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THREE-DIMENSIONAL GAIT ANALYSIS

Use of the Gait Deviation Index and spatiotemporal variables for the assessment of dual task interference paradigm

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Summary Three-dimensional gait analysis (3DGA) is an important element in the quantitative evaluation of gait in subjects with Parkinson's disease (PD). Indexes, such as the Gait Deviation Index (GDI), have recently been proposed as a summary measure of gait. The aim of the present study was to investigate the effectiveness of the GDI and spatiotemporal variables in the quantification of changes in gait during a dual-task (DT) exercise. Fourteen patients with idiopathic PD and nine healthy subjects (CG) participated in the study. All subjects walked under two conditions: free walking and DT walking. The GDI was computed from the 3DGA data. The results show gait impairment during DT, a significant difference between groups regarding GDI and an interaction effect involving the group, side and task factors. The CG and PDG were different independent of interference and side, but interference was only different for the PDG group. The results also demonstrate that the GDI should be an appropriate outcome measure for the evaluation of the effects of DT on patients with Parkinson's disease.

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Introduction

Parkinson's disease (PD) is a common neurodegenerative disorder among elderly individuals, affecting approximately six million people worldwide (Twelves et al., 2003). It is estimated that more than 40 million people in the world will have motor disorders secondary to PD by the year 2020 (Morris, 2000).

PD is caused in part by a loss of dopaminergic neurons in the *pars compacta* of the *substantia nigra*. The resultant abnormal neuronal oscillatory and synchronous activity between the subthalamic nucleus, *pars interna* of the *globus pallidus* and cerebral cortex lead to increasing problems with tremors, rigidity, bradykinesia and postural disturbances (Delong and Wichmann, 2007).

In the normal brain, there is dense serotonergic innervation of the basal ganglia (BG) of the raphe nuclei, particularly the dorsal raphe nuclei, which also sends projections to the frontal cortex, limbic system and diencephalon. The striatum and output regions of the BG, *pars reticulata* of the *substantia nigra* and medial *globus pallidus* receive a dense serotonergic input, suggesting a potential role for serotonin in PD. Serotonergic dysfunction appears to play a role in a number of Parkinsonian symptoms, including impaired motor function. The exact mechanisms remain unclear due to a lack of clinical-pathological and *in vivo* studies (Fox et al., 2009).

Movement disorders, with a loss of full motor control (automatism), are characteristic of PD (Morris, 2000). Gait disturbances, in particular, are characterised by a reduction in velocity, step length and range of motion of the lower limbs, with a consequent increase in the duration of the support phase (Morris et al., 1996; Rochester et al., 2004; Ellis et al., 2005). Other manifestations include the forward lean of the torso and reductions in the amplitude of hip extension with medium support, knee flexion during balance and plantar flexion while walking (Morris et al., 1996).

The regulation of variables and rhythm during normal human locomotion is apparently an automatic process that requires no attention. This activity requires adequate executive function for the planning, monitoring and performance of a sequence of systematically complex actions (Nordin et al., 2010). Among individuals with PD, dual-task interference is a particularly noticeable problem due to the disruption of motor functions of the BG, which play a major role in the control of learnt, repetitive movement sequences through outputs to the supplementary motor area and brain-stem locomotion regions. In the early stages of motor skill acquisition, the cortical regions of the brain are believed to play a major role in movement regulation. As movements become learnt and automatic, they are thought to be controlled by the BG. When this occurs, an individual, in theory, can concentrate on controlling more novel or attention-demanding tasks through the use of the frontal cortical regions. With PD, normal movement patterns can be generated when attention is focused on performance, as attention is thought to lead to a bypassing of the BG and the use of cortical regions to drive outputs. In dual-task situations, however, the cortical resources may be engaged in maintaining the performance of the secondary task, leaving responsibility for regulating the performance of the more automatic task to the defective BG circuitry (O'Shea et al., 2002).

