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Short communication

Extended Timed Up & Go test: Is walking forward and returning back to the chair equivalent gait?

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ABSTRACT

The Timed Up & Go test (TUG) is functional test and is a part of routine clinical examinations. The instrumented Timed Up & Go test enables its segmentation to sub-tasks: sit-to-stand, walking forward, turning, walking back, stand-to-sit, and consequently the computation of task-specific parameters and sub-tasks separately. However, there are no data on whether walking forward parameters differ from the walking back parameters. This study tested the differences between walking forward and walking back in the TUG extended to 10 m for 17 spatio-temporal gait parameters. All parameters were obtained from a GAITRite[®] pressure sensitive walkway (CIR Systems, Inc.). The differences were assessed for healthy controls and Parkinson's disease (PD) patients. None of investigated parameters exhibited a difference between both gait subtasks for healthy subjects group. Five parameters of interest, namely velocity, step length, stride length, stride velocity, and the proportion of the double support phase with respect to gait cycle duration, showed a statistically significant difference between gait for walking forward and walking back in PD patients. Therefore, we recommend a separate assessment for walking forward and walking back rather than averaging both gaits together.

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1. Introduction

The Timed Up & Go test (TUG), a modified timed version of the functional test "Get-Up and Go" (Mathias et al., 1986), is simple, requires no special equipment, and is a part of routine clinical examinations. Usually, the main parameter evaluated in clinical practice and research is the total time it takes to complete the TUG.

Along with the rapid progress in sensing technologies, the instrumented TUG and its extended modifications are increasingly being used in laboratory settings. The results of research related to the automatic examination of a TUG were extensively reviewed by Sprint et al. (2015).

The instrumented TUG enables its segmentation to sub-tasks: sit-to-stand, walking forward, turning, walking back, stand-to-sit, and consequently computation and assessment of timing and other task-specific parameters of all TUG sub-tasks separately. Despite

the growing number of research focused on the sit-to-stand sub-task (Zakaria et al., 2015) and the turning subtask (Bonnyaud et al., 2015; Vervoort et al., 2016; Zakaria et al., 2015), the gait sub-task still plays an important role in TUG assessment (Ansai et al., 2018; Craig et al., 2017; Greene et al., 2012; Sheehan et al., 2014; Smith et al., 2016; Weiss et al., 2013).

The gait sub-task consists of walking forward and walking back with a turn sub-task in between. However, the evaluation of gait sub-tasks in the TUG is not standardized, some studies assessed walking forward and back separately (Ansai et al., 2018), other studies combined the walking forward and walking back actions (Weiss et al., 2013) while, the majority of studies don't report whether the computation of gait parameters is based on both gait sub-tasks combined, e.g. an average of both sub-tasks, or only one of them (Adusumilli et al., 2018; Craig et al., 2017; Greene et al., 2012; Sheehan et al., 2014; Smith et al., 2016; Spain et al., 2012). Walking forward and walking back may be differentially affected by several factors: (1) the transition from sit-to-stand to regular walking, (2) the turn task which requires the central nervous system to coordinate with body segments allowing for reorientation towards a new travel direction while maintaining dynamic body stability (Patla et al., 1999), (3) preparation for the transition to

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stand-to-sit sub-task, and (4) increasing fatigue. The effects of these factors may be even more pronounced under pathologic conditions such as neurodegenerative disorders. However, no complex study has dealt with the comparison of gait parameters before turning and after turning in a healthy population nor in patients with neurologic disorders so far. This uncertainty regarding possible differences in parameters before turning and after turning may result in inconsistent comparisons of parameter values within clinical and research measurements.

The aim of this work is to examine whether TUG gait exhibits the same spatio-temporal parameters for forward walking and walking back in older adults and Parkinson's disease patients.

