

Spatio-Temporal Gait Parameters in Association with Medications and Risk of Falls in the Elderly

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Purpose: The aim of this study was to analyze factors affecting spatio-temporal gait parameters in elderly people of both genders and different ages with different risks of fall, fall history, and medications.

Patients and Methods: A total of 210 community-dwelling older adults (156 females, 54 males; mean age 72.84±6.26 years) participated in this study. To assess the risk of falls, the Downton Fall Risk Index was used. An additional question about medication intake (all prescribed drugs) was asked. To assess the spatio-temporal gait parameters, the Zebris FDM platform was used. Gait parameters and Downton Fall Risk Index, stratified by participants' history of falls, multiple medication use (0/1/2+), gender, age, and medication categories, were statistically analyzed using the Mann–Whitney *U*-test and Kruskal–Wallis test.

Results: When comparing different medication categories, a Downton Fall Risk Index score indicating a high risk of falls was observed in the psychotropic medication category (3.56±1.67). A gait velocity suggesting a higher risk of falls (≤ 3.60 km/h) was observed in the psychotropic (2.85±1.09 km/h) and diabetes (2.80±0.81 km/h) medication categories, in the age groups 70–79 years (3.30±0.89 km/h) and 80+ years (2.67±0.88 km/h), and in participants using two or more medications (3.04±0.93 km/h).

Conclusion: The results of this study confirm previous observations and show that higher age and multiple medication negatively affect the gait, and that the higher risk of falls is associated with psychotropic and diabetes medication use. These results provide important information for future fall preventive programs for the elderly that would be especially beneficial for elderly people taking psychotropic and diabetes medication.

Keywords: aging, medication, risk, falls, gait velocity

Introduction

Falls are one of the most common causes of injuries, hospitalization, and deaths among the elderly.^{5,17} As the majority of falls occur during locomotion,¹⁸ gait evaluation is recommended in current fall prevention guidelines for older people.¹⁹ With higher age, the medio-lateral margin of stability, pace, and base of support change.⁴⁷ New technologies such as deep brain stimulation implants have been introduced to treat the motor symptoms typical of some diseases (eg, Parkinson's disease).⁴⁸ Still, the association between medications and abnormalities in gait pattern in older people is unclear.

Medication use is one of the risk factors associated with falling in elderly people owing to its adverse effects, such as unsteadiness, impaired alertness, or dizziness.¹ The risk of falling and its negative consequences increase with the number of consumed medications,² especially when an antidepressant or a benzodiazepine is included,³ and with prolonged use of the medication.⁴ Drugs that increase the risk of a fall include medication for cardiovascular diseases, such as digoxin and type 1a antiarrhythmics, and diuretics, benzodiazepines, antidepressants, antiepileptics, antipsychotics, antiparkinsonian drugs, opioids, and urological spasmolytics.⁵ Psychotropic and cardiovascular medications have been most strongly associated with an increased risk of falling in elderly people in previous studies.^{1,4–10} Compared to their healthy peers, the gait of elderly people with higher depressive symptoms is characterized by slower velocity, and increased stride and swing time variability.¹¹ Similarly, cardiovascular diseases have been observed to impair the gait

velocity in the elderly.¹² Both low and high thyroid function are associated with alterations in gait velocity and the base of support.¹³ Diabetes mellitus has also been observed to alter the gait pattern in the elderly by decreasing the gait velocity and cadence and increasing the stride time.¹⁴ Previous studies show that changes in spatio-temporal gait parameters, eg, a gait velocity below 3.60 km/h, or in step length, increase the fall risk in the elderly.^{15,16,46} Furthermore, elderly fallers have been observed to show a longer stance phase, with increased double-stance phase during the gait.⁴⁶

Understanding the gait strategies of elderly people using different medications and with different risk of falls may lead to effective interventions (eg, preventive exercise programs) aimed at preventing falls in the elderly. The aim of this study was to analyze the spatio-temporal gait parameters in elderly people of both genders and different ages with different fall risk, fall history, and medication use.

