Quantification of Coordination Variability During Gait in Fallers and Non-fallers Older Adults at Different Speeds

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Abstract. The aim of the present study was to analyze segments coordination and coordination variability during gait of fallers and non-fallers older adults at different speeds (preferred walking speed (PWS), 120% of PWS and 80% of PWS) through vector coding technique (VC). Thirty-one young adults, 22 non-fallers and 17 fallers older adults participated in the study. All participants practice exercise regularly at least three times a week. They performed a protocol of three 1-min walking on a treadmill at each speed for data collection, in a randomized order. For thigh-leg segments pair, angles were computed during four gait phases (first double support, single support, second double support and swing phase). Data was exported and analyzed with a custom MatLab code (R2018a, MathWorks, Natick, MA). There were significant differences in thigh-leg segments pair coordination pattern, with the greatest differences observed at 80% and 120% PWS for all groups, with emphasis on the older adults groups.

Keywords: Coordination · Variability · Vector coding

1 Introduction

Coordination can be defined as a process in which motion components are sequentially organized over time, and their relative magnitude determined in the sense of producing a functional movement pattern or a synergy [1]. Coordination variability quantify the variety of movement patterns that an individual uses during a task and can provide a measure of the flexibility/adaptability of individual's motor system [2]. In order to quantify coordination variability, there are some nonlinear techniques that can be useful. This includes vector coding technique, adopted here for its versatility, requiring less rigor in data processing and, more important, shorter data collection time when compared to other traditional techniques, an essential characteristic for the target groups analyzed here. On the other hand, fall can be defined as an unintentional displacement of the body to a level lower than the initial position, with inability to correct in a timely manner, determined by multifactorial conditions that compromise stability [3], including a coordination impairment.

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While several gait parameters (speed reduction, stride length and increased double support time, among others) are strategies to reduce the risk of falls, the variability of the gait is the indicator that better represents the postural instability [4, 9]. It is not known exactly how many gait cycles are required to reliably estimate coordination variability during gait. The recent literature estimates that at least five [6], ten [7] to fifteen [8] gait cycles are required. However, there is a consensus that less than five gait cycles are a very small number and the reported values cannot be representative of the true coordination variability of an individual or group. Thus, for more reliable results, in this study the entire time series was used, a total of 25 gait cycles for each individual.

Therefore, the aim of the present study is to quantify the coordination variability of pairs of anatomical segments in fallers and non-fallers older adults during gait at different speeds, testing their potential use as a predictor of fall risk in the older population. For this, it was analysed the coordination variability of the thigh-leg segment in sagittal plane at different speeds (preferred walking speed (PWS), 120% of PWS and 80% of PWS), using vector coding technique (VC).

2 Materials and Methods

2.1 Participants

A control group of thirty-one young adults (17 males, 14 females – control group), and two experimental groups of 22 non-fallers (9 males, 13 females) and 17 (10 males, 7 females) fallers older adults were enrolled in this study. The older adults were characterized as fallers if they had three or more falls in the last 24 months (in this study, all fallers older adults had fallen more than 3 times in the last 24 months). All participants practice exercise regularly at least three times a week. The timed up and go (TUG) and International Physical Activity Questionnaire (IPAQ) tests were applied to evaluate the level of activity of all groups. All protocols were approved by the local ethics committee for human research, and the participants signed an informed consent form.

2.2 Equipment

Sixteen reflective markers were fixed at specific places according to Vicon's lower body plug-in-gait model (Vicon, Oxford Metrics, Oxford, UK), for movement registration. A 3D motion capture system comprising 10 infrared cameras operating at 100 Hz was used. The data were low pass filtered at 8 Hz.

2.3 Protocol

The preferred walking speed (PWS) on a treadmill was determined according to a previously reported protocol [9]. A 4-min walking on the treadmill for familiarisation was allowed. After a 2-min rest period, the participants executed three 1-min walking at PWS, 80% PWS and 120% PWS, in a randomized order. The thigh-leg segment pair was analysed for 25 strides, normalized with 100 points, for each 1-min walking, in four phases of the gait cycle: first double support, single support, second double support and swing phase. Segment angles were calculated in relation to the laboratory global coordinate system. Coupling angles represent the segments coordination pattern, while the standard deviation of the coupling angle at each instant of the gait cycle represents the segments coordination variability [10].

