variable of interest.

2.5. Data processing

The Mobility Lab software (version 2; APDM Inc., Portland, OR, USA) was used to start and stop the OPAL wearable sensors, to allocate the sensors to the particular body location, to place event markers during data collection, and to record, real-time visualize and analyse the data. During the test procedure, all markers were placed using a Bluetooth remote controller.

Participants completed the modified iTUG under three conditions: 1) without ADs (NAD), 2) with a single-tip cane (CAD); and 3) with a four-wheeled walker (WAD). Spatiotemporal gait parameters resulted from the automatic output of the Mobility Lab System software included mean values of (1) stride velocity (m/sec): the distance travelled from one point to another, measured during; (2) cadence: steps walked per minute; (3) stride length (m): the distance between two complete placements of the same foot on the floor; (4) turning velocity (deg/sec): range of turning (180°) divided by turning time in seconds; (5) sit-to-stand velocity (deg/sec): average trunk angular velocity during sit-to-stand in pitch axis (i.e., flexion/extension; deg/sec); (6) duration of turn-to-sit: time in seconds needed to turn and sit on a chair; and (7) stand-to-sit velocity (deg/sec): average of maximum angular trunk velocity in degrees per second during the turn-to-sit transition. The stride velocity, cadence and stride length data were obtained during walking in a straight line, turning peak velocity data were taken during turning 180°, sit-to-stand peak velocity data were acquired during standing up from a chair, duration of turn-to-sit data were obtained during turning to sit and finally stand-to-sit peak velocity data were taken while returning to sit on the chair (starting point). These parameters have been validated and found to be discriminative variables, with high sensitivity and specificity, between people with and without mobility impairments [17, 18, 19, 20, 24].

2.6. Data analysis

All statistical tests were performed using IBM SPSS Statistics for Windows, version 25.0 (SPSS Inc., Chicago, Illinois, USA). Demographic data were summarized descriptively. Multivariate linear mixed models (MANOVA) analyses, considering group as a fixed factor, were performed to assess the changes in the gait characteristics and turn-to-sit variables and to calculate the mean differences between the three groups (CAD, WAD, NAD). Post hoc comparisons with least square mean differences were performed to compare the gait parameters between each pair of the three walking conditions. Additionally, two one-way ANOVA tests were performed to assess the changes within the following variables: sit-to-stand peak velocity and turn peak velocity. The significance level was set to $p < .05$.

3. Results

Table 1 shows the comparisons of modified four iTUG components characteristics when moving under three conditions. The first MANOVA revealed a significant difference in the gait task performance ($F(2,57) = 16.37$, $p = .001$) in stride velocity, stride length, and cadence when participants moved with and without ADs. The results of the post hoc pair-wise comparisons with Tukey correction showed a significant slower stride velocity, shorter stride length, and fewer steps when using a single tip cane and a wheeled walker compared to when walking without a device. The second MANOVA revealed a significant difference in the performance of the turn-to-sit task ($F(2,57) = 14.29$, $p = .001$) in both velocity and duration when participants moved with and without ADs. The results of the post hoc pair-wise comparisons with Tukey correction showed that the participants had significantly slower turning velocity and longer turning duration when using both ADs compared to when walking without a device (all P values $<.005$).

Univariate ANOVA results showed a significant mean difference between the groups among both variables: sit-to-stand peak velocity ($F(2,57) = 5.97$, $P = .004$), and turn peak velocity ($F(2,57) = 38.98$, $P = .001$). A Tukey post hoc test revealed that the sit-to-stand velocity was significantly slower when using a walker ($77.77 \pm 19.99°$/sec, $P = .004$) and a cane ($78.26 \pm 21.88°$/sec, $p = .004$) compared to when walking without a device ($98.31 \pm 22.33°$/sec). No statistically significant difference was found between CAD vs. WAD groups ($P = .94$), as shown in the Table.

Additionally, the differences between all tested spatiotemporal gait variables in different groups (CAD, WAD and NAD) across all participants were plotted as shown in Figure 1.

