ORIGINAL ARTICLE

Gait characteristics measured with a standard smartphone, muscle weakness, and benzodiazepine in chronic psychiatric patients: a preliminary study

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Abstract

Objectives: To evaluate gait disturbances using a smartphone and reveal the association between gait, muscle strength, and medication in patients with chronic psychiatric disorders.

Methods: Chronic psychiatric patients were recruited from March 2019 to February 2020. We evaluated gait velocity, cadence, and stride length through a 10 m walking test (10mWT), and measured three direction acceleration of the body center of gravity (COG) using the iPhone6. The mean vertical (mVA), medio-lateral (mMLA), and antero-posterior (mAPA) amplitude of the relative trajectory of the COG were calculated from the acceleration data using MATLAB R2016a. Grip strength, drug induced extra-pyramidal symptoms scale (DIEPSS), and medication information were collected. Spearman's rank correlation coefficients were used to investigate associations among gait velocity, cadence, stride length, mVA, mMLA, mAPA, grip strength, and chlorpromazine/diazepam/biperiden equivalent doses. The level of statistical significance was set at $p < 0.05$, and p-values were adjusted using the Benjamini-Hochberg method for multiple comparisons.

Results: Fourteen males and six females participated, with 12 having schizophrenia spectrum disorders. The mean (SD) age and grip strength were 66.2 (12.4) years and 24.6 (8.5) kg, respectively. The mean (SD) velocity, cadence, and stride length were 1.0 (0.4) m/sec, 2.0 (0.2) steps/sec, and 0.5 (0.2) m/step, respectively in 10mWT. Velocity and stride length were significantly associated with mVA and mAPA. Velocity, stride length, and mVA were also significantly and positively related to grip strength, but not DIEPSS and medication. Cadence and mMLA were not related to any gait parameters. Diazepam equivalent doses were positively associated with mMLA.

Conclusion: Muscle weakness may affect gait disturbances with a small step in chronic psychiatric patients. The results suggest that sarcopenia has an impact on the physical performance of such patients. In addition, benzodiazepine medication may affect the impaired balance in these patients.

Key words: *schizophrenia, gait disturbances, gait analysis with a smartphone, relative trajectory of the body center of gravity, benzodiazepine*

INTRODUCTION

Falls are frequent adverse events in patients with chronic psychiatric disorders, and can lead to serious health issues such as fractures and death. In a cohort of 4156 inpatients with psychiatric disorders, the rate of falls was reported as 11.8% (Poster, 1991).

Gait disturbance is one of the risk factors for falls in patients with chronic psychiatric disorders. There are various causes of gait disturbance, such as muscle weakness due to disuse, drug-induced parkinsonism due to antipsychotics, or sedation and muscle hypotonia due to benzodiazepines. Some previous studies have reported gait disturbances in psychiatric patients. The gait of patients with schizophrenia is characterized by low velocity due to a shorter stride length and similar cadence (steps per second) as compared to that of healthy controls (Putzhammer, 2005). Upper body three-dimensional kinematics showed that patients with psychosis walked with reduced arm swing and increased mediolateral thorax movements (Stensdotter, 2012). However, no study has directly evaluated the association between gait and medication in psychiatric

patients.

Wearable sensors, including smartphones, have recently been used to evaluate gait (Ellis, 2015; Yamada, 2018). These sensors are widespread and are easy to use. However, there have been no reports on the gait analysis in patients with chronic psychiatric disorders using smartphones. The aim of this study was to evaluate gait disturbances in patients with chronic psychiatric disorders using a standard smartphone and reveal the relationships between gait, muscle weakness, and medication.

MATERIALS AND METHODS

Participants

We recruited chronic psychiatric inpatients at Mizuma Hospital and patients residing in group home attached to the hospital from March 2019 to February 2020. Inclusion criteria were (1) being treated in psychiatry for over a year, (2) ability to walk alone, and (3) ability to provide informed consent and agreement to participate in the research. This study was approved by the ethics committee of Osaka Kawasaki Rehabilitation University (approval No. OKRU30-A025, Osaka, Japan), following the guidelines for good clinical practice and the Declaration of Helsinki. Verbal and written information was provided, and written informed consent was obtained from all participants before inclusion into the study.

Assessment

We collected the basic characteristics of age, sex, height, weight, grip strength, and type of psychiatric disorder. We also collected the details of medication and calculated chlorpromazine/diazepam/biperiden equivalent doses.