2.4 Calculation of Coupling Angle

The coupling angles were calculated as the angle of a vector connecting consecutive data points, according to the following Eqs. (1) and (2):

$$\gamma_i = \tan^{-1}\left(\frac{\theta_{D(i+1)} - \theta_{D(i)}}{\theta_{P(i+1)} - \theta_{P(i)}}\right) . \frac{180}{\pi} \quad \text{for} \quad \theta_{P(i+1)} - \theta_{P(i)} > 0 \tag{1}$$

$$\gamma_i = \tan^{-1}\left(\frac{\theta_{D(i+1)} - \theta_{D(i)}}{\theta_{P(i+1)} - \theta_{P(i)}}\right) . \frac{180}{\pi} + 180 \text{ for} \quad \theta_{P(i+1)} - \theta_{P(i)} < 0 \tag{2}$$

where $0 \leq \gamma \leq 360°$, in which i represent the consecutive samples in a normalized gait cycle, and γ_i was calculated on the basis of the distal segmental angles (θ_D, $\theta_{D(i+1)}$) and proximal segment angles ($\theta_{P(i)}$, $\theta_{P(i+1)}$).

The coupling angle γ_i is corrected to show the value between 0° and 360° according to the Eq. (3):

$$\gamma_i = \begin{cases} \gamma_i + 360 & \gamma_i < 0 \\ \gamma_i & \gamma_i \geq 0 \end{cases} \tag{3}$$

The mean of the coupling angle γ_i should be computed using circular statistics.

For an individual (n) and then for a group, γ_i is calculated from the horizontal $(\bar{x}_\mathrm{i})$ and vertical $(\bar{y}_\mathrm{i})$ Cartesians components along multiple cycles of gait j, for each instant i of the gait cycle according to the Eqs. (4) and (5):

$$\bar{x}_\mathrm{i} = \frac{1}{n}\sum\nolimits_{j=1}^{n} \left(\cos \gamma_{ji}\right) \tag{4}$$

$$\bar{y}_\mathrm{i} = \frac{1}{n}\sum\nolimits_{j=1}^{n} \left(\sin \gamma_{ji}\right) \tag{5}$$

The mean of the coupling angle $\bar{\gamma}_\mathrm{i}$ is corrected to show the value between 0° e 360°, following the Eq. (6):

$$\bar{\gamma}_\mathrm{i} = \begin{cases} \tan^{-1}\left(\frac{\bar{y}_\mathrm{i}}{\bar{x}_\mathrm{i}}\right) . \frac{180}{\pi} & \bar{x}_\mathrm{i} > 0, \bar{y}_\mathrm{i} > 0 \\ \tan^{-1}\left(\frac{\bar{y}_\mathrm{i}}{\bar{x}_\mathrm{i}}\right) . \frac{180}{\pi} + 180 & \bar{x}_\mathrm{i} < 0 \\ \tan^{-1}\left(\frac{\bar{y}_\mathrm{i}}{\bar{x}_\mathrm{i}}\right) . \frac{180}{\pi} + 360 & \bar{x}_\mathrm{i} > 0, \bar{y}_\mathrm{i} < 0 \end{cases} \tag{6}$$

The length of the mean coupling vector is then defined according the Eq. (7):

$$\bar{r}_{\mathrm{i}} = \sqrt{\bar{x}_{\mathrm{i}}^2 + \bar{y}_{\mathrm{i}}^2} \tag{7}$$

Finally, the variability of the coupling angle CAV_i, is calculated according to the Eq. (8):

$$CAV_i = \sqrt{2.(1 - \bar{r}_{\mathrm{i}})}.\frac{180}{\pi} \tag{8}$$

The coupling angles were computed in four phases of the gait cycle: first double support, single support, second double support, and swing phases.