Three-dimensional motion analysis is a powerful tool for the quantitative assessment of movement due to the fact that it is non-invasive, allows the repetition of exams several times within a short period and provides quantitative and three-dimensional data for kinematics (trajectory, velocity, acceleration and angles), kinetics (force, joint movement and joint power) and the quantitative evaluation of muscle activity (electromyography). The quantitative evaluation of motion is fundamental to the analysis of human movement (Cimolin et al., 2011). The breakthrough in the clinical application of three-dimensional motion analysis can be attributed to gait analysis (the quantitative analysis of walking), which is generally applied to patients with walking difficulties. Gait analysis is an important method for gathering information that is crucial to the establishment of the level of functional limitation due to disease and following its evolution over time. Furthermore, gait analysis provides useful elements for evaluating the effects of rehabilitation interventions aimed at reducing functional limitation due to disease (Assi et al., 2009; Gage et al., 2009).

The concurrent execution of motor and cognitive tasks requires little or nearly no conscious attention, thereby allowing an individual to concentrate on items relevant to completing the cognitive task with no impediment to the primary motor task. However, the reduced function of the different systems in PD may affect this ability and increase the risk of falls (Nordin et al., 2010). Patients with PD require a greater amount of attention during gait, which worsens when a secondary task is inserted in the context (O'Shea et al., 2002). The increase in attention to maintain an unaltered gait pattern is denominated the "cost of a dual-task", which can be attributed to the limited resources of the central nervous system (CNS) with regard to compensating for the depletion of automaticity caused by defects in the BG (Morris et al., 1996; Woollacott and Shumway-Cook, 2002). Executive function, depression, anxiety and fatigue found in the different types of PD may also compete for attention and increase difficulties during the execution of dual or multiple tasks (Rochester et al., 2008). Thus, a better understanding of the relationship between the effect of a dual task and gait is important to clinical practice (Box 1).

Based on findings described in the literature, three-dimensional gait analysis (3DGA) provides highly informative data for the evaluation of specific gait variables. However, such analysis produces a large volume of data and a possible need to provide quantitative measures of a patient's overall gait (Wren et al., 2007). As a starting point, a number of global indexes have been proposed to summarise gait, such as the Gillette Gait Index (GGI) (Schutte et al., 2000) and the Gait Deviation Index (GDI). These indexes have been employed in gait analysis to provide a better global understanding of a patient's condition. The GDI is a new quantitative measure that uses pattern recognition and compares nine kinematic gait variables in a study group against those of a control group. This requires kinematics of the pelvis and hip on all three planes, the knee, the ankle on the sagittal plane and foot progression. The aim of this comparison is to reflect the extent of gait variation in relation to the control group. A GDI value close to 100 or higher indicates the absence of

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Box 1. Clinical relevance.

The understanding of the relationship between dual-task interference and gait will assist clinical practice, taking into consideration the following:

- Performing two tasks at once has been identified as a common problem for people with Parkinson's Disease;
- Cognitive and attention processes are particularly important in Parkinson's Disease to compensate for basal ganglia dysfunction and the loss of gait automaticity and are integral to cue-based rehabilitation strategies;
- Measures of gait variability during dual tasking may provide a sensitive marker for the risk of falls and the enhancement of cognitive function may reduce the risk of falls;
- The use of cognitive abilities with a variety of dual-task situations is common in daily living and may reduce the risk of falls;
- Since gait performance under dual-task conditions is influenced by attention, specific instructions can be used in training to manipulate attention and enhance the performance of everyday dual-manual tasks among individuals with Parkinson's Disease;
- Interventions and therapies designed to ameliorate gait disturbances in Parkinson's Disease should also emphasise cognitive aspects

gait pathology and each 10-point decrease below 100 indicates 1 standard deviation (SD) from normal kinematics (e.g., a GDI of 65 is 3.5 SD below normal) (Schwartz and Rozumalski, 2008).