2. Methods

2.1. Participants and data acquisition

In this observational study we included 26 treatment-naive patients with Parkinson's disease PD (16 men, 10 women), mean age 58.9 (± 13.2), mean PD duration 30.1 (± 15.8) months, and 19 healthy control (HC) subjects (17 men, 2 women), mean age 61.7 (± 8.3). PD patients were examined using the Movement Disorder Society Unified Parkinson's Disease Rating Scale (MDS-UPDRS), from which the motor subscore (part III) was calculated (30.15 \pm 12.65). Research protocol was approved by the local research Ethics Committee of the General University Hospital, Prague in accordance with the Declaration of Helsinki and an informed consent was obtained from all participants before entering the study.

As documented by [Zampieri et al. \(2010\)](#), the traditional TUG is not a sensitive enough tool to differentiate between untreated PD and healthy controls. In contrast, individual parameters of gait cycle measured using an instrumented TUG with an extended walking distance were shown to be sensitive enough to show gait abnormalities in early untreated PD and could potentially detect the progression of PD and their response to symptomatic and disease-modifying treatments ([Zampieri et al., 2010](#)).

Participants were instructed to perform an extended Timed Up & Go test ([Wall et al., 2000](#)) at their preferred, usual-walking speed. An extended TUG involves rising from a chair, walking 10 m in a straight line, turning 180°, walking back and sitting down in the chair. The turning point was designed by the marker on the floor. Subjects were given no instructions on which side to turn. One walking trial was performed by each subject. Gait was assessed using a 5.15 m long and 0.9 m wide instrumented walkway (Platinum model GAITRite®, CIR System Inc., Franklin, USA) placed 2.43 m from chair in the middle of the straight gait walkway. Pre-turn and post-turn gait were acquired as separate recordings on the walkway.

Previous studies showed that GAITRite is a valid and reliable tool for measuring the spatio-temporal parameters of gait ([McDonough et al., 2001](#); [Wong et al., 2014](#)). All data was processed by experienced person using the GAITRite application software (version 4.7). We processed 17 spatio-temporal gait characteristics twice for each TUG trial: once when the participant walked forward and once when they walked back. Then, the pre-turn and post post-turn gait data was further statistically evaluated.

Parameters of interest are provided by the GAITRite walkway (thus in line with manufacturer recommendation and definitions, refer (CIR Systems Inc., 2013)). These parameters are:

- velocity (cm/s) - mean velocity of walking (distance traveled per time)
- step count (steps)
- cadence (steps/min)
- step time (s)
- step length (cm)
- cycle time (s)
- stride length (cm)
- base width (cm) - width of support base
- swing percentage (%) - a percentage of the gait cycle time
- swing time (s) - duration of swing phase
- stance percentage (%) - duration of stance phase as a percentage of the gait cycle duration
- stance time (s) - duration of stance phase
- single support percentage (%) - a percentage of the gait cycle time
- single support time (s) - duration of single support phase
- double support percentage (%) - a percentage of the gait cycle time
- double support time (s) - duration of double support phase
- stride velocity (cm/s) - ratio of stride length to stride time

All parameters were recorded and averaged for the left and right limbs.

2.2. Statistical analysis

The paired *t*-test was used to compare the spatio-temporal parameters between the left and right lower limbs, and the parameters for walking forward and back. A two sample *t*-test was used to compare the parameters of PD patients and HC. The significance level was set to 0.05. A Holm-Bonferroni correction was applied to address problems with multiple testing. Thus *p*-values less than 0.002 are considered significant at the Holm-Bonferroni-corrected level.

3. Results

The mean total time to complete the extended TUG was slightly higher in PD (24.56 \pm 5.61 s) compared to HC (23.76 \pm 3.47 s) but the difference was not statistically significant (*p* = 0.94). The comparison of spatio-temporal gait parameters between the left and right lower limbs did not show any significant difference ([Table 1](#)).

The mean value and standard deviation of each parameter for walking forward and back, and their differences are reported in [Table 2](#); the table also shows the results of the paired *t*-test. The velocity, step length, stride length, and double support percentage were significantly different in the PD (*p* < 0.002) but not in the HC group. Namely, the PD group had decreased gait velocity and shortened steps and strides in the walking back subtasks in comparison with their forward gait. There was no significant difference between both subtasks in parameters values for the HC group. The Bland-Altman plot was used as a graphical representation of the differences between the two gaits ([Fig. 1](#)).