4. Discussion

An evaluation of the changes in normal gait spatiotemporal parameters and functional mobility with ADs would provide useful information for clinicians when prescribing ADs for elderly people and patients. Most of previous studies that examined gait spatiotemporal parameters when using an AD included participants with movement disorders such as Parkinson's and Huntington's diseases, whose gait patterns are negatively impacted by multiple factors including, neuromotor deficits, musculoskeletal impairments, and loss of balance. Therefore, comprehensive understanding of the normal gait spatiotemporal parameters is of utmost importance in assessing the limitations of the gait abnormalities and in prescribing the most suitable assistive device for ambulation [25]. The current study explicitly investigated the effects of ADs on the components of the modified iTUG in healthy adults. The findings showed a lower gait speed (stride velocity), decreased number of steps (cadence), and shorter stride length when using either a cane or a walker compared to when walking with an AD. In addition, the participants showed slower turning velocity and longer turning duration when using both ADs compared to when walking without an AD. These results are in line with the findings of previous studies [13, 15, 16, 26, 27] in which the ADs altered the spatiotemporal gait parameters in healthy adults and in elderly subjects with impaired balance. For example, Suica and colleagues reported that using rollator walking aid reduces the electromyographic activities of the lower extremity muscles but has no effect on trunk sway measurements in healthy subjects, suggesting that using a four-wheeled walker provides greater stability and minimizes the risk of falling [28]. Similarly, Sato et al. [29] investigated the effects of both assistive and resistive guidance on the gait parameters of elderly subjects using a smart walker. Their findings showed that assistive guidance increased gait velocity, step length, and cadence with increasing trunk acceleration variability [29].

The results of the current study indicated that walking with ADs slowed down both the turning velocity and the angular trunk velocity during the turn-to-sit task; thus, the time needed to turn and sit on a chair was increased compared to walking without ADs. This finding might be the result of performing a dual-task simultaneously (walking and handling an AD such as a walker) increasing sustained attention demands [11], given the fact that all participants in this study were healthy and first time assistive devices users with no experience or previous training. Consistently with this, studies have analysed the influence of the use of a walker on the spatiotemporal gait parameters among frequent users and first time users showed that first time users exhibited higher gait velocity and stride length compared to frequent users [13, 30]. Another possible explanation that using AD induced asymmetrical gait pattern due to biomechanical changes particularly, in the early stage of using AD [30].

Although the current findings indicated no statistically significant difference between CAD and WAD groups across different spatiotemporal parameters and functional mobility, using a walker showed a tendency to increase stride velocity, cadence, and stride length compared to using a cane. Moreover, using a walker resulted in a slower sit-to-stand velocity than using a cane. These findings suggest that the walker might be the

Table 1. Shows immediate gait changes with assistive ambulatory device.

Table. Gait changes with different assistive devices

Measures	CAD M±SD	WAD M±SD	NAD M±SD	p value[a]	p value[b]	p value[c]
Stride length (m)	1.1 ± 0.17	1.27 ± 0.14	1.4 ± 0.09	<.001*	.004*	<.001*
Speed (m/s)	0.56 ± 0.21	1.01 ± 0.16	1.26 ± 0.09	<.001*	<.001*	<.001*
Cadence (steps/min)	59.66 ± 11.58	95.19 ± 11.41	105.71 ± 9.25	<.001*	.003*	<.001*
Turn-to-sit velocity (degrees/sec)	140.67 ± 34.08	108.67 ± 19.04	202.40 ± 32.59	<.001*	.003*	<.001*
Turn-to-sit: duration (seconds)	5.09 ± 1.07	5.75 ± 1.02	3.64 ± 0.44	<.001*	.003*	<.001*
Sit-to-stand velocity (degrees/sec)	78.26 ± 21.88	77.77 ± 19.99	98.31 ± 22.33	.004*	.004*	.943
Turn velocity (degrees/sec)	107.88 ± 18.44	90.46 ± 15.46	147.73 ± 27.35	<.001*	<.001*	.011*

M, mean; SD, standard deviation; NAD, walking without assistive devices; CAD, walking with a cane; WAD, walking with a walker. Post hoc comparisons with Tukey correction. [a]NAD vs. CAD. [b] NAD walk vs. WAD. [c]CAD vs. WAD; significant at $p < .017$.

