Exploring Differences in Gait Assessment Using Inertial Sensors Among Elderly

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Abstract
Introduction: The general life expectancy for the elderly over 60's is constantly growing and with old age the risk of chronic diseases and health limitations increases. This leads to an increasing need for facilities in the health and social system. Being aware of the necessities of instrumented assessment we can act better to prevent falls, understand different gait patterns, and improve quality of life in this category. **Objective**: For this study, we aimed to analyze and identify the differences and/or similarities found after the assessment of the elderly with and without Parkinson's disease in terms of gait and risk of falling with the help of inertial sensors. **Methods**: A total of 20 participants were recruited for this study, 10 elderly people without neurological pathologies (mean age 76 ± 7.13 years) and 10 participants with Parkinson's disease (mean age 72.7 ± 8.32 years). The measurements were performed using the inertial sensor G-Walk, which transmitted information via Bluetooth to the software while participants were asked to perform the Timed Up and Go Test (TUG) and then the walking analysis over a distance of 10 meters. Results: For the TUG test only 5 out of the 17 variables extracted for the analysis, were statistically significant different. The Parkinson Disease group had a higher risk of falling compared to the elderly group, without neurological pathologies. **Conclusions**: BTS G-WALK system provide an accurate and reliable method of assessment, detecting even minimal changes in the patient's motor performance, which is impossible in case of classical assessments. This assessment, which is essential in the field of rehabilitation, helps specialists in the field to identify, quantify and monitor the effectiveness of recovery treatments and intervention programs.

Keywords: *risk of falling; gait; Parkinson; elderly; inertial sensors.*

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1. Introduction

The World Health Organization (WHO) estimates that by 2050, the global population of the elderly over 60 will increase to 2 billion, compared to 900 million in 2015. The general life expectancy for this category is constantly growing and with old age the risk of chronic diseases and health limitations rises, leading to an increasing need for facilities in the health and social system (World HealthOrganization, 2022). Along with the increase in life expectancy, the interest in finding effective solutions for improving the quality of life become more acute. More and more researchers are looking for solutions to identify the best methods of evaluation (Frontera, 2003). The necessity of using innovative technologies in the medical field made the utilization of wearable inertial sensors in the assessment and rehabilitation field a must (Bonato, 2005; Ruiz-Ruiz, 2021).

Based on recent surveys, the prevalence of neurological diseases in the elderly population is increasing. (Dumurgier & Tzourio, 2020) Among these neurological diseases Parkinson’s is one of the most encountered, being based on the progressive degeneration of various areas of the brain that produce dopamine and mostly affecting people over 50 years. (Slaughter, 2001)

Bradykinesia, stiffness, rest tremor and postural instability are the hallmarks of the disease and have a negative impact on movement quality, gait performance, balance, and risk of falling (Brodie, 2014). In addition, non-motor features such as cognitive decline, fatigue, apathy, and depression are common and substantially affect patient functioning and quality of life (Rizos, 2014).

Inertial sensors are an excellent option for evaluating the biomechanics of human movement (Kobsar, 2020). These technologies use accelerometers, magnetometers and gyroscopes and can be a bridge between the complex systems found in movement analysis laboratories and clinical systems. They bear a potential for dynamic three-dimensional analysis of gait without the various constraints like space or costs (Muro-de-la-Herran, Garcia-Zapirain, & Mendez-Zorrilla, 2014).

In recent years, the validity and reliability of wearable inertial sensors have been the subject of many studies (Macadam, Cronin, Neville, &

Diewald, 2019) (Mark, Schall, Chen, & Cavuoto, 2022), including fall risk assessment in which researchers (Montesinos, 2018) showed that inertial sensors provides an objective data and a greater accuracy.

The aim of the present research was to analyze and identify the differences and similarities, found after the assessment of the elderly without neurological pathologies and Parkinson's disease patients, in terms of gait and risk of falling with the help of inertial sensors.