A large number of studies have been published on the applications of these indexes for the quantification of functional limitations during gait and specific treatment outcomes. The validity of the GDI in the evaluation of children with cerebral palsy has been demonstrated in a recent study involving a statistical comparison between the Gross Motor Function Measure and 3DGA (Molloy et al., 2010). However, Rose et al. (2010) applied the GDI to patients with cerebral palsy between the ages of four and nine years who had not undergone surgical treatment and found that the index lacked accuracy in detecting slow changes over time due to the natural progression of the disease.

To our knowledge, no studies have previously employed the GDI to evaluate dual-task effects in adults with PD. Thus, the aim of the present study was to investigate the effectiveness of the GDI and spatiotemporal variables in the quantification of changes in gait during a dual-task exercise in adults with and without Parkinson's disease.

Methods

Sample

The present prospective, cross-sectional study received approval from the local ethics committee (protocol # 93/08). Fourteen volunteers (7 women and 7 men), with a mean age (SD) of 67.5 (5.6) years and a diagnosis of idiopathic PD were sent to the Physical Therapy sector of the Brazil Parkinson's Association (São Paulo, Brazil). The control group (CG) was formed by nine healthy volunteers (5 women and 4 men) with no history of pre-existing diseases or complaints affecting activities of daily living, specifically gait. Tables 1 and 2 display the characteristics of both groups.

The study included individuals capable of walking barefoot independently with or without a gait-assistance device; having achieved a score of $\geq$24 on the Mini-Mental State Examination (MMSE) (Folstein et al., 1975); classification Stages 2 and 3 on the Hoehn & Yahr scale (Hoehn and Yahr, 1967); and in the ON phase of the active medication cycle. Individuals with other types of PD were excluded, as were individuals with rheumatic disease, orthopaedic and other associated neurological problems or previous orthopaedic surgery of the lower limbs. The data acquisition was performed at the Movement Laboratory of the Centro Universitário São Camilo (CUSC-Brazil).

Instruments and materials

The following instruments and materials were used: eight optic-electronic cameras (Motion Analysis Corporation, Santa Rosa, CA, USA); a computer with special plate circuit for motion analysis [MIDAS Duo WORKSTATION, Evart® 5.0 and Orthotrack 6.2® (Motion Analysis Corporation, Santa Rosa, CA, USA]) and reflective markers.

Experimental protocol

All the participants remained barefoot and wore bathing suits. A total of 29 reflective markers were attached to the skin of each participant at specific anatomic points based on the Helen Hayes model (Kadaba et al., 1990; Davis et al., 1991). The area designated for performing locomotion measured 1.5 $\times$ 6.0 m. Eight cameras were attached to the

Table 1 Clinical characteristics of control group (CG) of healthy individuals.

Group	Age (years)	Gender	Height (m)	Body mass (kg)	MMSE
1	61	Male	1.62	70	26
2	75	Male	1.72	75	27
3	61	Female	1.56	62	26
4	71	Male	1.70	72	30
5	69	Female	1.58	54	30
6	61	Female	1.62	67	30
7	62	Male	1.68	68	25
8	61	Male	1.72	89	30
9	65	Female	1.64	56	29
Mean (SD)	65.111 (5.3)		1.648 (0.059)	68.111 (10.5)	28.111 (2.0)

Values expressed as mean and standard deviation; MMSE: Mini-Mental State Examination.

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Table 2 Clinical characteristics of Parkinson's Disease group (PDG).