Patients and Methods

Study Participants

A total of 210 community-dwelling older adults (156 females, 54 males) from the city of Brno, Czech Republic, and its rural surroundings participated in this study. The inclusion criteria for participating in this study consisted of being >60 years of age and being able to walk at least 10 m without aid. The exclusion criteria consisted of dementia or severe cognitive impairment, wearing a limb prosthesis, hip or knee arthroplasty, and using a walking aid, as using a walking aid limits gait analysis testing.³⁸ Informed consent was provided by all participants before participating in the study. The study was performed according to the Declaration of Helsinki and was approved by the Research Ethical Committee of Masaryk University (EKV-2020-007).

Participants' characteristics can be found in Table 1. The mean age of participants was 72.94±5.92 and 73.07±6.18 years for females and males, respectively. The mean weight and height were significantly different between females and males ($p<0.001$); however, no statistically significant difference in body mass index (BMI) was observed (29.95±5.85 and 28.57±4.31 kg/m² for females and males, respectively). The number of medications used differed significantly between females and males ($p=0.001$). The mean number of medications used was higher in females (1.65±1.11) compared to males (1.09±0.83). The mean Downton Fall Risk Index did not differ with statistical significance between genders.

Fall-Risk Assessment

The Downton Fall Risk Index was used to assess the risk of falls. A trained kinesiologist (MG, LS, MS) performed the Downton Fall Risk Index assessment. The Downton Fall Risk Index consists of 11 risk factors divided into five categories: 1) previous falls (yes; no; reported by participants themselves), 2) medication (none; sedatives; diuretics; antihypertensives; antiparkinsonian drugs; antidepressants; other medication), 3) sensory deficit (none; visual impairment; hearing impairment;

Table 1 Participants' Characteristics, Divided by Gender

	Females (n=156)		Males (n=54)		p	All (n=210)	
	Mean	SD	Mean	SD		Mean	SD
Mean age (years)	72.94	5.92	73.07	6.18	0.935	72.84	6.26
Mean weight (kg)	76.64	15.42	85.69	13.30	0.000*	78.96	15.39
Mean height (cm)	159.99	6.77	173.26	6.08	0.000*	163.40	8.78
Mean BMI (kg/m ²)	29.95	5.85	28.57	4.31	0.216	29.60	5.52
Number of medications	1.65	1.11	1.09	0.83	0.001*	1.50	1.07
Downton Fall Risk Index	2.21	1.34	1.96	1.45	0.150	2.14	1.37

Note: *Statistically significant difference.

limb impairment), 4) mental state (oriented; confused), and 5) gait (safe without walking aids; safe with walking aids; unsafe; unable).³⁹ The score ranges between 0 and 11, with a higher score indicating a higher risk of falls. A score of 3 and more indicates a high risk of falls. Additional question about medication intake (all prescribed drugs) was asked. The Downton Fall Risk Index was used to assess the risk of falls in previous studies by Rosendahl et al²⁰ and Štefan et al.²¹

Medication Assessment

The information about medication obtained from the Downton Fall Risk Index and the additional question about prescribed medication was sorted out into three categories by the number of medications used (none; one; two or more) and into five categories of medication: 1) none, 2) cardiovascular, 3) psychotropic, 4) diabetes, and 5) thyroid function. These five categories covered most of the medications used by our participants.

Spatio-Temporal Gait Parameter Assessment

To assess the spatio-temporal gait parameters, the Zebris platform (FDM; Zebris Medical GmbH, Munich, Germany) was used. The Zebris force distribution measurement platform (sensor area: 149×54.2 cm) with built-in capacitive sensors (number of sensors: 11,264; sampling rate: 100 Hz) enables the measurement and analyses of the force distribution under the feet. All participants were asked to walk barefoot across the platform at their natural speed. The platform was placed in a custom-designed 10-meter-long walkway to provide a level walking surface. Each participant was instructed to walk toward the end of the walkway, then to turn 180° around and continue walking over the platform. This cycle was repeated several times to obtain five step cycles across the platform. This methodology was used also in previous studies by Kasović et al²² and Štefan et al.²¹

Zebris software generated the data regarding gait velocity (km/h), foot rotation (°), step length (cm; % of body height), step width (cm), stance phase (% of the gait cycle), double-stance phase (% of the gait cycle), swing phase (% of the gait cycle), and cadence (steps/min).