2. Materials and Methods

A total of 20 participants from Cluj-Napoca were recruited for this study, 10 elderly people without neurological pathologies (mean age 76 ± 7.13 years) and 10 participants with Parkinson's disease (mean age 72.7 ± 8.32 years). The demographic and anthropometric characteristics of the subjects are summarized in Table 1.

Table 1. Demographic and anthropometric characteristics of the subjects

Group	*Subjects (n)*	*Gender (F /M)*	*Age (years)*	*Weight (kg)*	*Height (m)*	*BMI*
Parkinson's	**10**	**7/3**	**72.7 ± 8.32**	**79.4± 23.09**	**1.61± 1.14**	**30.43± 6.77**
Elderly	**10**	**8/2**	**76 ± 7.13**	**74.10± 13.11**	**1.62± 1.17**	**28.13± 3.76**

Mean ± standard deviation, BMI - body mass index

From the point of view of demographic and anthropometric data, no significant differences were identified between the two groups. The patients were informed about the study and gave their consent by signing the informed consent form, assuring them of the confidentiality of the recorded data.

The inclusion criteria for the elderly group were:

- the ability to walk without physical assistance or assistive devices,
- the absence of neurological diseases,
- age over 60 years.

For the Parkinson's group, the inclusion criteria were:

- patients with confirmed Parkinson's disease,

- permission from the neurologist to carry out physical activity,
- Hoehn & Yahr scale (H&Y) ≤3 in Levodopa “ON” conditions,
- partial or total autonomy of the patient to walk.

For the present study we used as an assessment tool the BTS G-Walk system (BTS Bioengineering S.p.A. Italy), a wireless system consisting of an inertial sensor, composed of a triaxial accelerometer, a magnetic sensor, and a triaxial gyroscope that is positioned on the L5 vertebra allowing a functional analysis of gait. (Bissolotti, Gaffurini, & Meier, 2015)

The tests performed using the G-Walk system were as follows:

The Timed Up and Go (TUG) test is widely used in healthcare to assess fall risk and distinguish between high and low fallers. Also, the TUG test, in addition to the risk of falling, assesses the tested person's mobility and balance. Before sitting in the chair, the patient was strapped with the G-Walk sensor at the L5-S1 level. Then the patient sat on a chair, with his back against its back and his feet on the ground. It is recommended to use a chair with the seat at a height of 44-47 cm. The patient stands up at the therapist's command: he walks 3 meters at a comfortable speed, turns around, bypassing the 3-meter mark and sits down after turning his back to the chair. Timing starts at the “Start” command and stops when the patient is back in the chair.

There are several opinions regarding the interpretation and normal values of this test, the average times obtained varying according to the study and the participants. According to Shumway-Cook et. all if a patient performed the test in 14 seconds or more, then he was classified as at high risk of falling (Shumway-Cook, 2000). Average TUG scores can range from 8 to 12 seconds (in people with Parkinson's disease) to 13.5 seconds (elderly) or 15 seconds (if subjects have fallen prior to the test or have a double duty) (Morris, 2001).

Following the TUG evaluation, an individual report was generated on the evaluated parameters: duration of TUG analysis, fall risk. Also, the assessment with the G-Walk sensor allowed us to analyze this test in stages, more precisely the values obtained in seconds for different parameters: rising from the chair, walking forward, bypassing the 3 m sign, turning, sitting on the chair, acceleration anterior-posterior, lateral, vertical. This would not have been possible through a classic evaluation.

Gait analysis – 10 m walking test

After establishing the distance of 10 meters in the corridor of the institution, we trained the patients in sight covering the predetermined distance, at a speed at which he usually walks. After that, he was fitted with the belt with the G-Walk sensor, at the L5-S1 level. The BTS G-Walk system measures gait cycles performed by the right lower limb and the left lower limb.