To evaluate gait, the participants performed a 10 m walking test (10mWT) with a standard smartphone on the waist back, and we manually measured the time and steps to calculate gait velocity (m/s), cadence (steps/s), and stride length (m/step). We also measured the acceleration of the body center of gravity (COG) using an accelerometer built in the smartphone. The 10mWT was performed twice on the same participant to evaluate the reliability of gait parameters, and the first result was used for statistical analyses.

Psychiatric symptoms were evaluated using the Brief Psychiatric Rating Scale (BPRS) (Overall and Gorham, 1962), extrapyramidal symptoms with the Drug Induced Extra-Pyramidal Symptoms Scale (DIEPSS) (Inada, 2009), apathy with Apathy Scale (AS) (Starkstein, 1993; Okada, 1997), depression with Beck Depression Inventory Second Edition (BDI-2) (Kojima, 2002), and cognitive impairment using Addenbrooke's Cognitive Examination-Revised (ACE-R) (Mioshi, 2006; Yoshida, 2012).

Analysis of gait with iPhone6

All participants performed two trials of 10mWT with a standard smartphone (iPhone6, Apple, Cupertino, CA, USA) set on the lumbar midline on the Jacoby line (Figure 1A). The accelerometer sampled three-dimensional data at a rate of 100 Hz.

We calculated the mean three-dimensional amplitude of the relative movement using MATLAB R2016a (MathWorks Inc., Sherborn, MA, USA), according to the "relative trajectory" method (Komoto, 2009) as the following: 1) acceleration data was processed through a high pass filter to avoid the high frequency band due to vibration caused by landing of the foot, 2) filtered acceleration was integrated to velocity data, 3) regression line of velocity data was calculated and the velocity data was subtracted from this regression line to avoid the linear increase or decrease in velocity due to accelerometer measurement residuals, 4) the modified velocity data was integrated again to position data, 5) regression curve of position data was calculated and the position data was subtracted from the regression curve to make the relative trajectory.

We extracted the relative trajectory of 10 steps from the third step in 10mWT (Figure 1B), and calculated the mean vertical (mVA), medio-lateral (mMLA), and antero-posterior (mAPA) amplitude of the relative movement.

Statistical Analysis

To evaluate the reliability of the results of 10mWT, the intraclass correlation coefficient (ICC) (1,1) was calculated for six gait parameters (velocity, cadence, stride length, mVA, mMLA, and mAPA). To evaluate the characteristics of gait, we used Spearman's rank correlation coefficients between the six gait parameters, age, grip strength, DIEPSS, and chlorpromazine/diazepam/biperiden equivalent doses.

All statistical analyses were performed using SPSS statistics for Mac Version 25 (IBM Corp., Armonk, NY, USA). The statistical significance level was set at $p < 0.05$. p-values were adjusted using the Benjamini-Hochberg method for 57 multiple comparisons.