Group	Age (years)	Gender	Height (m)	Body mass (kg)	H&Y	MMSE
1	65	Female	1.52	54	2	29
2	66	Female	1.42	49	2	24
3	64	Female	1.59	60	3	29
4	65	Female	1.56	42	2.5	30
5	68	Male	1.74	96	2.5	30
6	73	Male	1.75	83	2.5	25
7	60	Female	1.65	72	2.5	29
8	68	Female	1.60	70	2.5	29
9	60	Male	1.67	59	2	28
10	75	Female	1.76	72	2	29
11	72	Male	1.70	74	3	27
12	76	Male	1.68	90	2.5	26
13	60	Male	1.63	64	2.5	26
14	73	Male	1.69	74	2.5	26
Mean (SD)	67.500 (5.5)		1.640 (0.095)	68.500 (15.1)	2.429 (0.33)	27.643 (1.9)

Values expressed as mean and standard deviation; H&Y: Hoehn & Yahr scale; MMSE: Mini-Mental State Examination.

walls such that the entire area could be captured. Before each data acquisition, the capture volume was calibrated both statically and dynamically in accordance with the manufacturer's regulations. Data acquisition only began when the error in the central area of each marker was less than 1 mm.

The participants were informed of the data acquisition procedures, familiarised with the site at which data would be collected and trained so that gait would be as normal as possible. After being familiarised with the procedures, the participants were positioned at a distance from the destined area of locomotion to exclude the acceleration of the initial movement. The procedure was repeated for a total of six gait cycles. The participants did not use any gait-assistance devices and absolute silence in the laboratory was requested during data acquisition so that no noises would interfere with the participants' attention during the task.

Dual task

Gait performed at a comfortable pace with no other competing tasks was denominated the simple task. The dual task (DT) involved a cognitive task that required attention during gait, consisting of a mathematical test of decreasing consecutive subtraction, initiated when the evaluator asked for the answer to the mathematical problem "500 − 7" (Yogev et al., 2007). The individuals did not receive specific orientation regarding giving priority to one task or another.

Data analysis

Image capturing and three-dimensional reconstruction were performed with the Evart® 5.0 program (Motion Analysis Corporation, Santa Rosa, CA, USA). Kinematic variables for analysis were based on the Helen Hayes biomechanical model used in the Orthotrack® 6.2 program (Motion Analysis Corporation, Santa Rosa, CA, USA). The angular and linear gait values [velocity (m/s), cadence (steps/min), step length (m) and step width (m)] were exported as ASCII archives to the Orthotrack® program for each group (Parkinson's and control) under the simple-task and DT conditions. A total of six gait cycles were used to achieve these values.

All graphs obtained from 3DGA were normalised to a percentage of the gait cycle and all available trials of kinematic data were exported using a specific program (Orthotrack® 6.2 Motion Analysis, Santa Rosa, CA, USA). This produced kinematic plots of the pelvis, hip, knee and ankle for each cycle. The GDI method (as described by its authors) was implemented using the electronic addendum provided by the GDI article, i.e. using control data from Schwartz and Rozumalski (Hollman et al., 2007). Subsequently, the GDI scores for the patients with PD were calculated using only results from patients performing and not performing the DT.

Descriptive statistics for demographic data and all outcome measures were expressed as mean [standard deviation] values. A statistical power analysis was performed using the G*POWER program (Erdfelder et al., 1996), based on the detection of a 10-point difference in the Gait Deviation Index (Schwartz and Rozumalski, 2008), two-tailed analysis, an alpha level of 0.05 and 70% power. Possible differences between the conditions (based on predefined GDI and spatiotemporal variables) were compared using three-way analysis of variance (ANOVA), the factors of which were side, group (patients vs. controls) and task (interference effect).

Results

Descriptive and demographic characteristics at baseline are displayed in Table 1 for the control group (CG) and Table 2 for the Parkinson's Disease Group (PDG). Statistically significant differences were found between groups for step length and width, cadence and GDI. Differences were found between tasks for velocity, stance phase and GDI. In the comparison of sides, differences were found in step length, cadence, velocity, stance and swing phase. No difference was found regarding double support.

Table 3 summarises the results in mean and standard deviation values for all variables. An interaction effect was observed for the GDI, with an interaction between task and group (Tables 4 and 5).

