Effects of counting the stride numbers as a secondary task on gait in people with Parkinson's Disease: An idea about the cause of dual task interference during gait and a new hope for early diagnosis

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Abstract

In this study, we tried to analyse changes in walking performance under both single and dual task conditions in people with Parkinsonِ Disease (PD) and healthy subjects. To this end, the participantsِ trunk acceleration signals were recorded under dual task (counting the stride numbers while walking) and single task (walking without performing any other secondary tasks) conditions. The healthy subjects counted the number of their strides correctly; however, 85% of the patients made glaring errors in counting. Then variances of stride time interval (STI) signals were calculated for each participant. STI signals of patients had greater variance than the healthy subjects in dual-task condition. Separating the two groups in dual task condition is easier. Therefore, we think that the diseased state can be detected in early stages. It is thought that counting is performed independently of walking. PD affects the function of the basal ganglia that leads to motor timing dysfunction. So, it seems that timing in motor tasks is disrupted while timing in cognitive tasks is not affected. This led us to the conclusion that perhaps inconsistency between the two clocks (motor tasks and cognitive tasks clocks) is the main cause of dual task interference during gait in patients.

Keywords: Parkinsonِ Disease; early diagnosis; internal biological clock; dual-task.

1. Introduction

Parkinsonی Disease (PD) is a degenerative and progressive disorder of the central nervous system (CNS), which results from degeneration of Substantia Nigra Pars Compacta (SNc) of the basal ganglia (BG). The real cause of this destruction is still unknown and no cure exists for this disease yet. Unfortunately, there are not enough diagnostic tests that can be used as effective screening tools in order to identify the patients with PD in early stages of the disease. In fact, approximately about 50ـ80 % of SNc neurons have already been damaged, when the disease become diagnosed by a physician. It is thought that early diagnosis and treatment of PD can reduce the speed of the progression of the disease; as a result, it can postpone the severe stages of the disease [1].

PD mainly affects the motor system. Gait disturbances in PD are motor system disorders that generally get worse over time. They are characterized by bradykinesia, muscle rigidity, asymmetry of the left and right parts of the body, abnormal rhythmicity, decreased force generation, and abnormal scaling of pace length. PD negatively affects gait parameters such as step length, stride length, speed, cadence, double support time and etc. [2]. Since postural imbalance and rigidity are cardinal symptoms of PD and are shown in gait disorders, gait analysis may be crucial for the diagnosis. It is important to point out that the underlying mechanism of gait disturbances in PD has not yet been fully elucidated.

Several studies have been done to analyse the gait disturbances in PD since 1980s [3]. Sarbaz et. studied the frequency variations of stride time intervals in people with PD [4]. Also, chaotic features of gait in PD have been studied by this group and they have proposed some quantitative models for gait disturbances that can be effective in early diagnosis of the disease [5,6,7]. Hausdorff et al. investigated gait disturbances in people with PD and they found statistical differences in stride behaviour between healthy subjects and patients with PD [8]. In 2007, Hausdorff et al. claimed that rhythmic auditory stimulation (RAS) can improve speed of gait, swing time and stride length [9].

It was also shown that dual-tasking is impaired in patients with PD [10-12]. Extensive studies have investigated dual-task performance during gait in patients with PD [13-15]. In 2002, O'Shea et al. compared the walking patterns of 15 patients with PD and 15 healthy subjects under single and two dual-tasks (a cognitive and a motor secondary task) conditions. The participants were asked to walk at their self-selected speed in each condition. For the secondary motor and cognitive tasks, coin transference and digit subtraction were implemented. The results revealed that gait patterns were exacerbated under both dual-task conditions [16]. In 2014, Stegemنlerی research group examined the impact of cognitive performance on gait spatiotemporal parameters. In this study, 35 patients with PD participated. They walked barefoot over ground along a 12-m walkway: 1) at their preferred speed, and 2) while simultaneously counting backward from a 3-digit number by 3ی. Based on the results, dual-task reduces gait speed and stride length and also leads to an increment of gait variability [17]. Also, similar studies have found the same results [18-19].

Based on the previous studies, gait is disturbed during dual task walking in people with PD. However, less attention has been paid to the cause of dual task interference during gait. In our previous study [20], we tried to present a clinical gait test protocol and its potential value for separating patients with PD from healthy subjects was studied. In the current study, efforts were made to analyse gait disturbances under single task and dual task conditions. Finally, based on the clinical observations, an idea for the cause of dual task interference during gait will be proposed.