The data obtained after the gait evaluation: the qualitative index of the walking cycles performed by the left lower limb LEFT WALK QUALITY INDEX, respectively the right lower limb – RIGHT WALK QUALITY INDEX, the symmetry index that shows the symmetry between the walking cycles performed by the right lower limb compared to the left lower limb and propulsion

Main characteristics obtained from the evaluation:

1. analysis of the spatio-temporal parameters of walking:

- evaluation duration (evaluated in seconds)
- cadence (number of steps/minute)
- walking speed (meters/second)
- the length of the walking cycle for the left side and for the right side expressed in meters
- the length of the walking cycle for the left side and for the right side expressed as a percentage
- the number of steps analyzed

2. analysis of the symmetry of the pelvic kinematics in the three planes: sagittal, frontal, and transverse.

In our research, we considered only the spatio-temporal parameters for the statistical analysis.

3. Statistical Analysis

In the framework of the preliminary research, the data obtained from the evaluations were exported to Microsoft Excel following their processing and interpretation with the help of IBM SPSS Statistics 23 (Statistical Package for Social Sciences) statistical program, that allowed the creation of statistical-mathematical indices such as:

- Mean
- Standard deviation.
- Minimum value.
- Maximum value.

T-tests were performed to compare groups for age, body mass, and body height. The first tests applied in the statistical analysis were the Shapiro-Wilk test for testing the normality of the data distribution and the homogeneity of variance test (Levene's). The meaning statistic was set at a threshold value of 0.05. The effect size was calculated with the formula Cohen's ratio given by the ratio of the difference of the means (M) of the two groups to the mean of the standard deviations (SD) of the two groups, as follows: *effect size = M1(gr1) – M2(gr2)/ (SDgr1 + SDgr2)/2* (Cohen, 1988)

4. Results

The total duration of the TUG test varied greatly between the two groups (table 2), the software automatically classifying those in the Parkinson's group as being at increased risk if they recorded values >12 s.

Recorded values ranged from 10.76 to 37.85 s for both groups. The subjects in the elderly group obtained an average TUG time of 14.10 ± 2.25 and those in the Parkinson's group obtaining an average time of 23.65 ± 9.74 s, the result being statistically significant different between the two groups in terms of TUG duration (p=0.007, Cohen's d=1.34).

Table 2. Spatiotemporal parameters for timed up and go test (TUG)

TUG Parameters	Group	Mean	Standard deviation	Standard error	*p*
TUG analysis duration	EG	14,104	2,256	0,713	0,007
	PD	23,652	9,745	3,082	
Forward gait (s)	EG	3,524	1,787	0,565	0,134
	PD	7,534	7,879	2,492	
Mid turning (s)	EG	2,921	0,652	0,206	0,064
	PD	3,516	0,695	0,220	
Return gait (s)	EG	3,174	1,360	0,430	0,452
	PD	4,339	4,594	1,453	

TUG Parameters	Group	Mean	Standard deviation	Standard error	*p*
End turning (s)	EG	1,700	0,772	0,244	0,005
	PD	2,842	0,838	0,265	
STS duration (s)	EG	0,980	0,282	0,089	0,034
	PD	1,410	0,522	0,165	
STS AP acc m/s²	EG	1,464	0,536	0,170	0,419
	PD	1,717	0,804	0,254	
STS lateral acc	EG	0,988	0,503	0,159	0,517
	PD	0,838	0,512	0,162	
STS vertical acc	EG	2,513	0,552	0,175	0,479
	PD	2,828	1,263	0,399	
Stand TS duration	EG	1,634	0,524	0,166	0,907
	PD	1,610	0,367	0,116	
Stand TS AP acc	EG	2,152	1,109	0,351	0,004
	PD	0,914	0,445	0,141	
Stand TS lateral acc	EG	2,022	0,824	0,260	0,048
	PD	1,294	0,702	0,222	
Stand TS vertical acc	EG	2,652	1,381	0,437	0,849
	PD	2,512	1,838	0,581	
STS flexion peak	EG	23,750	9,501	3,004	0,204
	PD	29,860	11,175	3,534	
STS extension peak	EG	18,430	6,532	2,066	0,578
	PD	20,070	6,401	2,024	
Stand TS flexion peak	EG	30,750	6,125	1,937	0,578
	PD	28,810	8,932	2,825	
Stand TS extension peak	EG	7,360	5,406	1,710	0,062
	PD	3,790	1,697	0,537	