Discussion

The influence of cognitive activity has frequently been studied in patient populations and healthy individuals and the results typically point to the interference of DT in gait. The inability to change tasks is recognised as an attention control problem in PD, which compromises security and the efficient performance of functional tasks, such as walking in both familiar places and unpredictable places that require coordination, cognitive responses and immediate,

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Table 3 Spatiotemporal gait variables (step length, cadence, velocity, step width, stance phase, swing phase, double support phase) and GDI during normal gait and dual task interference gait analysis on both sides for each group.

			Right side		Left side	
			Normal gait	Dual task	Normal gait	Dual task
Step Length (cm)	CG	Mean	117.46	107.27	118.17	107.94
		SD	10.42	14.40	9.67	14.58
	PDG	Mean	98.12	80.97	98.24	81.52
		SD	16.68	22.54	16.95	22.99
Cadence (step/min)	CG	Mean	103.31	94.15	103.58	94.42
		SD	12.03	9.74	12.91	9.89
	PDG	Mean	115.06	109.35	115.52	110.23
		SD	16.11	18.93	15.56	18.93
Velocity (cm/s)	CG	Mean	100.76	84.19	102.20	84.87
		SD	14.66	16.49	15.07	16.81
	PDG	Mean	95.55	74.24	96.32	75.33
		SD	26.93	28.24	26	28.43
Step width (cm)	CG	Mean	11.63	8.80	11.63	8.80
		SD	2.65	2.78	2.65	2.78
	PDG	Mean	10.50	10.92	10.50	10.92
		SD	2.80	3.36	2.80	3.36
Stance (% gait cycle)	CG	Mean	58.85	60.64	58.54	58.85
		SD	1.49	1.77	2.11	1.49
	PDG	Mean	56.82	59.41	56.41	56.82
		SD	2.89	4.98	4.37	2.89
Swing (% gait cycle)	CG	Mean	41.15	39.4	41.46	39.36
		SD	1.49	1.94	2.11	1.77
	PDG	Mean	43.18	39.44	43.59	40.59
		SD	2.89	6.43	4.37	4.98
Double support (% gait cycle)	CG	Mean	8.78	10.71	8.65	10.21
		SD	1.22	1.72	1.56	2.38
	PDG	Mean	6.81	11.08	6.94	16.27
		SD	3.18	4.93	2.73	23.41
GDI	CG	Mean	87.33	85.88	82.89	82.61
		SD	10.70	9.68	8.53	6.03
	PDG	Mean	73.08	66.08	72.80	69.45
		SD	8.83	9.88	6.11	6.15

Values expressed as mean and standard deviation.

flexible motor responses. The change in attention span seems to be mediated by dopamine energy, although this description is complex, non-linear and influenced by genotype in PD (Williams-Gray et al., 2008).

The use of this model as a clinical test to identify the risk of falls has frequently been suggested for patients with PD due to the relation to secondary postural strategies stemming from the loss of attention and a reduction in gait

Table 4 Comparisons between side, group (patient vs. control) and task (interference effect) of GDI and spatiotemporal gait variables during normal and dual task interference gait analysis.

Comparisons	GDI	Cadence	Velocity	Stance	Swing	Double support	Step length	Step width
	p-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value
Group	<0.001	0.028	0.410	0.074	0.267	0.728	0.003	0.004
Side	0.547	0.026	<0.001	0.006	0.002	0.061	<0.001	0.987
Task	0.168	0.118	0.015	0.006	0.573	0.586	0.11	0.936
Side * group	0.004	0.555	0.637	0.593	0.348	0.254	0.292	0.354
Task * group	0.032	0.489	0.864	0.593	0.692	0.490	0.574	0.584
Side * task	0.121	0.741	0.789	0.251	0.848	0.562	0.771	0.847
Side * task * group	0.415	0.748	0.515	0.822	0.595	0.503	0.724	0.824

Abbreviation: GDI, Gait Deviation Index.

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Table 5 Interaction effect for Group (control and Parkinson disease group) and Task (normal and dual-task gait) related to Gait Deviation Index.