In addition, all participants reported their age, and their body height and weight were measured by a portable stadiometer and scale.

Statistical Analysis

Most of the variables did not meet the assumptions of the normal distribution, as tested by the Kolmogorov–Smirnov, Lilliefors, and Shapiro–Wilk tests. The Mann–Whitney *U*-test was used to compare gender differences (participants' characteristics, gait parameters) and history of falls (fallers, non-fallers). To compare the multiple medication use (none, one, two or more drugs), medication category (none, cardiovascular, psychotropic, diabetes, thyroid function), and age groups (60–69, 70–79, 80+ years of age), the Kruskal–Wallis test was used. An alpha level of 0.05 was used to define statistical significance. The statistical analysis was performed using Statistica 14 by TIBCO Software.

Results

In Table 2, spatio-temporal gait parameters, Downton Fall Risk Index, and number of medications used, stratified by history of falls, multiple medication, gender, and age, are shown. Gait parameters for participants with one or more fall history (fallers) and participants with no history of falls (non-fallers) in the past year did not differ with statistical significance. These two groups of participants differed significantly only in the Downton Fall Risk Index ($p < 0.001$), which was higher in fallers. Participants divided by multiple medication use differed with statistical significance in most of the spatio-temporal gait parameters, including gait velocity, step length, cadence, and swing phase, which were lower in people using two or more medications. Gender differences were observed with statistical significance in foot rotation and step width, which were higher in males, and in cadence, which was higher in females. Age groups differed with statistical significance in most of the spatio-temporal gait parameters, as the participants in the 80+ group walked more slowly, with fewer steps per minute and with prolonged double-stance and stance phases of the gait.

Table 2 Gait Parameters Stratified by History of Falls, Multiple Medication, Gender, and Age