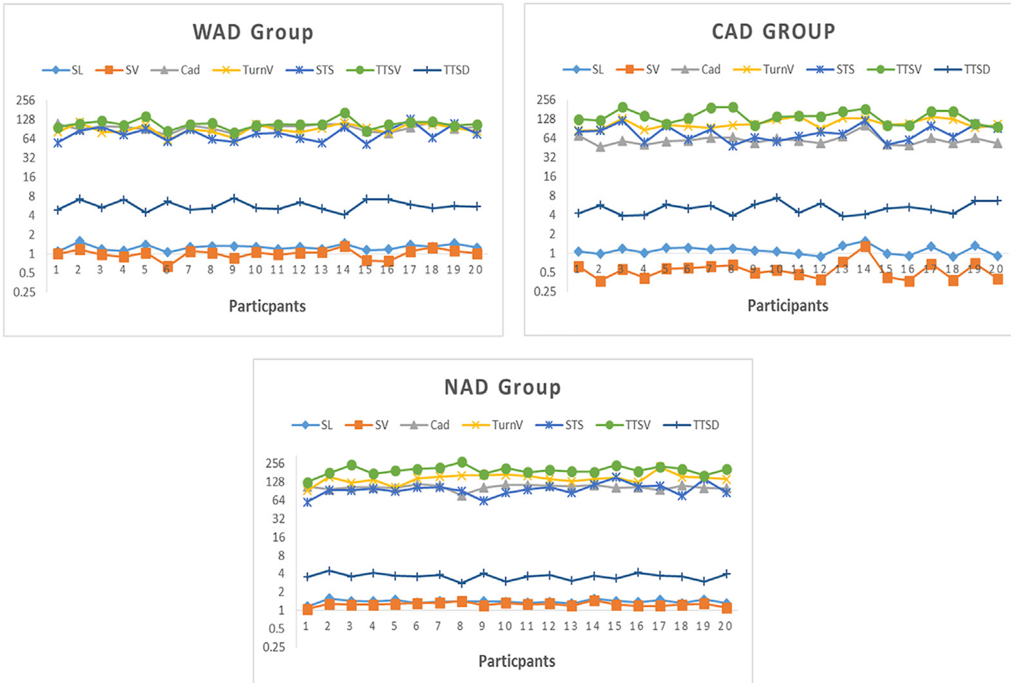

Figure 1. A line plot graph shows differences between gait variables under different conditions (CAD, WAD and NAD) across all participants. SL, stride length; SV, stride velocity; Cad, cadence; TurnV, turning velocity; STS, sit-to-stand velocity; TTV, turn-to-sit velocity; TTSD, stand-to-sit duration.

most efficient AD and can be considered a feasible option because it has an impact on trunk angular velocity, which is essential for dynamic balance control during gait [13, 15, 16, 29, 31, 32].

This study has some limitations that might limit the generalizability of the findings. First, all participants were adults; younger and older ages were not involved in the study. Second, only two types of the most common ADs—a single-tip cane and a four-wheeled walker—were used in this study. However, other common ADs such as a four-point cane and a two-wheeled walker were not used, which might induce variations different from the current results. Finally, no comparable group with gait disorders was recruited in this study to compare the gait changes when using the walking devices between both groups. Future studies should therefore compare the impact of several types of ADs on the spatiotemporal parameters and functional mobility of healthy adults and patients.

5. Conclusion

The findings of this study might guide health professionals to determine which type of AD will be least likely to alter normal gait pattern, and change mobility parameters. Such alteration should be taken into account during gait training. The results may also be helpful for health professionals in assessing the limitations of the gait abnormalities. The current findings indicate that the walker is the least AD that alters the gait parameters, allowing for more natural gait patterns, and might be feasible option for balance support. However, this should be taken with caution as this study involved only healthy adult participants. Future studies should involve patients with movement disorders and compare their spatiotemporal gait parameters data with healthy subjects in order to provide a valuable information in prescribing the most appropriate ambulatory devices for the patients.

Declarations

Author contribution statement

Turki S Abualait: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ghazi Alnajdi: Conceived and designed the experiments; Performed the experiments.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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