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Is it possible to predict falls in older adults using gait kinematics?

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ABSTRACT

Background: Gait kinematic parameters have been reported as an important clinical tool to assess the risk of falls in older adults. However, the ability of these parameters to predict falls in the older population is still unclear.
Objective: To identify the ability that gait kinematic parameters present to predict fall in older adults.
Methods: Data from 102 older adults, who live in a community setting, were considered for this study. For data collection, older subjects had to walk on a 14 meter-walkway in their preferred gait speed. The incidence of falls was recorded at baseline together with gait kinematics and then every three months during the period of the study. The ability of gait kinematic parameters to predict falls was tested using the ROC curve.
Results: Stance time variability, swing time, and stride length presented a sensitivity to predict falls in older adults higher than 70%.
Conclusion: Gait kinematic parameters, such as stance variability, swing time, and stride length may predict future falls in older adults.

1. Introduction

Falls are one of the major causes of injury and death in older adults (Schulz et al., 2010). About 30% of older adults fall every year, and 14% of older adults experience multiple falls in a period of 12 months (Kirkwood et al., 2011). Falls lead to sedentary behavior, loss of functional capacity and a decreased level of quality of life (Milat et al., 2011; Van Dieen and Pijnapeels, 2008). Thus, the ability to walk safely is important to maintain the mobility and health status (Callisaya et al., 2011).

Gait kinematic assessment may be an important clinical tool to screen older adults with increased risk of falls (Chen and Chou, 2010; Owings and Grabiner, 2004). In this regard, previous studies have already described differences on gait kinematics in older faller and non-faller adults (Kirkwood et al., 2011; Donoghue et al., 2013; Marques et al., 2013, Marques et al., 2017). According to these studies, faller older adults had decreased gait speed, stride length and single limb support time, and increased gait variability and double limb support time (Callisaya et al., 2011; Kirkwood et al., 2011; Lord et al., 2013; Donoghue et al., 2013; Marques et al., 2013, Marques et al., 2017).

Among the gait kinematic parameters, the gait variability deserves special attention because it has been described as a more sensitive parameter to detect differences on gait kinematics between older fallers and non-fallers (Callisaya et al., 2011; Marques et al., 2017). Gait variability can be defined as the stride-to-stride fluctuations during walking and it offers a complementary way to quantify locomotion and represents the accuracy and reliability of the gait regulation (Hausdorff, 2005). Increased gait variability in older fallers leads to an unstable gait and increases the risk of falls (Brach et al., 2007). In this regard, Marques et al. (2017) identified that stance time variability could discriminate between female older fallers and non-fallers with a level of sensitivity and specificity of 100%. However, the ability of gait kinematic parameters to predict falls in older adults remains unknown.

Few studies have investigated the ability of gait biomechanics to predict falls in older adults (Swanenburg et al., 2010; Van Schooten et al., 2016). According to Van Schooten et al. (2016) and Swanenburg et al. (2010), gait stability and the center of mass displacement may predict falls in older adults (Swanenburg et al., 2010; Van Schooten et al., 2016). However, Van Schooten et al. (2016) also considered clinical characteristics (i.e. alcohol and medication ingestion, depression, and cognition) and handgrip strength in their model to predict falls.

Falls prevention programs have been implemented worldwide. Thus, the importance of more accurate methods to screen older adults in increased risk of falls is critical to ensure the efficiency of such programs. Considering that gait kinematics could discriminate between

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older fallers and non-fallers and that previous studies demonstrated that gait instability could predict falls, the present study has three objectives: to compare gait kinematics of older faller and non-faller adults, to identify the best discriminant gait kinematic parameters of older faller and non-fallers, and to test the ability of gait kinematic parameters to predict falls in older adults. The first hypothesis is that older fallers would have slow gait speed, shorter stride length, longer stance and stride time, shorter swing time, and higher gait variability. Also, the other hypothesis is that gait kinematic parameters, especially gait kinematic variability, such as stance time variability, would discriminate and predict future falls.