TUG – Timed Up and Go; STS – Sit to Stand; AP – antero-posterior; STS – Sit To Stand; Stand TS – Stand To Sit; acc – acceleration; EG – Elderly Group; PD – Parkinson's Disease

From the 17 variables extracted for analysis (table 2), only 4 were found to be statistically significant different, more precisely: the End Turning at 180^0 (p=0.005, Cohen d=1.41), the time to get up from the chair in STS (p=0.034, Cohen d=1.02), the antero-posterior acceleration during Stand to Sit AP acc (p=0.004, Cohen d=1.46) and the lateral acceleration Stand to sit lateral acc (p=0.048, Cohen d= 0.95).

Table 3. Gait parameters

Gait Parameters	Group	Mean	Standard deviation	Standard error	*p*
Walk QI left	EG	93.45	3.43	1.09	0.953
	PD	93.35	3.92	1.24	
	EG	93.76	3.59	1.14	

Gait Parameters	Group	Mean	Standard deviation	Standard error	*p*
Walk QI right	PD	92.87	8.39	2.65	0.761
Symmetry Index	EG	93.14	3.40	1.07	0.490
	PD	91.34	7.33	2.32	
Strides Length (m)	EG	1.10	0.14	0.04	0.504
	PD	1.06	0.14	0.05	
Left Stride duration (s)	EG	1.05	0.09	0.03	0.001
	PD	1.30	0.17	0.05	
Right Strides duration (s)	EG	1.04	0.08	0.03	0.001
	PD	1.30	0.18	0.06	
Propulsion Index Left	EG	5.78	1.36	0.43	0.017
	PD	4.22	1.30	0.41	
Propulsion Index Right	EG	5.54	1.56	0.49	0.019
	PD	3.87	1.31	0.42	
Cadence (steps/min)	EG	116.39	9.35	2.96	0.002
	PD	99.73	11.05	3.49	
Speed (m/s)	EG	1.06	0.17	0.05	0.018
	PD	0.87	0.17	0.05	

QI – Quality Index; (m) – meters; (s) – seconds; EG – Elderly Group; PD – Parkinson's Disease

Table 3 shows the parameters analyzed after the gait assessment. Out of the 10 parameters analyzed, significant differences could be observed between the two groups for the following variables: left and right stride duration (p=0.001, with strong effect size Cohen d=1.82, respectively d=1.83), left/right propulsion (p=0.017/p=0.019, with a strong effect size Cohen d=1.17, respectively d=1.15), cadence (p=0.002, Cohen d=1.62) and speed (p=0.018, Cohen d=1.16). As a conclusion, the elderly group without neurological pathologies presents significant differences, when compared to the one with Parkinson's disease, regarding the analysis of walking.

5. Discussion

Gait analysis using an inertial sensor system is indicated both in elderly people without neurological disease and in people suffering from neurological diseases, in our case Parkinson's disease, as it allows detailed quantitative and qualitative assessments, useful in scientific research and clinical practice.

The use of the BTS G-Walk instrument in the evaluation of the patients allowed us to carry out a complete initial analyzes, the tests being easy to perform generating results that could be compared with normal intervals.

The BTS G-Walk system offers a precise and reliable evaluation method, even detecting the patient's motor performance changes, which is impossible in the case of a classic evaluation. This evaluation, essential in the field of rehabilitation, helps doctors and specialists analyze and quantify the effectiveness of treatments and rehabilitation therapies.

Following the comparative analysis between people with Parkinson's disease and the elderly without neurological pathologies we could identify more than one variable, different from a statistical point of view. Thus, the most significant differences among people without Parkinson were encountered for the analysis of gait, where out of 10 parameters analyzed, 6 were identified being significant different, more precisely stride duration, propulsion index for both legs, cadence, and speed.