2. Material and Methods

In our previous study a protocol for gait data acquisition was designed, in which the participants were asked to walk in an بـ8-shaped pathپـfor 3 minutes and count the number of strides taken while walking, and their acceleration data was recorded. The study included 7 healthy subjects and 7 patients with PD [20]. As larger sample sizes give more reliable results with greater precision, we increased the number of participants and repeated the study. Also, in order to understand the effects of dual task intervention on gait performance of patients with PD, participantsبـtrunk acceleration signals were recorded under single task (walking without counting) condition.

The current study included 20 male patients with PD, who had the ability to walk without any help and 18 age-matched male healthy subjects. Patients did not take any drug eight hours before initiation of the test. This helped us to fully determine the effects of the disease on the patientsبـbehaviour and prevented drug effects on symptoms. Falling or freezing of gait (FOG) were not present in the patients. The stage of gait disturbances in the studied patients was between 1 and 3. The severity of illness was determined by an expert physician, according to Hoehn and Yahr Stage Scale [1]. The characteristics of the participants are presented in Table1.

Table 1. The characteristics of the participants.

Participantsبـ Characteristics	Patients	Healthy Subjects
Age, Mean±SD	59(± 10.90)	55(± 11.05)
Participants	20	18
Hoehn and Yahr stage	1.7(±0.6)	-

The designed device for measuring the stride time intervals (STI) included a three-axis acceleration sensor (ADXL303) that was able to measure the trunk acceleration of the participants [20, 21]. The accelerometer outputs were digitized at a sampling rate of 256 Hz. Then, an AVR microcontroller sent the acceleration data to a wireless RF transmitter. The RF receiver was connected to a PC to relay the recorded

signals to the PC via AVR and FT232 chip. In order to record the acceleration signals, the transmitting part of the device was placed on the participantsب waist, in a midline position. The participants were instructed to walk at their normal speed in an ب 8-shaped pathپ (between 2 chairs with a distance of 2 meters from each other) for 3 minutes and count the number of strides, taken while walking (dual task condition). An observer also counted the participantsب stride numbers, simultaneously. They did the same test after resting (at least 3 minutes) without counting or performing any other cognitive tasks (single task condition). Comparing the STI signals of some healthy subjects (under single and dual task condition) showed they had similar stride behaviour under both conditions. Therefore, the rest of the healthy subjects did not perform the second test.

Matlab was implemented to process the recorded signals, in order to extract STI signals, by detecting the peaks of the acceleration raw signals. Indeed, the time between every other peak was considered as one stride time interval. For example, the time between the first and the third peak was the first stride of the left foot and the time between the second and the fourth peak was the first stride length of the right. It is better to point out that the transmitter part of the device was placed on the participantsب waist, in a midline position. It should be noted that there was no need to find the exact position of all participantsب bodies to place the transmitter. Since time intervals between two consecutive peaks of the acceleration signals are considered, minor positioning differences between the subjectsب bodies does not affect the acceleration signals.

According to this, all participantsب STI (right foot and left foot) signals were extracted. The patientsب signals showed great stride-to-stride fluctuations, while in healthy subjectsب STI signals small variations were observed. After evaluating the behaviour of STI signals, it has been realized that there may be differences between the variances of STI signals of the patients and healthy subjects. Therefore, the variances of STI for left and right foot of each subject were calculated.

After extracting variances of STI signals, we wished to know whether or not the differences between healthy subjects and PD patients are meaningful, so we used the following statistical analyses. To test whether these distributions (healthy subjects and patients) are significantly different from each other, we performed a two-sample Kolmogorov-Smirnov test on each pair of distributions. Thereafter, One-way analysis of variance (ANOVA) were applied to compare STI variances between healthy subjects and PD patients. This was done in order to determine if there were any significant differences between the mean values of the two groups (healthy subjects and PD patients). In the following we used the Tukey-Kramer method for doing post-hoc comparisons of healthy subjectsب and patientsب mean to determine the differences between the groups more precisely.

3. Results

At this stage, the number of strides that were reported by the participants and the observer were compared to each other. The healthy subjects counted the number of their strides correctly (error of less than 1 %). Whereas, 85% of the patients made glaring errors in counting the stride numbers. Where there was a more than 20% difference between the reported numbers by the participant and by the observer, this was recorded as a glaring error.