2. Methods

2.1. Study design and sample

The present study is a cohort study, which considered data from gait kinematics and the incidence of falls within a period of one year. Data from 102 older male and female adults, who were living in a community setting, were considered for this study. The subjects were recruited from groups of physical activities for older adults. Subjects were separated into two groups according to their self-reported falls over the period of 12 months after the baseline: older fallers (n = 53) and non-fallers (n = 49). Table 1 shows the subjects' characteristics.

The eligibility criteria were: age from 60 to 80 years old, no use of any gait assistive device (i.e. cane), no history of progressive or non-progressive neurological disease, normal cognition (according to Mini-Mental Scale), normal or corrected vision, and no cardiovascular, metabolic or muscle-skeletal dysfunction that could impact the safe performance of data collection. One subject was excluded because of heart failure and a higher perception of effort during the gait test.

The sample size was determined using G*Power 3.0 (University of Dusseldorf, Dusseldorf, Germany) considering the stance time variability as an outcome. Thus, the sample consisted of 70 subjects, considering an effect size = 1.2, power = 0.95, and alpha error = 0.05. Also, considering a sample loss of 40% or more, over one year of the study, 103 volunteers were recruited at the beginning. The present study was approved by the Research Ethics Committee and all subjects signed an informed consent form.

2.2. Procedures

Data collection was conducted in one visit to the data collection environment. In this visit, the subjects' assessment consisted of anamneses, cognition assessment, subjects' anthropometric characterization, mobility test (Short Physical Performance Battery, SPPB), and gait test. Every three months, volunteers were contacted by phone calls and their histories of falls were recorded.

For the gait kinematic assessment, two footswitches (Inline, Noraxon, Phoenix, and USA) that were connected to an electromyography (Myotrace, Noraxon, Phoenix) were attached on the heel and on the base of the first metatarsus. Data were sampled at a frequency of 1000 Hz.

Table 1
Mean (standard deviation) of sample characteristics.

	Older faller adults (n = 53)	Older non-faller adults (n = 49)	p
Age (years)	67.6 (5.37)	64.52 (7.12)	0.36
Mass (kg)	76.51 (14.77)	67.42 (11.39)	0.22
Height (m)	1.56 (0.06)	1.55 (0.05)	0.88
Body mass index ($kg{\cdot}m^{-2}$)	31.01 (4.86)	27.94 (4.58)	0.96
SPPB (score)	9.6 (1.73)	11.1 (1.09)	< 0.001*
MEEM (score)	23.05 (2.44)	23.72 (3.01)	0.91

SPPB = Short Physical Performance Battery; MEEM = Mini Mental Scale.
* $p < 0.05$ = significant difference.

2.3. Gait test

For the gait test, subjects were asked to walk on a 14 meter-long walkway in their preferred walking speed. Six to ten trials were recorded until the subjects completed 50 consecutive strides (Konig et al., 2014). For the data analysis, data recorded at the first and last 2 m of the walkway were discarded.

2.4. Data and statistical analysis

Data from 50 consecutive strides were considered for the data analysis. The signals of footswitches were analyzed in a specific routine developed in the Matlab (Mathworks, Natick, EUA) environment. The following gait kinematic parameters were obtained: gait speed, stride length, stance time, swing time, stride time, double limb support time, stance time variability, swing time variability, and stride time variability. Gait speed, stride length, stance time, swing time, stride, and double support time were calculated by the mean of 50 strides. Stance time, swing time, and stride time variability were calculated by the standard deviation of 50 strides.

The PASW 18.0 statistical package (SPSS Inc.) was used for the statistical analysis. Mean and standard deviation was used to summarize participant characteristics. Then, the Shapiro-Wilk test was used to determine if the data were normally distributed, and MANOVA was used to compare kinematic data between groups. Stepwise discriminant analysis and ROC curve were used to identify the discriminant and predictive parameters of falls, the cut-point, sensitivity and specificity of these parameters. The significance level was set at $p < 0.05$.