		Age (years)	Number of Medications	BMI (kg/m ²)	Downton Fall Risk Index	Velocity (km/h)	Foot Rotation (Degree)	Step Length (cm)	Step Length/Height (%)	Step Width (cm)	Cadence (Steps/min)	Stance Phase (%)	Double-Stance Phase (%)	Swing Phase (%)	
History of falls	Non-fallers (n=122)	Mean	72.97	1.50	29.16	1.69	3.52	9.66	53.54	0.33	11.96	108.76	64.40	28.75	35.60
		SD	6.14	1.05	5.32	1.07	0.89	7.01	10.25	0.06	3.73	13.13	3.35	5.75	3.35
	Fallers (n=82)	Mean	73.01	1.59	30.41	2.95	3.24	8.98	50.55	0.31	12.03	105.04	65.05	30.38	34.95
		SD	5.90	1.07	5.83	1.39	1.02	6.51	11.02	0.07	3.80	15.64	4.24	7.23	4.24
	Mann–Whitney <i>U</i>		4923	4703	4414	2297.5	4186.5	4517	4145	4264	4926.5	4290	4405.5	4308.5	4405.5
	<i>p</i> -Value		0.849	0.470	0.155	0.000*	0.072	0.324	0.058	0.108	0.856	0.123	0.208	0.134	0.208
Medication	Participants taking no drugs (n=32)	Mean	69.84 ^c	0.00 ^c	28.73 ^c	0.97 ^{bc}	3.67 ^c	9.27	56.27 ^c	0.34 ^c	11.95	109.28	64.42	28.37	35.59
		SD	5.66	0.00	5.12	0.86	0.85	5.79	10.23	0.06	3.26	11.75	2.16	3.55	2.16
	Participants taking one drug (n=86)	Mean	72.43 ^c	1.00 ^c	27.98 ^c	1.94 ^{ac}	3.71 ^c	8.21	55.26 ^c	0.34 ^c	11.33	110.46 ^c	63.39 ^c	27.16 ^c	36.61 ^c
		SD	5.96	0.00	4.71	1.02	0.86	6.87	9.42	0.06	3.58	12.98	3.02	4.60	3.02
	Participants taking 2+ drugs (n=92)	Mean	74.57 ^{ab}	2.50 ^{ab}	31.41 ^{ab}	2.74 ^{ab}	3.04 ^{ab}	10.32	48.19 ^{ab}	0.30 ^{ab}	12.59	103.72 ^b	65.92 ^b	31.76 ^b	34.08 ^b
		SD	5.63	0.76	5.86	1.49	0.93	6.93	10.28	0.06	3.96	15.34	4.24	7.59	4.24
	Kruskal–Wallis <i>H</i>		17.859	194.706	17.401	44.628	23.632	5.581	21.693	10.176	3.559	10.176	15.982	21.819	15.982
<i>p</i> -Value		0.000*	0.000*	0.000*	0.000*	0.000*	0.061	0.000*	0.006*	0.169	0.006*	0.000*	0.000*	0.000*	
Gender	Females (n=156)	Mean	72.936	1.647	29.95	2.21	3.42	8.70	51.89	0.32	11.36	108.76	64.81	29.61	35.19
		SD	5.924	1.106	5.85	1.34	1.00	6.94	10.81	0.06	3.75	14.20	4.06	6.79	4.06
	Males (n=54)	Mean	73.074	1.092	28.57	1.96	3.39	11.01	53.55	0.31	13.73	103.17	64.18	28.60	35.82
		SD	6.179	0.830	4.31	1.45	0.78	6.06	9.69	0.06	3.11	13.54	2.24	4.81	2.24
	Mann–Whitney <i>U</i>		4180	3023	3735	3658	4062	3302.5	3810	3462	2550.5	3245.5	4010.5	3849	4010.5
	<i>p</i> -Value		0.935	0.001*	0.216	0.15	0.905	0.033*	0.432	0.088	0.000*	0.023*	0.799	0.495	0.799

Age	60–69 years (n=62)	Mean	66.45 ^{ef}	1.16 ^{ef}	28.87	1.82 ^f	3.99 ^{ef}	8.50	58.26 ^{ef}	0.35 ^{ef}	11.50	113.30 ^{ef}	63.50 ^f	26.89	36.50 ^f
		SD	2.08	0.98	4.84	0.92	0.74	5.77	8.17	0.05	3.45	12.06	2.38	3.39	2.38
	70–79 years (n=118)	Mean	73.74 ^{df}	1.63 ^d	30.17	2.13 ^f	3.30 ^{df}	9.57	51.54 ^{df}	0.32 ^{df}	12.00	105.75 ^d	64.74	29.54	35.26
		SD	2.81	1.10	6.02	1.52	0.89	6.79	10.16	0.06	3.87	13.64	3.26	6.18	3.26
	80+ years (n=30)	Mean	83.43 ^{de}	1.73 ^d	28.87	2.87 ^{de}	2.67 ^{de}	9.77	43.47 ^{de}	0.27 ^{de}	12.82	101.64 ^d	66.58	33.54	33.42
		SD	3.16	0.98	4.58	1.33	0.88	8.55	9.12	0.06	3.73	16.66	6.03 ^d	8.89	6.03 ^d
	Kruskal–Wallis <i>H</i>		166.48	10.959	1.599	12.402	41.808	2.719	42.546	36.402	2.485	14.622	14.623	3849	14.623
	<i>p</i> -Value		0.000*	0.004*	0.450	0.002*	0.000*	0.257	0.000*	0.000*	0.289	0.001*	0.001*	0.495	0.001*

Notes: *Statistically significant difference. Statistically significant difference from participants taking no drugs; ^bstatistically significant difference from participants taking one drug; ^cstatistically significant difference from participants taking 2+ drugs; ^dstatistically significant difference from 60–69 years; ^estatistically significant difference from 70–79 years; ^fstatistically significant difference from 80+ years.