Group	Comparison	*p*-value
CG	Normal gait vs. Dual task	0.559
PDG	Normal gait vs. Dual task	<0.001
Task	**Comparison**	***p*-value**
Normal gait	CG vs. PDG	<0.001
Dual task	CG vs. PDG	<0.001

Abbreviation: CG, control group, PDG, Parkinson disease group.

performance during a DT exercise and the consequent increased risk of falling (Allock et al., 2009).

The aim of the present study was to evaluate the effect of dual-task interference in adults with and without PD using the recently proposed summary measure denominated the Gait Deviation Index (GDI) and spatiotemporal variables. A previous study validated the GDI and obtained a strong relationship in patients with cerebral palsy between the GDI and gross motor function, as expressed by the Gross Motor Function Measure and Gross Motor Function Classification System (Molloy et al., 2010). To our knowledge, no individual analysis using GDI has been reported for the evaluation of the effects of DT interference. Multiple attempts have been made to assess gait in patients with PD during a DT exercise using spatiotemporal outcomes. However, with the exception of 3DGA, the majority of studies employed other instruments (Morris et al., 1999; Sofuwa et al., 2005; Cimolin et al., 2011). Nonetheless, an analysis of interrelated variables is difficult. Thus, the representation of a wide variety of variables in a single score that can be used to measure changes in gait quality could be clinically useful (Fig. 1).

Dual-task interference led to a global reduction in gait pattern among the patients who participated in the present study, as a significant difference in mean values in the gait analysis occurred between groups (CG and PDG), interference (normal walking and dual-task) and side. These results corroborate those reported in previous studies on the effect of a DT exercise on gait among patients with PD, namely, a reduction in gait velocity (O'Shea et al., 2002; Galletly and Brauer, 2005; Hackney and Earth, 2009; Brauer and Morris, 2010) and an increase in double support (Galletly and Brauer, 2005; Hackney and Earth, 2009). The present results demonstrate a significant difference between groups regarding GDI and an interaction effect involving the group and task factors. The CG and PDG were different independent of interference and side, but interference was only different for the PDG group.

GDI was effective at offering an overview of gait deviation from the normal pattern according to the literature as well as quantitatively illustrating the overall changes in pathological gait as a result of a particular DT interference.

Spatiotemporal gait variables were studied and not used in the GDI calculation, but offer important information demonstrating changes in gait performance. During the gait analysis, the DT interfered in the stance phase and velocity independent of group and side. Velocity decreased both in the CG and PDG and stance time increased in both groups. The use of a motor task combined with a cognitive task hindered the overall gait performance in the PDG, reduced the total time of locomotor activity and increased the need for stability by increasing the length of the stance phase during the gait cycle in both groups.

Regardless of the interference of task and side, comparisons between groups demonstrated that cadence (number of steps per minute) was greater in the PDG, whereas step length was smaller and step width was practically the same. These variables are not influenced by dual tasks and illustrate the classical pattern of patients with Parkinson's, namely, small steps and the need to increase the frequency of exchange steps to prevent falls, as the support base (step width) is not increased.

Regardless of the dual task and group difference, the comparative analysis of lower limb side revealed differences in velocity, cadence, step length, stance phase and swing phase. This likely occurred because perfect symmetry between the lower limbs is improbable during human locomotion. However, these variables are related, since there was a reduction in gait velocity, with a consequent reduction in cadence and stride length. Moreover, the reduction in gait velocity led to an increase in the stance phase and a consequent reduction in the swing phase, with no change observed in the double support phase.

These results agree with those of previous studies evaluating linear gait variables during a DT exercise, which report a reduction in velocity and step length (O'Shea et al., 2002; Galletly and Brauer, 2005; Hackney and Earth, 2009; Brauer and Morris, 2010) and differ from others that report an increase in double support time (Galletly and Brauer, 2005; Hackney and Earth, 2009) in groups with and without PD. These studies justify their findings by showing that the use of a secondary task can draw attention to mechanisms from automatic movement and direct them towards a cognitive task in both patients with PD and healthy individuals (Morris et al., 1996; Rochester et al., 2004; Galletly and Brauer, 2005; Allock et al., 2009; Hackney and Earth, 2009).