3. Results

3.1. Comparison between groups

Stance time, stride time, and double limb support time were 17.2, 8.1, and 33.3% longer in older faller adults ($p < 0.001$; p = 0.016; and p = 0.02, respectively; Table 2). Swing time was 15.7% less in older faller adults ($p < 0.001$). Stride length was 12.06% shorter and gait speed was 9.8% slower in older faller adults (p = 0.02 and p = 0,01; Table 2). Stance time variability was 58.3% higher in older faller adults (p = 0.03; Table 3).

3.2. Discriminant and predictive analysis

According to discriminant analysis, the three best parameters to

Table 2
Mean (standard deviation) of gait kinematic comparison between older fallers and non-fallers.

	Older faller adults (n = 53)	Older non-faller adults (n = 49)	p
Gait speed ($m{\cdot}s^{-1}$)	1.01 (0.16)	1.12 (0.17)	0.017*
Stance time (s)	0.58 (0.12)	0.48 (0.11)	< 0.001*
Swing time (s)	0.48 (0.11)	0.57 (0.16)	< 0.001*
Stride time (s)	1.11 (0.13)	1.02 (0.17)	0.016*
Double limb support time (s)	0.15 (0.08)	0.1 (0.04)	0.02*
Stride length (m)	1.02 (0.1)	1.16 (0.1)	0.02*
Stance time variability (s)	0.12 (0.01)	0.05 (0.01)	0.03*
Swing time variability (s)	0.25 (0.03)	0.17 (0.07)	0.67
Stride time variability (s)	0.23 (0.06)	0.21 (0.08)	0.5

* $p < 0.05$ = significant difference.

Table 3
Comparison of gait kinematic variability parameters between older fallers and non-fallers.

	Older faller adults (n = 53)	Older non-faller adults (n = 49)	p
Stance time variability (s)	0.12 (0.01)	0.05 (0.01)	0.03*
Swing time variability (s)	0.25 (0.03)	0.17 (0.07)	0.67
Stride time variability (s)	0.23 (0.06)	0.21 (0.08)	0.5

* $p < 0.05$ = significant difference.

discriminate between older fallers and non-fallers were: stance time variability, swing time, and stride length (for all $p < 0.001$; and canonic correlation coefficients were 0.94, 0.7, and 0.54, respectively).

Predictive analysis was conducted by using parameters with higher discriminant values. Thus, for stance time variability, the ROC curve area was 0.72, the cut-point was 0.05 s, sensitivity = 77.8%, and specificity = 57.1% (Fig. 1A); for the swing time, the ROC curve area was 0.246, the cut-point was 0.459 s, sensitivity = 88.9%, and specificity = 100% (Fig. 1B); and for stride length, the ROC curve area was 0.97, the cut-point was 0.97 s, sensitivity = 77.8%, and specificity = 92.9% (Fig. 1C).

4. Discussion

The main objective of the present study was to identify the ability of gait kinematic parameters to predict falls in older adults. The most novel aspect of the present study is that it demonstrated that gait kinematic parameters, such as stance time variability, swing time, and stride length can predict falls in older adults. Also, gait kinematics was different between older fallers and non-fallers. Our results support the initial hypothesis of the present study that older fallers and non-fallers adults have different gait kinematic patterns and that gait kinematic parameters would discriminate and predict falls in older adults.

4.1. Comparison between older fallers and non-fallers

For almost all gait kinematic parameters, there were significant differences between older fallers and non-fallers. Gait speed was significantly slower in older faller adults. The reduction of gait speed in the older faller group is a compensatory adaptation, which may be caused by fear of falling or an attempt to reduce the swing perturbation on the center of mass, caused by the absorption of ground reaction forces (Brunjin et al., 2009). Despite the fact that both groups can be classified as normal mobility, the older faller adults had a gait speed close to the impaired mobility threshold of 1.0 $m \cdot s^{-1}$. Thus, the occurrence of falls may also be associated with a decline in mobility status, which reduces functional capacity.