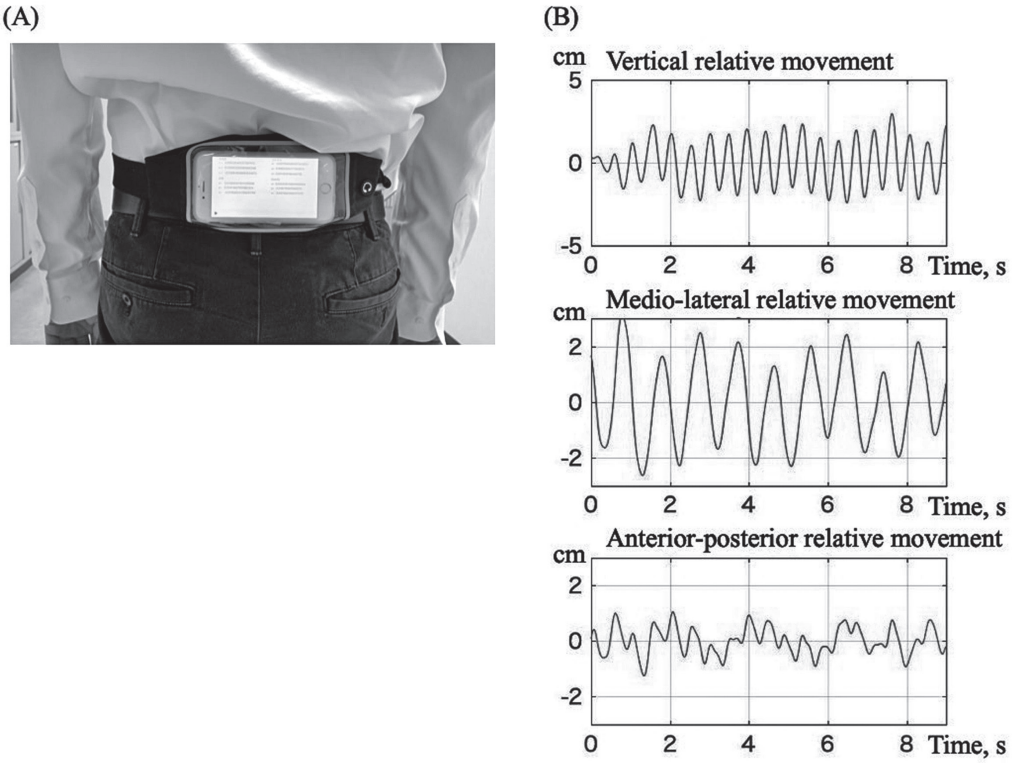

Figure 1. Analysis of gait with iPhone6
(A) In the 10 m walking test, iPhone6 was set on the lumbar midline on the Jacoby line.
(B) An example of three-dimensional relative movement of the body center of gravity resulting from analysis of the data from the accelerometer in the iPhone6.

RESULTS

Characteristics

Eighteen inpatients and two patients residing in the group home participated in the present study (Table 1). There were 14 males and six females, with 12 having schizophrenia spectrum disorders, two each with bipolar, depressive, and alcohol-related disorders, and one each having dissociative and autism spectrum disorder. The mean (SD) age and grip strength were 66.2 (12.4) years and 24.6 (8.5) kg, respectively. The mean (SD) chlorpromazine/ diazepam/ biperiden equivalent doses were 592.2 (738.8)/ 16.6 (21.6)/ 0.9 (1.3) mg.

Gait parameters and intraclass correlation coefficients

Table 2 shows the results of the six gait parameters in the 10mWT. Average (SD) time and steps were 11.5 (5.5) s and 22.9 (10.0) in the first 10mWT as well as 11.1 (5.2) s and 22.5 (9.3) in the second 10mWT. Therefore, the mean (SD) velocity, cadence, and stride length were 1.0 (0.4) m/s, 2.0 (0.2) steps/s, and 0.5 (0.2) m/step in the first 10mWT as well as 1.1 (0.4) m/s, 2.1 (0.2) steps/s, and 0.5 (0.2) m/step in the second 10mWT. The average mVA, mMLA, and mAPA were almost the same in both 10mWT.

ICC(1,1) was almost perfect for velocity (0.832), stride length (0.987), mVA (0.919), and mAPA (0.960). ICC(1,1) was substantial for cadence (0.735) and mMLA (0.772).

Characteristics of gait

The relationships between the six gait parameters and other variables are shown in Table 3. Velocity was significantly correlated with stride length (rs = 0.956, $p < 0.001$) but not cadence. Velocity and stride length were significantly and positively associated with mVA (rs = 0.830, $p < 0.001$, and rs = 0.813, $p < 0.001$, respectively) and mAPA (rs = 0.663, $p = 0.001$, and rs = 0.728, $p < 0.001$, respectively). On the other hand, cadence and mMLA were not related to any gait parameters.

Grip strength was positively associated with velocity (rs = 0.763, $p < 0.001$), stride length (rs = 0.800, $p < 0.001$), and mVA (rs = 0.758, $p < 0.001$). The significance between grip strength and mAPA (rs = 0.496, $p = 0.036$) disappeared after adjustment for multiple comparisons. Regarding medication, diazepam equivalent dose was positively associated with mMLA (rs = 0.600, $p = 0.005$).