The divided attention in the neural circuit of the frontal and motor cortex reflects a possible adaptation to reduce the risk of falling in circumstances that require considerable attention, suggesting a direct relationship between cognitive function and gait velocity (Hollman et al., 2007). This hypothesis is reinforced by the fact that patients improve velocity and step length when oriented to direct their attention to gait after specific training with a DT exercise (Yogev et al., 2007; Brauer and Morris, 2010).

Gait deficits are exacerbated during the performance of a DT exercise by patients with PD, as the need to concentrate on both walking and concurrent tasks exceeds the available attention resources (Bloem et al., 2001). In PD, the excess attention needed to perform the task or hyperstimulation provoked by unexpected stimuli induces a hypo-excitability that can be manifested as a motor block. However, during simultaneous tasks, the response time to the cognitive task is reduced due to the increase in attention needed to perform the motor task, which results in the exacerbation of gait defects during the performance of a DT exercise among patients with PD (Rochester et al., 2004; O'Shea et al., 2002).

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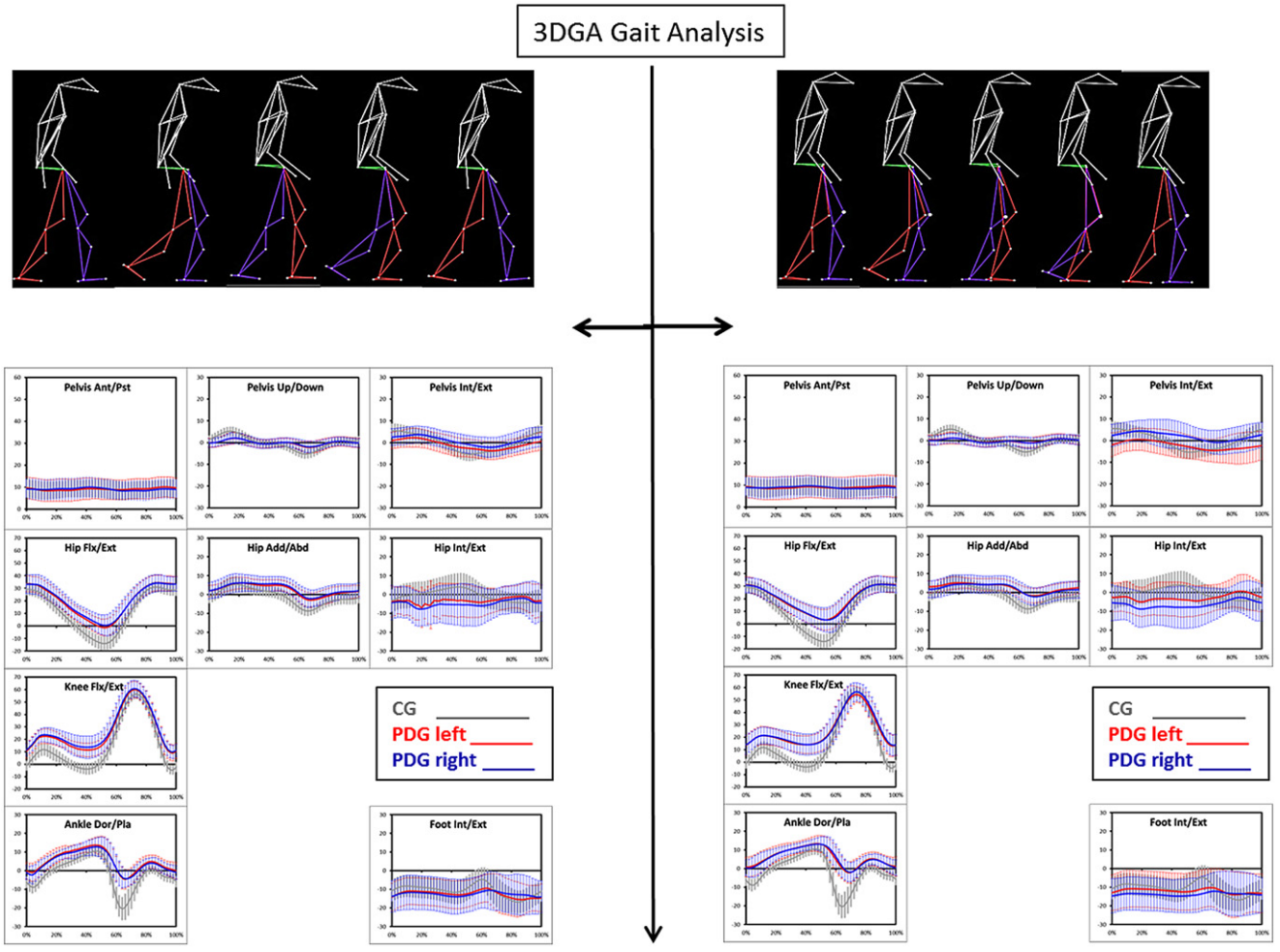