The reduction of gait speed in older faller adults also impacts other kinematic parameters such as stride length, stance time, swing time, stride time, and double limb support time. Our results are in accordance with previous studies that demonstrated that older adults have gait kinematic abnormalities that reduce the mechanical efficiency of the gait and increase the risk of falls (Callisaya et al., 2011; Donoghue et al., 2013; Kirkwood et al., 2011; Lord et al., 2013; Marques et al., 2013; Marques et al., 2017). Among these kinematic alterations, longer stance

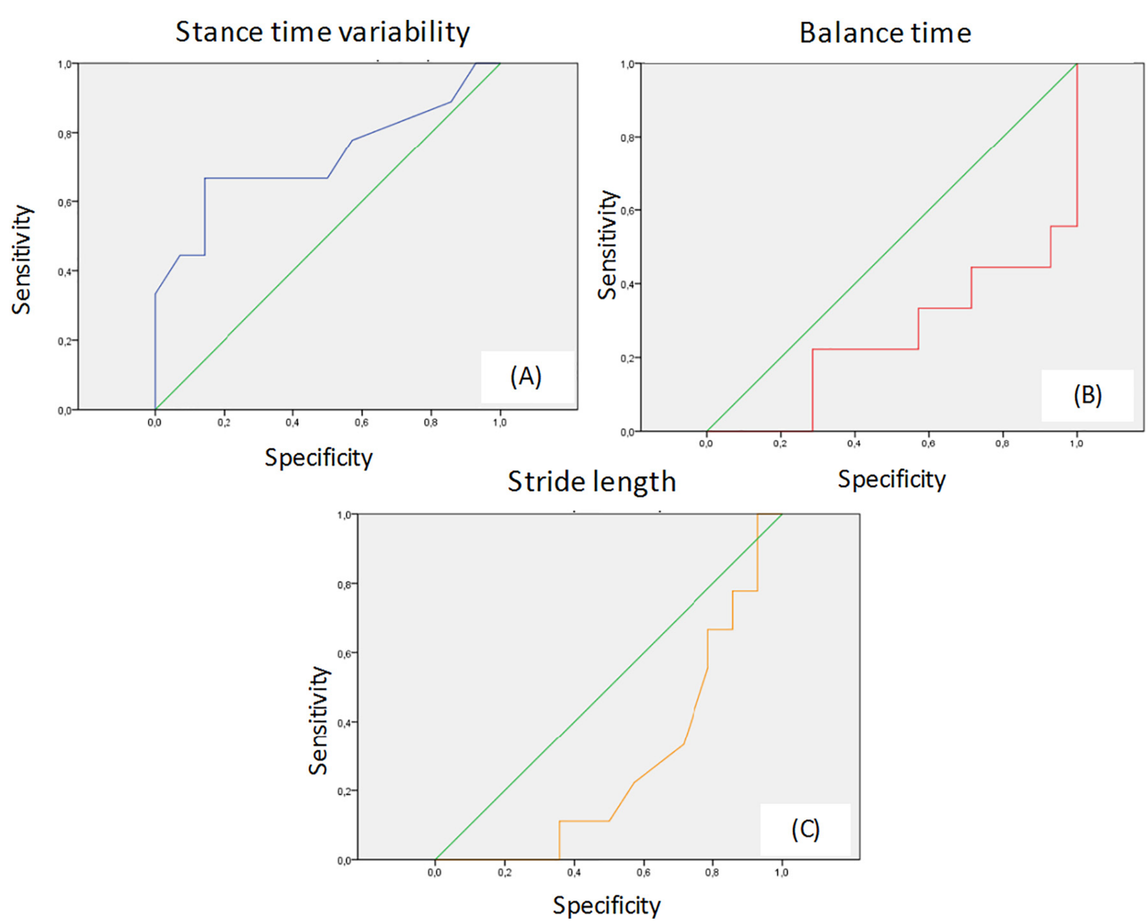

Fig. 1. Predictive analysis using ROC curve for (A) stance time variability; (B) swing time; and (C) stride length. The green line corresponds to a positive and negative random test; blue, red and yellow lines correspond, respectively, to the threshold values of stance time variability, swing time, and stride length. In order to choose the best predictive threshold for each parameter, the points of higher values of sensitivity (X-axis) and specificity (Y-axis) are considered. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