The results showed that neither forward walking nor walking back differed between the PD and HC group ([Table 3](#)). The comparison of differences between walking forward and walking back also did not exhibit a distinction between the PD and HC group ([Table 3](#)).

4. Discussion

The current study compared the gait parameters of walking forward to walking back from an extended Timed-Up and Go test and provided statistical assessment of 17 spatio-temporal parameters extracted from the pressure sensitive walkway. Additionally, this study contains a comparison of gait parameters for different subject groups: healthy subjects and Parkinson's disease patients.

Table 1

Comparison of gait parameters between the left and right lower limb (p-values are reported). bolded - statistically significant difference ($p < 0.05$), no p-value met Holm-Bonferroni-corrected level of p (for 17 tests performed, $p < 0.002$).

	Walking forward (p-value)		Walking back (p-value)	
	PD	HC	PD	HC
Step time	0.568	0.353	0.318	0.653
Step Length	0.224	0.007	0.876	0.131
Cycle Time	0.943	0.369	0.335	0.343
Stride Length	0.010	0.547	0.654	0.548
Support Base	0.158	0.644	0.962	0.253
Swing perc.	0.993	0.444	0.977	0.568
Swing time	0.977	0.407	0.103	0.811
Stance perc.	0.987	0.423	0.987	0.558
Stance time	0.978	1.000	0.422	0.369
Single support perc.	1.000	0.387	0.086	0.159
Single support time	0.977	0.407	0.103	0.811
Double supp. perc.	0.517	0.327	0.197	0.280
Double supp. time	0.533	0.364	0.287	0.327
Stride velocity	0.220	0.293	0.416	0.357

Our findings showed that some spatial and temporal parameters differed between walking forward and walking back and that these parameters affected healthy subjects and PD patients differently. From Table 2 it can be seen that, out of the total 17 parameters, no parameters in healthy subjects and 5 parameters in PD patients demonstrated a statistically significant difference when comparing the gait between walking forward and walking back. The absolute timing of the gait cycle seems to be preserved while the distribution of time within the gait cycle differed in PD. The parameters of healthy subjects were generally more stable within gait subtasks compared to PD patients.

The axial rigidity in PD during turning could increase lateral instability (Yang et al., 2016b). Thus, one possible explanation of the altered walking back parameters may be recovering to a stable steady gait. Another explanation may be the anticipation of the turn-to-sit transition or increased fatigue.

A number of studies segmented the TUG into subtasks (Craig et al., 2017; Greene et al., 2012; Sheehan et al., 2014; Smith et al., 2016; Zakaria et al., 2015). It has been shown that turn parameters are affected by gait velocity (Akram et al., 2010). However, the effect of the turn to the consequent gait has not yet been (to the authors' knowledge) studied. Our results suggest that its

influence is not negligible and is different from a healthy and diseased population. Future studies should elucidate a mechanism for changes in gait parameters relating to the turn task and analyze the mutual relationship between instrumented TUG sub-tasks. For example, investigating the effect of the turning side with respect to lateral dominance or a more affected side of the body to walking back parameters might bring additional information. Although some research included assessment of turning strategy (Yang et al., 2016a) or the turning side (Bovonsunthongchai et al., 2014), none of the studies focused on the turning side and consecutive gait.

Contrary to our results, other recent studies demonstrated differences in spatio-temporal gait parameters between de novo, drug naive Parkinson's disease patients and a control group (Gračić et al., 2015; Kwon et al., 2017). Both studies averaged gait data from multiple walk cycles over a pressure sensitive mat (six and 10 walks, respectively). As the current study employed a single trial, discrepant results may be justified by distinct learning effects on the gait dynamics of the control group. Moreover, the gait initiation segment before entering the mat in our and other studies might have also affected the results. Overall, our data suggests that differences between walking forward and back might be a better marker of gait abnormalities in early stages of PD than simple spatio-temporal gait parameters.