For TUG analysis out of the 17 variables extracted for analysis we could see statistically significant differences only for 5 of them. The PD group, having a higher risk of falling compared to elderly group. Time obtained for End turning 180^0 (p=0.005, Cohen D=1.41), Sit to Stand STS (p=0.034, Cohen D=1.02), antero-posterior acceleration during sitting stool stand to sit APC (p=0.004, Cohen D=1.46) and the side acceleration stand to lateral site (p=0.048, Cohen D=0.95) being statistically significant different for the two groups.

References

Bissolotti, L., Gaffurini, P., & Meier, R. (2015). *BTS G-WALK version 3.1.0 clinical notebook english.* Kassel Group Inc.

Bonato, P. (2005). Advances in wearable technology and applications in physical medicine and rehabilitation. *J NeuroEngineering Rehabil, 2*(2). doi: https://doi.org/10.1186/1743-0003-2-2

Brodie, M. A. (2014). Gait as a biomarker? Accelerometers reveal that reduced movement quality while walking is associated with Parkinson's disease, ageing and fall risk. *36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society* (pp. 5968-5971). Chicago, IL, USA: IEEE. doi: 10.1109/EMBC.2014.6944988.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences.* New York: Routledge.

Dumurgier, J., & Tzourio, C. (2020). Epidemiology of neurological diseases in older adults. *Revue Neurologique, 176*(9), 642-648. doi:https://doi.org/10.1016/j.neurol.2020.01.356.

Frontera, W. (2003). The importance of technology in rehabilitation. *IEEE engineering in medicine and biology magazine : the quarterly magazine of the Engineering in Medicine & Biology Society,*.

Kobsar, D. C. (2020). Validity and reliability of wearable inertial sensors in healthy adult walking: a systematic review and meta-analysis. *J NeuroEngineering Rehabil,* -. doi:https://doi.org/10.1186/s12984-020-00685-3

Macadam, P., Cronin, J., Neville, J., & Diewald, S. (2019). Quantification of the validity and reliability of sprint performance metrics computed using inertial sensors: A systematic review. *Gait & Posture, 73*, 26-38. doi:https://doi.org/10.1016/j.gaitpost.2019.07.123.

Mark, C., Schall, J., Chen, H., & Cavuoto, L. (2022). Wearable inertial sensors for objective kinematic assessments: A brief overview. *Journal of Occupational and Environmental Hygiene*, 501-508. doi:DOI: 10.1080/15459624.2022.2100407

Montesinos, L. &. (2018). Wearable Inertial Sensors for Fall Risk Assessment and Prediction in Older Adults: A Systematic Review and Meta-Analysis. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*. doi:10.1109/TNSRE.2017.2771383.

Morris, S. M. (2001). Reliability of measurements obtained with the Timed "Up & Go" test in people with Parkinson disease. *Physical therapy*, 810-8.

Muro-de-la-Herran, A., Garcia-Zapirain, B., & Mendez-Zorrilla, A. (2014). Gait Analysis Methods: An Overview of Wearable and Non-Wearable Systems, Highlighting Clinical Applications. *Sensors*, 3362–3394. doi:http://dx.doi.org/10.3390/s140203362

Rizos, A. M.-M.-M. (2014). Characterizing motor and non-motor aspects of early-morning off periods in Parkinson's disease: an international multicenter study. *Parkinsonism & related disorders*, 1231–1235. doi:https://doi.org/10.1016/j.parkreldis.2014.09.013

Ruiz-Ruiz, L. J.-V. (2021). Detecting Fall Risk and Frailty in Elders with Inertial Motion Sensors: A Survey of Significant Gait Parameters. *Sensors, 21*(20), -. doi:https://doi.org/10.3390/s21206918

Shumway-Cook, A. B. (2000). Predicting the probability for falls in community-dwelling older adults using the timed up & go test. *Phys Ther*, 896-903.

Slaughter, J. S. (2001). Prevalence, clinical manifestations, etiology, and treatment of depression in Parkinson's disease. *Journal of Neuropsychiatry and Clinical Neurosciences*, 187-196.

Tinetti, M., & Kumar, C. (2010). The patient who falls: it's always a tradeoff. *JAMA*, 258-266.

World HealthOrganization. (2022). *Ageing*. Retrieved from http://www.who.int.