time and double limb support time in older fallers deserve special attention. These changes in gait kinematics could be a compensatory adaptation in an attempt to increase the base of support area and maintain the swing. However, a longer period of time with the feet in contact with the ground also increases the energy cost of walking (Umberger, 2010). The higher the cost of walking is, the higher will be the sense of effort and the earlier will be the onset of fatigue, which also increases the risk of falls.

Increased stance time variability in older faller adults was reported in previous studies. According to Marques et al. (2017), the stance phase is the most challenging gait phase because the musculoskeletal system must absolve the ground reaction force and generate the impulse to the next step. Thus, it is the phase that the muscles are activated and neuromuscular control is required. The increased stance time variability in older faller adults may demonstrate that the adjustment stride by stride is less efficient. In this regard, if a swing perturbation occurs, the older faller adults may have a reduced capacity to restore the swing.

4.2. Discriminant and predictive analysis

According to our results, stance time variability, swing time, and stride length were the best three parameters to discriminate between older fallers and non-fallers. Also, these parameters could predict falls in older adults with a sensitivity higher than 70%, which supports the clinical use of this parameters to predict falls in older adults.

Sensitivity and specificity are statistical measures that allow researchers to test the ability of a predictor variable to screen a population for a specific health characteristic. Sensitivity describes the ability to correctly detect people with the disease, and specificity describes the ability to correctly identify people without the disease. Also, the ROC curve analysis provides the cut-point.

The cut-off point for stance time variability (0.05 s), swing time (0.459 s), and stride length (0.97 m) can be used to discriminate between older fallers and non-fallers as much as a systolic blood pressure above 140 mm Hg suggests hypertension and the possibility of cardiovascular disease. Therefore, the cut-off point value may be a useful benchmark for the clinical assessment of falls prediction, particularly for older adults without a history of falls or for those who cannot remember fall episodes.

According to our knowledge, the present study is the first investigation focused on identifying the ability of gait kinematic parameters to predict falls in older adults. In this regard, it is hard for us to confirm that the cut-point is adjusted correctly. Only for stance time variability, a previous study (Marques et al., 2017) identified a cut-point of 0.102 s to discriminate between older fallers and non-fallers. However, this study was retrospective and the kinematic data were recorded with the older subjects walking on the treadmill.

4.3. Limitations

Despite the fact that the present study has demonstrated that kinematic parameters could predict falls in older adults, it is important to emphasize that falls are multifactorial, and factors such as age, sex, comorbidity, level of physical activity, medication ingestion, and others, must influence the risk of falls. Also, the present study only assessed the gait kinematics at the baseline. Thus, we could not detect the changes in gait kinematics that influenced the fall episode.

We performed a simple walking test using an inexpensive footswitch device to assess gait variability in older adults. The entire test (subjects' preparation and data collection) took about 30 min. Thus, multi-centric studies with a larger population must be conducted to confirm the findings of the present study.

5. Conclusion

The most important finding of the present study was that it demonstrated that gait kinematic parameters were different between older fallers and non-fallers. Also, some gait kinematic parameters, such as stance variability, swing time, and stride length may predict falls in older adults with a sensitivity of 70%. The results of the present study may be explained to the fact that age-related impairments in neuromuscular system causes an inability to regulate the postural control, generate strength and regulate the stride to stride fluctuation, which are factors those impact the gait biomechanics.