Some limitations of this study need to be mentioned. The most important is that the subjects sample size was relatively small and may not have been representative enough of larger populations of different age groups. However, the number of patients and healthy subjects proved to be sufficient for preliminary research which managed to test and evaluate the basic attributes of the TUG test. Another limit of this study is that only one trial was measured per subject. Further studies should examine repeatability of both parts of gait, i.e. walking forward and back.

In conclusion, we have documented significant differences in the parameters of walking forward and walking back subtasks of the TUG which are more pronounced in patients with Parkinson's disease compared to controls. Taking into account that both parts of gait (forward, back) might be biased by previous and ongoing sub-tasks, i.e. sit-to-stand transition, turn maneuver, and stand-to-sit transition the parameter analysis of its entirety instead of analysing the parts separately could lead to neglectation of information that might be of high clinical importance. Therefore, the analysis of both gait parts should be performed separately.

Table 2

Descriptive statistics of all parameters (mean and standard deviation) and statistical evaluation of walking forward and walking back (p-value). bolded - statistically significant difference ($p < 0.05$), * differences significant at the Holm-Bonferroni-corrected level (for 17 tests performed, $p < 0.002$).

	Walking forward		Walking back		Difference between walking forward and back		t-test of forward vs back data (p-value)	
	PD	HC	PD	HC	PD	HC	PD	HC
Velocity (cm/s)	111.90 (25.52)	108.90 (14.35)	104.61 (23.55)	105.76 (15.50)	7.29 (6.27)	3.14 (6.07)	<0.001*	0.034
Step count (steps)	5.62 (0.96)	5.80 (0.63)	6.15 (1.07)	6.10 (0.88)	-0.54 (0.66)	-0.30 (0.67)	0.136	0.162
Cadence (steps/min)	109.88 (15.07)	105.79 (8.82)	107.89 (14.37)	106.35 (9.43)	1.99 (4.45)	-0.56 (2.37)	0.037	0.465
Step time (s)	0.56 (0.08)	0.57 (0.05)	0.63 (0.24)	0.57 (0.05)	-0.07 (0.22)	<0.01 (0.02)	0.236	0.302
Step Length (cm)	60.45 (7.60)	61.5 (4.75)	57.61 (7.33)	59.48 (4.95)	2.84 (1.51)	2.01 (2.40)	<0.001*	0.007
Cycle Time (s)	1.12 (0.16)	1.14 (0.11)	1.19 (0.27)	1.14 (0.10)	-0.07 (0.21)	<0.01 (0.04)	0.187	0.258
Stride Length (cm)	120.92 (15.12)	123.16 (9.47)	115.44 (14.83)	119.58 (9.96)	5.48 (2.93)	3.58 (4.60)	<0.001*	0.007
Support Base (cm)	9.32 (3.02)	10.25 (2.51)	9.98 (2.65)	9.87 (2.69)	-0.66 (1.57)	0.38 (1.03)	0.368	0.112
Swing perc. (%)	37.31 (2.43)	37.10 (2.35)	35.27 (3.56)	36.98 (1.91)	2.04 (3.17)	0.12 (1.82)	0.008	0.181
Swing time (s)	0.41 (0.05)	0.42 (0.04)	0.41 (0.04)	0.42 (0.03)	0.01 (0.02)	<0.01 (0.03)	0.071	0.346
Stance perc. (%)	62.71 (2.43)	62.92 (2.35)	64.73 (3.56)	63.03 (1.92)	-2.02 (3.16)	-0.11 (1.82)	0.007	0.185
Stance time (s)	0.70 (0.12)	0.72 (0.08)	0.78 (0.24)	0.72 (0.08)	-0.08 (0.21)	<0.01 (0.02)	0.126	0.247
Single support perc.(%)	37.37 (2.34)	37.26 (2.02)	35.24 (3.62)	36.96 (1.90)	2.13 (3.16)	0.29 (1.35)	0.006	0.172
Single support time (s)	0.41 (0.05)	0.42 (0.04)	0.41 (0.04)	0.42 (0.03)	0.01 (0.02)	<0.01 (0.03)	0.071	0.346
Double supp. perc. (%)	24.73 (4.51)	26.66 (7.98)	28.88 (5.72)	26.45 (3.93)	-4.15 (4.30)	0.21 (7.11)	0.001*	0.306
Double supp. time (s)	0.28 (0.09)	0.30 (0.08)	0.36 (0.17)	0.30 (0.07)	-0.08 (0.14)	<0.01 (0.06)	0.033	0.234
Stride velocity (cm/s)	112.12 (25.27)	108.36 (14.23)	101.86 (25.46)	106.35 (15.49)	10.26 (11.90)	2.01 (5.59)	0.001*	0.051