Figure1.a shows a healthy subjectِ raw (without any filtering) acceleration signal over time under the dual task condition. Figure1.b is presented at a shorter time scale in order to show the acceleration signal behaviour more clearly.

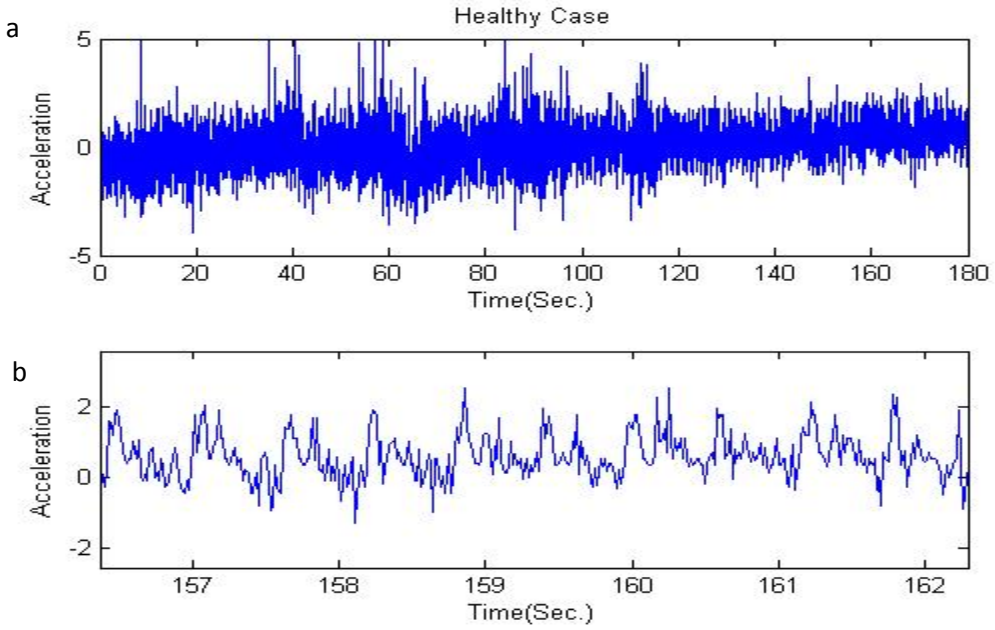

Figure1. a). A healthy subjectِ raw acceleration signal over time. b). A healthy subjectِ raw acceleration signal over time in a shorter time scale.

Figure 2 shows the STI variances of healthy subjects, along with STI signals of patients under single task condition. The vertical axis shows the right STI variance and the horizontal axis shows the left STI variance. Figure 3 represents the STI variances of healthy subjects, along with STI signals of patients under dual task condition.

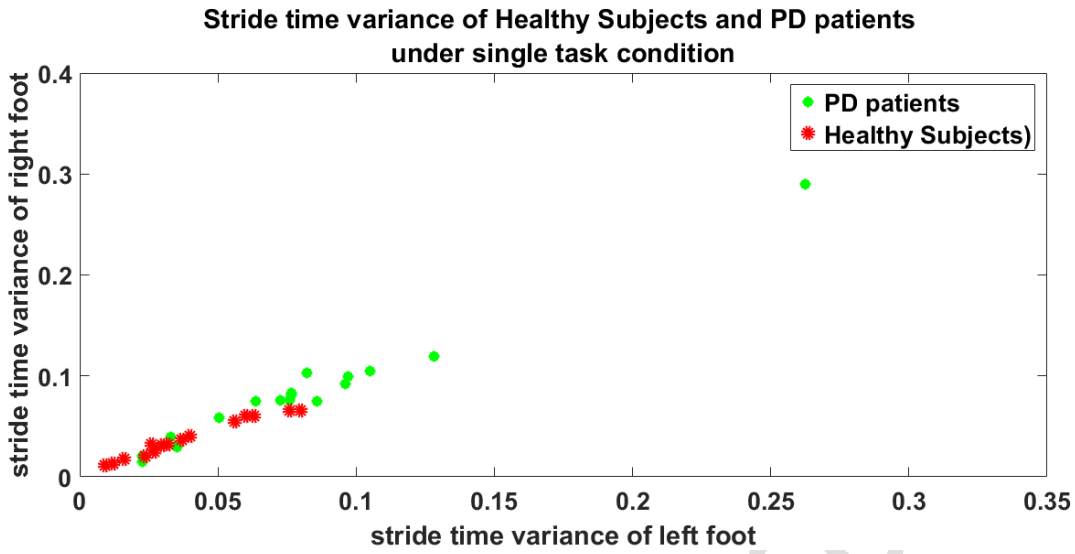

Figure 2. STI variances for healthy subjects and patients with PD under single-task condition.