Table 3 Comparison of Downton Fall Risk Index and Gait Parameters in Five Categories of Medication

		Downton Fall Risk Index	Gait Velocity (km/h)	Foot Rotation (°)	Step Length (cm)	Step Width (cm)	Cadence (Steps/min)	Stance Phase (%)	Double- Stance Phase (%)	Swing Phase (%)
None (n=32)	Mean	0.94 ^{bcd}	3.69 ^{CD}	9.34	56.67 ^{cd}	12.11	109.21	64.32	28.25	35.68
	SD	0.85	0.85	5.87	10.15	3.18	11.94	2.12	3.54	2.12
Cardiovascular (n=126)	Mean	2.52 ^{ac}	3.26	10.35	50.67	12.45	106.06	65.17	30.46	34.83
	SD	1.33	0.98	7.02	10.98	3.98	15.29	4.06	7.23	4.06
Psychotropic (n=34)	Mean	3.56 ^{abe}	2.85 ^a	9.38	46.42 ^a	12.93	99.06	66.15	32.54	33.85
	SD	1.67	1.09	6.66	11.28	4.02	17.47	4.47	8.42	4.47
Diabetes (n=23)	Mean	2.57 ^a	2.80 ^a	12.43	44.11 ^a	14.11	105.10	66.99	33.48	33.01
	SD	1.27	0.81	7.32	10.15	4.52	13.63	4.34	7.76	4.34
Thyroid function (n=21)	Mean	1.95 ^c	3.49	8.38	52.23	11.62	109.85	64.49	28.87	35.51
	SD	0.97	0.92	8.94	11.76	3.35	11.51	4.26	6.57	4.26
Kruskal–Wallis <i>H</i>		58.534	18.906	3.517	20.969	4.185	9.094	8.123	11.431	8.123
<i>p</i>		0000*	0.001*	0.475	0.000*	0.381	0.059	0.087	0.022	0.087

Notes: ^aStatistically significant difference. ^bStatistically significant difference from none; ^cstatistically significant difference from cardiovascular; ^dstatistically significant difference from psychotropic; ^estatistically significant difference from diabetes; ^fstatistically significant difference from thyroid function.

A slower mean gait velocity than the cut-off gait velocity of 3.60 km/h, widely used when identifying elderly fallers,^{15,16} was observed in the age groups 70–79 years and 80+ years, in the group using two or more medications, and in both females and males and fallers and non-fallers.

To analyze differences between the five categories of medication, participants using more than one medication were included in all categories of medication that they used. In Table 3, descriptive statistics, and the results of the comparison of the Downton Fall Risk Index and gait parameters in the different medication categories are shown.

When comparing the five categories of medication, a statistically significant difference was observed in the Downton Fall Risk Index between the no-medication (none) category and the cardiovascular, psychotropic, and diabetes medication categories (Figure 1). Gait velocity and step length differed significantly between the none and psychotropic, and none and diabetes categories (Figures 2 and 3). Both gait velocity and step length were higher in the none category compared to psychotropic and diabetes. The mean gait velocity in the cardiovascular, psychotropic, diabetes, and thyroid function categories was slower than the widely used cut-off gait velocity of 3.60 km/h when identifying elderly fallers.^{15,16}

Discussion

The main aim of this study was to analyze factors affecting spatio-temporal gait parameters in elderly people with different fall risk, fall history, and medication use. The results of this study confirm previous observations and show that higher age and multiple medication use negatively affect the gait. However, a higher risk of falls was associated solely with a specific medication use in this study.