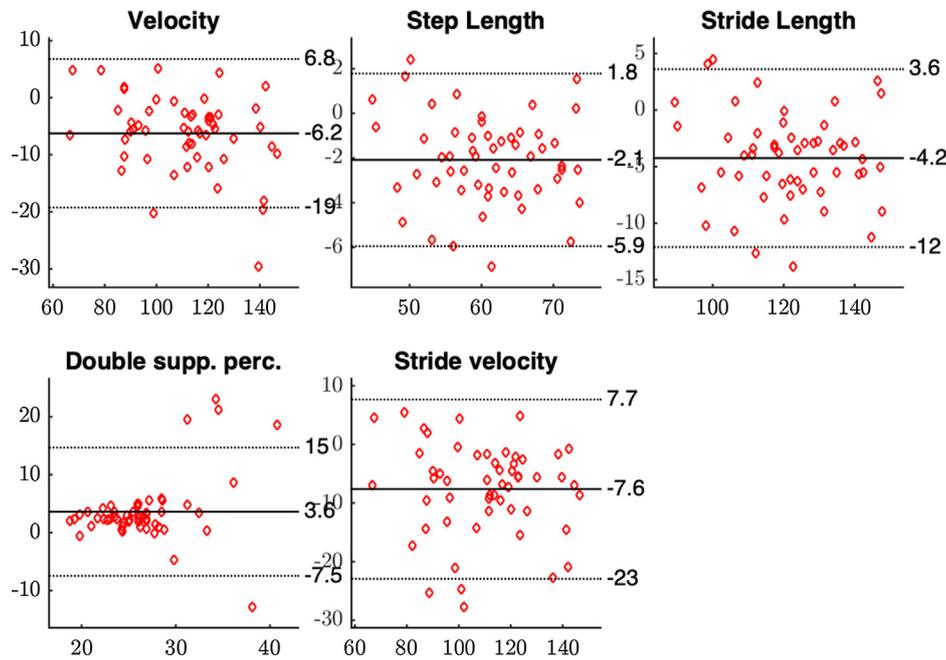


Fig. 1. Bland-Altman plots showing the differences between walking forward and walking back vs. the mean of the two gait subtasks in PD. The x-axis represents the parameter mean of walking forward and walking back; y-axis represents the parameter difference between walking forward and walking back (a positive value denotes a higher value for walking back); solid line: mean difference of all subjects, dotted lines: confidence interval limits for mean difference ($\pm 1.96SD$).

Table 3

Comparison of PD patients and healthy controls (p-value). bolded - statistically significant difference ($p < 0.05$), * differences significant at the Holm-Bonferroni-corrected level (for 17 tests performed, $p < 0.002$).

	Walking forward (p-value)	Walking back (p-value)	Difference between walking forward and back (p-value)
Velocity	0.647	0.853	0.031
Step count	0.469	0.858	0.244
Cadence	0.296	0.685	0.017
Step time	0.579	0.308	0.121
Step Length	0.599	0.341	0.121
Cycle Time	0.641	0.470	0.122
Stride Length	0.571	0.296	0.120
Support Base	0.282	0.888	0.010
Swing perc.	0.770	0.064	0.014
Swing time	0.566	0.161	0.355
Stance perc.	0.779	0.065	0.014
Stance time	0.700	0.289	0.077
Single support perc.	0.860	0.065	0.011
Single support time	0.566	0.161	0.355
Double supp. perc.	0.307	0.117	0.022
Double supp. time	0.421	0.173	0.020
Stride velocity	0.563	0.498	0.003

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Conflict of interest

The authors declare no conflict of interest.

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