2.5 Statistical Analysis

As all the results presented a normal distribution (Shapiro-Wilk test, ($p > 0.05$)), repeated measure analysis of variance (ANOVA) with mixed design was used to compare the three groups, the main effect of speed, and the interaction effect between groups and speed, followed by post-hoc test with Bonferroni correction. The TUG and IPAQ tests were compared using one-way analysis of variance (one-way ANOVA). Statistical analysis was performed using SPSS software, version 23 (SPSS Inc., Chicago, IL, USA), with a significant level set at $p < 0.05$.

3 Results and Discussion

The young adults, non-fallers and fallers older adults groups did not present significant differences regarding height, body mass, IMC and IPAQ. However, young adults presented significant higher PWS than older adults ($p = 0.014$), as shown in the Table 1.

With respect to the coordination variability, statistical differences were found for all groups at speeds of 80% of PWS and 120% of PWS. For the sagittal thigh segment and sagittal leg segment, the statistical differences between young adults and non-fallers older adults occurred in the first double support and swing phase at 120% of PWS, with the variability being higher in the young group.

Table 1. Characteristics of the groups: Young adults, Non-Fallers and Fallers older adults.

	Groups		
	Young (n = 31)	Non-Fallers (n = 22)	Fallers (n = 17)
PWS (km/h)*	4,78 ± 0,67	3,98 ± 0,55	3,79 ± 0,96
IPAQ	1,78 ± 0,64	1,67 ± 0,12	1,62 ± 0,35
TUG(s)	5,98 ± 0,94	9,56 ± 1,68	11,02 ± 2,85

Values expressed as mean ± standard deviation. PWS (Preferred Walking Speed); IPAQ (International Physical Activity Questionnaire); TUG (timed up and go). *Significant difference (one-way ANOVA, $p = 0.014$)

Comparing young adults with fallers older adults, there were significant differences in the first double support phase at 80% of PWS, the variability being greater in the young adults group.

Table 2 shows the results of mains effects of group and speed, and interaction effect on the coordination variability for each gait phase.

Table 2. Effects of group and speed on coordination variability for each gait phase.

Effect	Phases of Gait	F	p	η^2
Group	First Double Support	4,956	**0,010**	0,150
	Single Support	3,925	**0,025**	0,123
	Second Double Support	7,399	**0,001**	0,209
	Swing	21,091	**<0,001**	0,430
Speed	First Double Support	NS	NS	NS
	Single Support	7,859	**0,002**	0,123
	Second Double Support	NS	NS	NS
	Swing	10,431	**<0,001**	0,157
Group vs. Speed	First Double Support	2,731	**0,033**	0,089
	Single Support	NS	NS	NS
	Second Double Support	6,513	**<0,001**	0,189
	Swing	5,054	**0,001**	0,153

Mixed repeated measures ANOVA. F is used to test the overall fit of a regression model to a data set; p is the significance of the test; η^2 is a measure of the effect size; NS = Not Significant.

Finally, when comparing non-fallers with fallers older adults, differences in the first double support phase occurred at 80% and 120% PWS, in the second double support phase at 80% and 120% of PWS, and in the swing phase at 120% of PWS; in this case, the variability was always higher for non-fallers compared to fallers older adults. The analyzed segments had rotation in the same direction, being, therefore, in-phase.

4 Conclusions

There were significant differences in all analyzed segments, however the greatest differences were observed at 80% of PWS and 120% of PWS, with variability being higher for the non-fallers older adults in comparison with the fallers older adults. Thus, there are differences between fallers and non-fallers older adults with respect to segmental coordination variability that can be used as a potential predictor of fall risk. Reduced coordination variability in fallers older adults can be an indicative of reduced adaptability and increased risk of fall. Future studies may examine what leads to this difference in coordination variability, and assess physical exercises focusing on increasing coordination variability to decrease the risk of falls.

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Conflict of Interest Declaration. There are no conflicts of interest to declare.

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