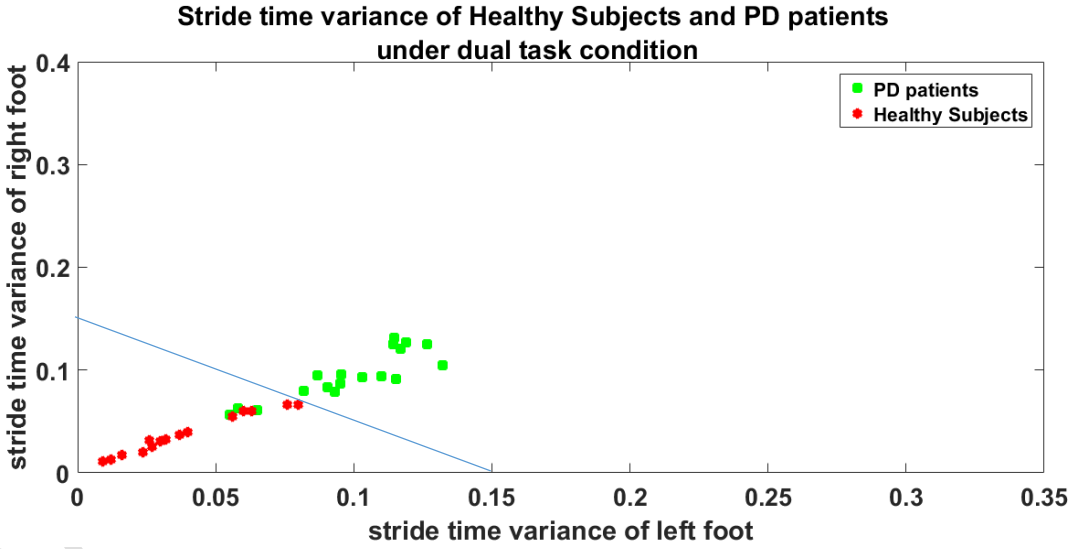

Figure 3. STI variances for healthy subjects and patients with PD under dual-task condition.

In order to separate healthy subjects from patients with PD (under dual task condition), the variance space was divided into two distinct (healthy and diseased) sections in the figure above by a straight line with the following equation:

$$y = f(x) = -x + 0.15$$

It is worth mentioning that the selected classifier in this study is a linear space divider. This has divided the healthy and diseased states space with the presented relation. This classifier is simple and elementary. It has been presented only to show significant differences between the groups. It is clear that more powerful classifiers such as artificial neural networks (ANN) or Support Vector Machines (SVM), will increase the accuracy of this screening. The results of the classifier are presented in the table 2.

Table2. Accuracy, Sensitivity and Specificity values of the classifier.

	Accuracy	**Specificity**	**Sensitivity**
Result	92.10%	100%	85%

Based on the two sample Kolmogorov-Smirnov test, The healthy subjects and patients with PD were found to be significantly different from each other at significance level, $\alpha = 0.001$. P-values in the one-way ANOVA have been presented in the table 3. Post hoc analysis results are shown in figure 4 and 5.

Table 3. One-Way ANOVA p-values for healthy subjectsبand patients with PDبSTI variances.

	Healthy subjects and patients with PD (single task condition)	Healthy Subjects and patients with PD (dual task condition)
P-value	0.048	P<0.01