Table 1. Characteristics of the participants

Age, years	66.2 (12.4)
Gender, male : female	14 : 6
Inpatient : GH patient	18 : 2
Diagnosis	
Schizophrenia spectrum disorders	12
Bipolar disorders	2
Depressive disorders	2
Alcohol-related disorders	2
Dissociative disorders	1
Autism spectrum disorder	1
Height, cm	160.7 (8.5)
Weight, kg	58.7 (7.3)
Grip strength, kg	24.6 (8.2)
BPRS total score	42.9 (10.1)
DIEPSS total score	6.8 (3.9)
Apathy Scale	19.7 (9.1)
BDI-2	13.0 (6.8)
ACE-R total score	59.9 (19.1)
ACE-R attention	13.4 (3.7)
ACE-R memory	10.1 (5.1)
ACE-R fluency	6.9 (4.5)
ACE-R language	19.4 (4.5)
ACE-R visual cognition	10.2 (4.9)
Chlorpromazine equivalent dose, mg	592.2 (738.8)
Diazepam equivalent dose, mg	16.6 (21.6)
Biperiden equivalent dose, mg	0.9 (1.3)

Data represent the mean (SD).
Abbreviations: GH, Group home; BPRS, Brief Psychiatric Rating Scale; DIEPSS, Drug Induced Extra-Pyramidal Symptoms Scale; AS, Apathy Scale; BDI-2, Beck Depression Inventory Second Edition; ACE-R, Addenbrooke's Cognitive Examination-Revised.

Table 2. Gait parameters and intraclass correlation coefficients

	first 10mWT	second 10mWT	ICC(1,1)	95%CI	*p*
Velocity, m/s	1.0 (0.4)	1.1 (0.4)	0.832*	0.629-0.929	<0.001
Cadence, steps/s	2.0 (0.2)	2.1 (0.2)	0.735*	0.451-0.885	<0.001
Stride length, m/step	0.5 (0.2)	0.5 (0.2)	0.987*	0.969-0.995	<0.001
mVA, cm	3.6 (1.8)	3.6 (1.5)	0.919*	0.806-0.968	<0.001
mMLA, cm	4.8 (1.4)	4.6 (1.1)	0.772*	0.506-0.905	<0.001
mAPA, cm	2.2 (1.1)	2.2 (1.0)	0.960*	0.901-0.984	<0.001

Data represent the mean (SD). * $p < 0.05$, after adjustment for multiple comparisons.
Abbreviations: 10mWT, 10 m walking test; ICC, intraclass correlation coefficients; CI, confidence interval; mVA, mean vertical amplitude of the relative trajectory of the body center of gravity (COG); mMLA, mean mediolateral amplitude of the relative trajectory of COG; mAPA, mean anterior-posterior amplitude of the relative trajectory of COG.

Table 3. Spearman's rank correlation coefficients between six gait parameters, age, grip strength, parkinsonism, and medication

	Velocity		Cadence		Stride length		mVA		mMLA		mAPA	
	rs	*p*	rs	*p*	rs	*p*	rs	*p*	rs	*p*	rs	*p*
Velocity, m/s	1.000											
Cadence, steps/s	0.347	0.133	1.000									
Stride length, m/step	0.956*	<0.001	0.130	0.586	1.000							
mVA, cm	0.830*	<0.001	0.317	0.173	0.813*	<0.001	1.000					
mMLA, cm	-0.032	0.895	-0.277	0.238	0.021	0.930	-0.090	0.705	1.000			
mAPA, cm	0.663*	0.001	-0.080	0.738	0.728*	<0.001	0.438	0.054	-0.045	0.850	1.000	
Age, years	-0.412	0.071	0.041	0.865	-0.414	0.069	-0.297	0.203	-0.221	0.348	-0.202	0.392
Grip strength, kg	0.763*	<0.001	0.177	0.483	0.800*	<0.001	0.758*	<0.001	0.005	0.984	0.496	0.036
DIEPSS total score	-0.437	0.054	0.057	0.812	-0.420	0.065	-0.282	0.229	-0.312	0.180	-0.277	0.238
Chlorpromazine equivalent dose, mg	0.098	0.681	0.131	0.581	0.074	0.758	0.010	0.967	-0.345	0.136	0.184	0.438
Diazepam equivalent dose, mg	0.244	0.300	-0.023	0.925	0.256	0.276	0.214	0.364	0.600*	0.005	-0.027	0.909
Biperiden equivalent dose, mg	-0.216	0.361	0.271	0.248	-0.271	0.247	-0.091	0.703	-0.291	0.213	-0.323	0.165

* $p < 0.05$ after adjustment for multiple comparisons.
Abbreviations: mVA, mean vertical amplitude of the relative trajectory of the body center of gravity (COG); mMLA, mean mediolateral amplitude of the relative trajectory of COG; mAPA, mean anterior-posterior amplitude of the relative trajectory of COG; DIEPSS, Drug Induced Extra-Pyramidal Symptoms Scale.