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References

Brach, J.S., Studenski, S.A., Perera, S., VanSwearingen, J.M., Newman, A.B., 2007. Gait variability and the risk of incident mobility disability in community-dwelling older adults. J. Gerontol. A Biol. Sci. Med. Sci. 62 (9), 983–988 (Sep).

Brunjin, S.M., Van Dieen, J.H., Meijer, O.G., Beek, P.J., 2009. Is slow walking more stable? J. Biomech. 42 (10), 1506–1512.

Callisaya, M.L., Blizzard, L., Schimidt, M.D., McGinley, J.L., Srikanth, V.K., 2011. Ageing and gait variability – a population-based clinimetric properties. Gait Posture 34, 443–450.

Chen, C.J., Chou, L.S., 2010. Center of mass position relative to the ankle during walking: a clinically feasible detection method for gait imbalance. Gait Posture 31 (3), 391–393.

Donoghue, O.A., Cronin, H., Savva, G.M., O'Regan, C., Kenny, R.A., 2013. Effects of fear of falling and activity restriction on normal and dual task walking in community dwelling older adults. Gait Posture 38 (1), 120–124.

Hausdorff, J.M., 2005. Gait variability: methods, modeling and meaning. J. Neuroeng. Rehabil. 20, 2–19.

Kirkwood, R.N., Trede, R.G., Moreira, B.S., Kirkwood, S.A., Pereira, L.S.M., 2011. Decreased gastrocnemius temporal muscle activation during gait in elderly women with history of recurrent falls. Gait Posture 34 (1), 60–64.

Konig, N., Singh, N.B., Von Beckerath, J., Janke, L., Taylor, W.R., 2014. Is gait variability reliable? An assessment of spatio-temporal parameters of gait variability during continuous overground walking. Gait Posture 39 (1), 615–617.

Lord, S., Galna, B., Verghese, J., et al., 2013. Independent domains of gait in older adults and associated motor and non-motor attributes: validation of a factor analysis approach. J. Gerontol. A Biol. Sci. Med. Sci. 68 (7), 820–827.

Marques, N.R., LaRoche, D.P., Hallal, C.Z., et al., 2013. Association between energy cost of walking, muscles activation, and biomechanical gait parameters in older female fallers and non-fallers. Clin. Biomech. 28, 330–336.

Marques, N.R., Spinoso, D.H., Morcelli, M.H., Crozara, L.F., Gonçalves, M., Hallal, C.Z., 2017. Applying different mathematical variability methods to identify older fallers and non-fallers using gait variability data. Aging Clin. Exp. Res. 29 (3), 473–481.

Milat, A.J., Watson, W.L., Monger, C., Barr, M., Giffin, M., Reid, M., 2011. Prevalence, circumstances and consequences of falls among community-dwelling older people: results of the 2009 NSW Falls Prevention Baseline Survey. N. S. W. Public Health Bull. 22, 43–48.

Owings, T.M., Grabiner, M.D., 2004. Variability of step kinematics in young and older adults. Gait Posture 20, 26–29.

Schulz, B.W., Lloyd, J.D., William, E., 2010. The effects of everyday concurrent task on overground minimum toe clearance and gait parameters. Gait Posture 32 (1), 18–22.

Swanenburg, J., de Bruin, E.D., Uebelhart, D., Mulder, T., 2010. Falls prediction in elderly people: a 1-year prospective study. Gait Posture 31 (3), 317–321.

Umberger, B.R., 2010. Stance and swing phase costs in human walking. J. R. Soc. Interface 7 (50), 1329–1340.

Van Dieen, J.H., Pijnapeels, M., 2008. Falls in older people. J. Electromyogr. Kinesiol. 18, 169–171.

Van Schooten, K.S., Pijnappeels, M., Rispen, S.M., et al., 2016. Daily-life gait quality as predictor of falls in older people: a 1-year prospective cohort study. PLoS One 11 (7), e0158623.