A Downton Fall Risk Index score of 3 or more indicates a high risk of falls.²⁰ In a previous study, the Downton Fall Risk Index was confirmed to be a useful tool for predicting the risk of falls in elderly people living in a residential care facility.²⁰ The predictive accuracy of this index has also been confirmed in other populations, such as stroke patients⁴¹ and older hospitalized patients after discharge from hospital.⁴² A mean score on the Downton Fall Risk Index of 3 or more was observed in this study only when stratifying participants into five categories by the

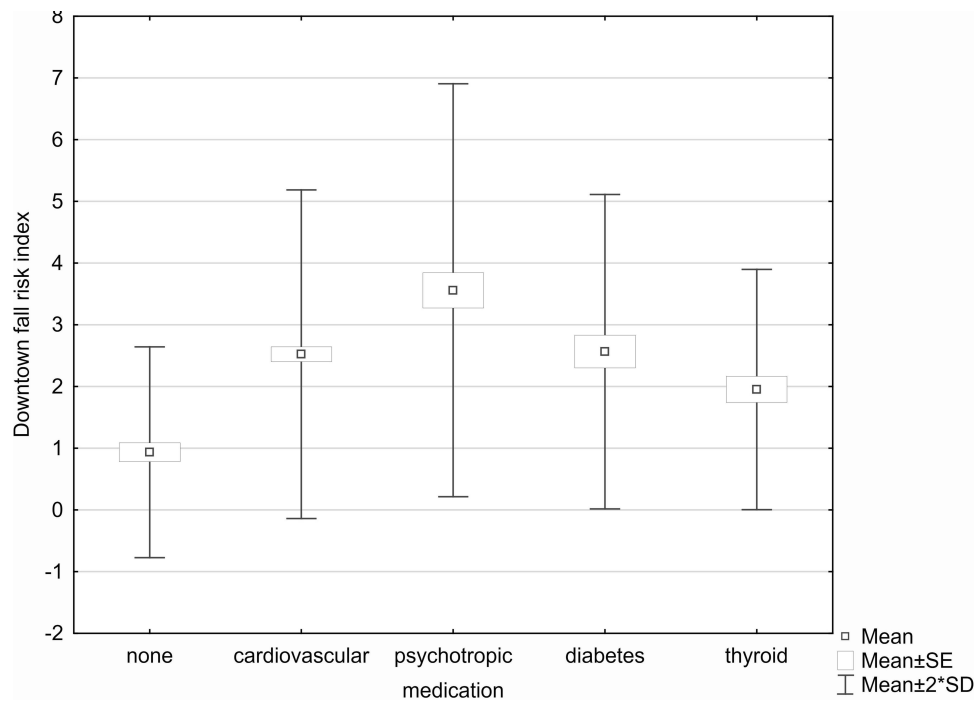