DISCUSSION

In the present study, we revealed that the gait velocity of patients with chronic psychiatric disorders was related to stride length, but not cadence, and the velocity and stride length were positively related to the vertical and anterior-posterior movement of the COG. The mediolateral movement of the trunk was not associated with any gait parameters; however, it was related only to the benzodiazepine dose. This is the first study to reveal the relationships between gait characteristics and medication using smartphones.

In patients with chronic psychiatric disorders, gait velocity was positively related to stride length, but not cadence. A previous study reported that patients with schizophrenia showed a significantly decreased gait velocity due to a shorter stride length but not cadence (Putzhammer, 2004), and that the latter did not differ between the patients and controls (Putzhammer, 2005). These results are in accordance with the present results. In addition, mVA and mAPA were positively associated with both gait velocity and stride length, but not with cadence. The results were acceptable because these parameters expressed the magnitude of vertical and anterior-posterior movement in a step related to stride length. In addition, we revealed high ICC(1,1) of the gait parameters measured by the accelerometer in the iPhone6. Therefore, it is considered that the present gait analysis using iPhone6 is reliable.

The gait velocity, stride length, and mVA were related to grip strength, but not age, DIEPSS, and chlorpromazine/biperiden equivalent doses. The results showed decreased dynamics in gait due to muscle weakness. A previous study reported the relationship

between muscle force and walking speed in patients with schizophrenia (Tsuji, 2019). In addition to patients with psychiatric disorders, the relationship between grip strength and gait velocity was reported in those with diabetes (Yokoyama, 2020), new to dialysis (Moorthi, 2020), community-dwelling people (Cawthon, 2020), and more. These results suggest that sarcopenia affects both grip strength and gait speed (Cruz-Jentoft, 2019). Some previous studies reported that the muscle strength and physical performance, including gait speed, were impaired in patients with psychiatric disorders compared with healthy controls (Vancampfort, 2016; Nygard, 2019), which suggests prevalence of sarcopenia in the former. The present results suggest that gait disturbances with small steps in patients with chronic psychiatric disorders were affected by sarcopenia rather than drug-induced parkinsonism. In sarcopenic older adults, exercise programs have positive effects on muscle strength including grip and physical performance with gait speed (Bao, 2020). Therefore, exercise programs would be effective for patients with psychiatric disorders to improve their muscle weakness and gait disturbances.

On the other hand, the magnitude of mediolateral trunk movement was not related to any other gait parameters. In general, slow gait can make the movement of COG small, which can decrease the risk of falls. However, the present results showed that slow gait did not make the mediolateral movement of COG small in patients with chronic psychiatric disorders. In addition, a previous study reported that mediolateral thorax movements during walking in patients with psychosis were greater than in healthy controls (Stensdotter, 2012). Patients with psychiatric disorders may have the characteristic of COG swaying in the mediolateral direction during walking, which they cannot suppress even on walking slowly. In addition, the present ICC analyses showed substantial reliability of mMLA, although the reliabilities of mVA and mAPA were almost perfect. The results showed the fluctuation of the mediolateral movement in gait of the participants. The fluctuation of COG is associated with impaired balance, which can also increase the risk of falls. A previous study reported that a decrease in balance ability was correlated with falls in patients with schizophrenia (Tsuji, 2017). Therefore, the mediolateral movement in gait would be associated with falls in patients with chronic psychiatric disorders.

In the present study, mMLA was positively related to diazepam equivalent doses but not chlorpromazine/biperiden equivalent doses. A prospective multicenter study revealed that benzodiazepines, but not antipsychotics, were related to the risk of falls in residents of the United Kingdom care homes (Izza, 2020). The mediolateral movement of COG in gait caused by benzodiazepine would increase the risk of falls.

The strength of the present study is the objective assessment of gait using accelerometers. In addition, our assessment was conducted using a standard smartphone. Therefore, the same assessment can be easily performed anywhere. On the other hand, the small sample size was a high-impact limitation. Therefore, we could not perform a multivariate analysis in the present study.

In the present preliminary study, we observed that gait velocity was associated with stride length, antero-posterior and vertical trunk movement, and that these gait parameters were also associated with grip strength in patients with chronic psychiatric disorders. The slow gait did not decrease the mediolateral movement of the body COG. The mediolateral movement was related to the dosage of benzodiazepine, reported to be associated with the risk of falls. We will conduct further studies using a larger sample size to reveal more detailed relationships between falls, gait, and medication in patients with psychiatric disorders.

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