		Right Side		Left Side	
		Normal Gait	Dual Task	Normal Gait	Dual Task
GDI	CG	87.33	85.88	82.89	82.61
		10.70	9.68	8.53	6.03
	PDG	73.08	66.08	72.80	69.45
		8.83	9.88	6.11	6.15

Figure 1 Illustration that characterizes the acquisition of three-dimensional gait analysis information, presented in a conversional graphical gait analysis report and the summary results using the GDI for both group and tasks. Normative database normality is presented in grey, left side in red and right side in blue (Mean and SD).

The mathematical problems chosen as the second task tax working memory and information processing related to executive function (Morris et al., 2005). The combination of this task with gait leads to a high demand of competiveness for executive motor function, suggesting that the automaticity of the performance under the complex conditions of walking is multidimensional (Rochester et al., 2004).

The results of the present study have important implications for the rehabilitation of individuals with motor impairment associated with PD. Therefore, an improvement in walking performance under dual-task conditions may occur with practice due to motor learning.

According to other synthetic indexes proposed in the literature, the main limitation to the GDI is that the quantification of gait strategy and the assessment of changes in gait following a specific intervention are conducted using an overall measurement rather than the analysis of individual variables. The analysis of GDI scores and spatiotemporal gait variables provides the extent to which gait has changed, but does not reveal the cause or nature of the change. Clearly, a positive change is beneficial to patients, but, given the single-value format of a synthetic index, the GDI should not be used alone to assess the effect of DT interference. However, given that

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overall gait performance was the main interest in the present study, the GDI seems to be an appropriate outcome measure when used together with the spatiotemporal gait variables.

Individuals with PD tested during a dual-task interference exercise require motor skills, executive function and attention processes while walking. Task requirements are highly selective and different executive processes and motor characteristics are required to fulfil the demands of the different tasks. Further research is needed to confirm this complex relationship, which has implications for the rehabilitation of gait among patients with PD. Studies employing the GDI and spatiotemporal gait variables should be conducted to evaluate the suitability of this index in detecting changes following other interference interventions generally used for training patients with Parkinson's disease and its effectiveness in perceiving small changes in gait.

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Appendix

PD	Parkinson's disease
BG	basal ganglia
GDI	Gait Deviation Index
3DGA	three-dimensional gait analysis
DT	dual task
CNS	central nervous system
GGI	Gillette Gait Index
SD	standard deviation
CUSC	Centro Universitário São Camilo
MMSE	Mini-Mental State Examination
ANOVA	analysis of variance
CG	control group
PDG	Parkinson's disease group

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