Figure 1 Downton Fall Risk Index. Score ranges from 0 to 11.³⁹

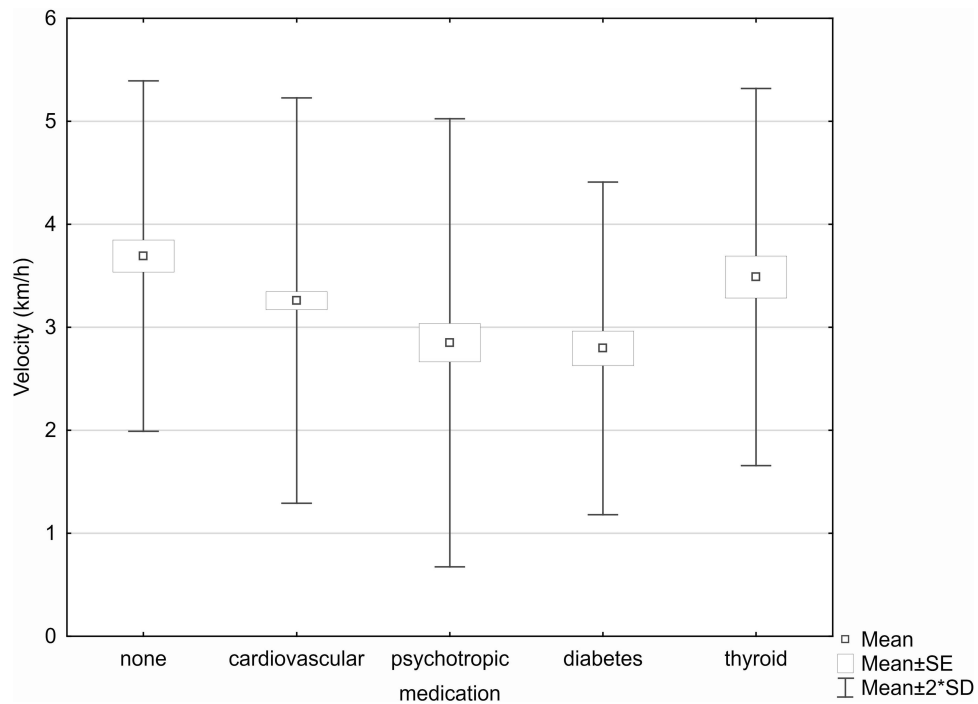


Figure 2 Downton Fall Risk Index grouped by medication categories.

medication that they used. A score indicating a high risk of falls was observed in the psychotropic category. In addition, the psychotropic and diabetes categories were observed to be related to the greatest impairment of the gait, characterized by slower gait velocity and shorter step length, compared to the other medication categories in this

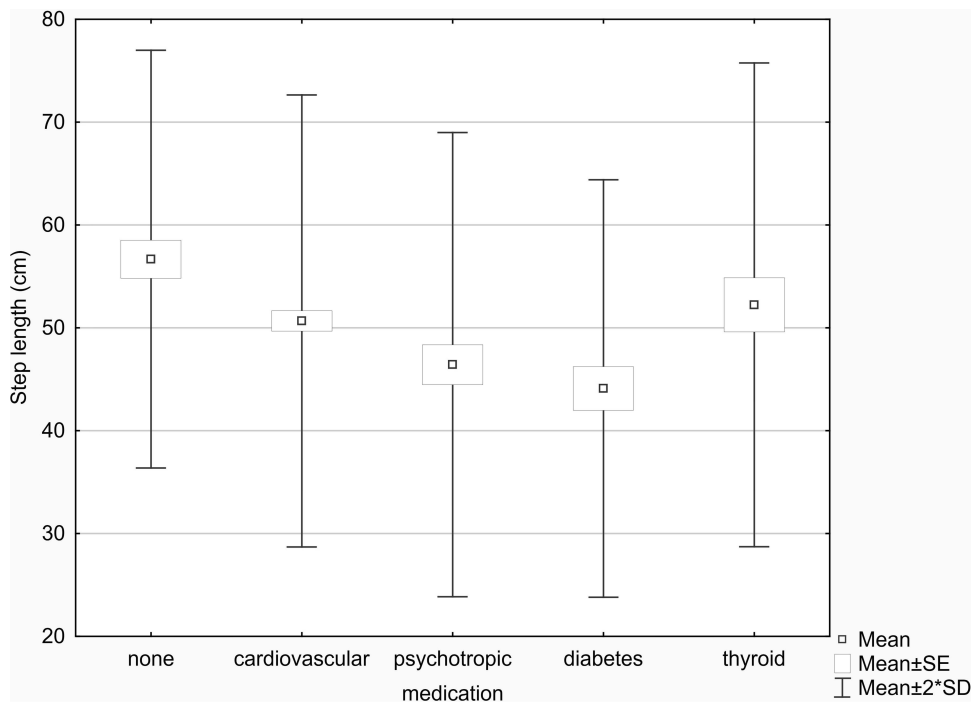


Figure 3 Gait velocity grouped by medication categories.

study. The gait velocity in these categories was slower than the cut-off forward gait velocity of 3.60 km/h that is widely used to identify elderly fallers.^{15,16}

Psychotropics are used as a standard treatment in mental disorders in elderly patients, whereas psychotherapy is rarely provided.²³ Psychotropics are a significant factor that increases the risk of falls.^{24–27} Psychotropics increase the risk of falls by various mechanisms, including sedation, confusion, vision changes, drowsiness, and neuromuscular incoordination.²⁸ Elderly people with diabetes are at higher risk of falls, with the possible risk factors including retinopathy, the most common cause of vision loss in adult age, peripheral neuropathy, which increases postural instability, and hypoglycemia, resulting in dizziness.²⁹ People taking medication in either of these categories should especially benefit from exercise interventions designed to prevent falls. Exercise interventions in elderly people have been observed to reduce the risk of falls. Especially effective were observed to be multiple component group exercises, Tai Chi as a group exercise, and individually prescribed multiple-component exercises for the home.^{30,31} These exercise interventions usually contain balance and strength training, and besides reducing falls they appear to reduce fall-related fractures.³¹ Furthermore, regular exercise has considerable health benefits for people with type 1 diabetes (eg, improved insulin sensitivity) and type 2 diabetes (eg, improved insulin sensitivity and glucose control).⁴³ In previous studies, an association between physical activity and reduced risk of antidepressant, sedative, and sleep medication use was observed.^{44,45} Higher volumes of physical activity showed further benefits for mental health.⁴⁴

The use of multiple medications, ie, taking two or more medications, was observed to negatively affect the gait in this study, decreasing the gait velocity, step length, and cadence. The gait velocity of this group suggests a higher risk of falls.^{15,16} Polypharmacy was also associated with a higher risk of falls in previous studies.^{2,3,18}

The incidence of gait abnormalities increases with advancing age; however, some gait parameters, such as slow gait velocity or short steps, have been recognized as disease markers.^{32,33} An abnormal gait is prevalent in 60% of elderly people at the age of 80 and older.³² This was confirmed by the results of our study. The gait velocity, step length, and cadence were especially affected in the oldest age category in this study. Recognition and monitoring of frailty by a simple test measuring gait speed were suggested in a previous study for the effective care for the elderly,³³ as gait disorders are associated with a greater risk of institutionalization and death.³²

The gender differences observed in this study are similar to those observed in young adults. Shorter stride length, higher cadence, and narrower step width were observed in women compared to men in gait studies in young adults.^{34–36} A higher cadence and narrower step width were also observed in women in this study. In addition, a higher foot rotation angle was observed in males in this study. The foot progression angle and step width are balance-related gait variables and an increase in these variables helps to increase the stability of the gait.³⁷

There are several limitations to this study. The number of participants was limited because of COVID-19 restrictions. Therefore, the number of participants in each category when stratifying the participants by age, gender, history of falls, and medication number and category is not equally distributed. The cross-sectional design of this study represents another limitation, as it does not allow us to discern the cause-and-effect relationship in the analysis of the factors impairing the gait and increasing the risk of falls. The retrospective assessment of the history of falls during the past year represents another limitation, as monthly monitoring of daily reports of falls has been suggested for the standardization of fall events.^{31,40} Future studies focused on prospective recording of falls and gait abnormalities in relationship to medication use will provide more detailed knowledge on this topic.

Conclusion

This study analyzed the spatio-temporal gait parameters in elderly people of both genders and different ages with different risk of falls, fall history, and medication use. The results of this study confirm previous observations and show that higher age and the use of multiple medications negatively affect the gait. Our results when stratifying the participants by medication category show that a higher risk of falls is associated with psychotropic and diabetes medication use. These results provide important information for future fall-prevention programs for the elderly that would be especially beneficial for elderly people taking psychotropic and diabetes medication.

Data Sharing Statement

All the data can be accessed upon reasonable request from the corresponding author.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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