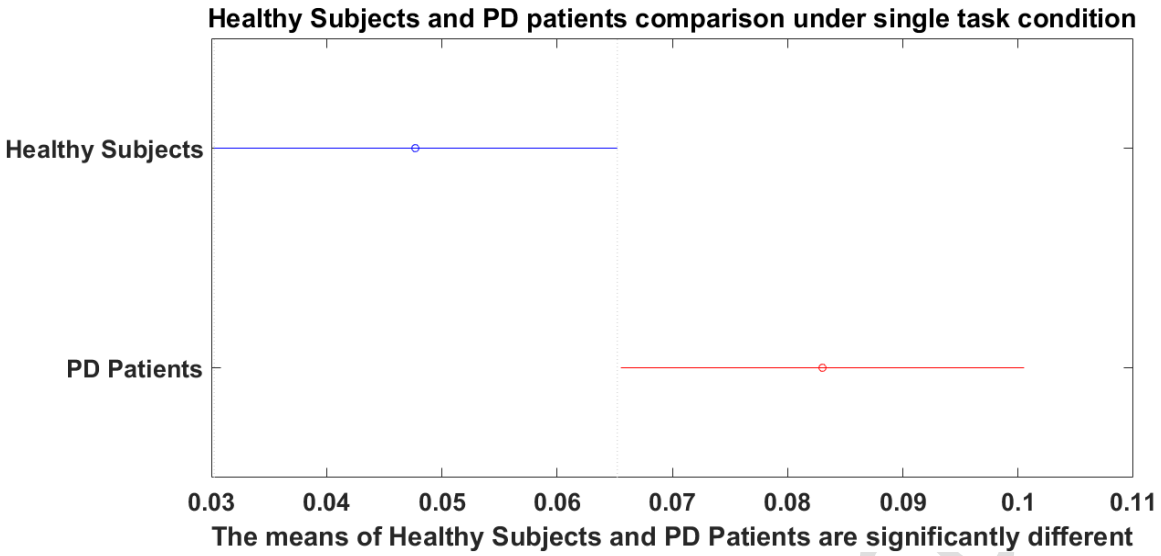

Figure 4. Post hoc analysis results for healthy subjects and patients with PD under single-task condition.

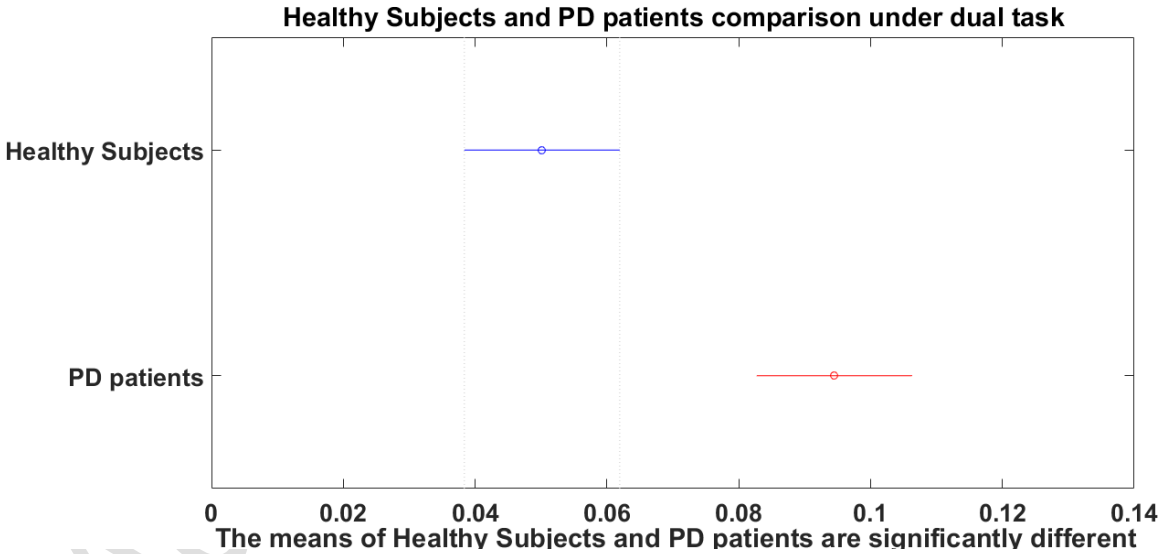

Figure 5. Post hoc analysis results for healthy subjects and patients with PD under dual-task condition.

As the results demonstrated, dual task revealed statistically significant differences between the healthy subjects and patients with PD. In the final stage, the patients بSTI signals under single task and dual task conditions were compared. Figure 6 shows the STI variances of patients with PD under single task condition, along with STI signals of patients with PD under dual task condition. ANOVA has a p-value of 0.08. Also, post hoc analysis result is shown in the figure 7. Of course, we didn بt expect performing the

secondary task would screen patients under dual task and single task conditions, obviously. Counting the stride numbers exacerbates gait disturbances. It should be noted if healthy subjects and patients with PD are compared under single and dual task conditions, significant differences between healthy subjects and patients under the dual task condition are observed when compared to the single task condition, as seen in the post hoc results (figure 5). As a result, performing such a cognitive task makes screening patients with PD and healthy subjects simpler and more effective.

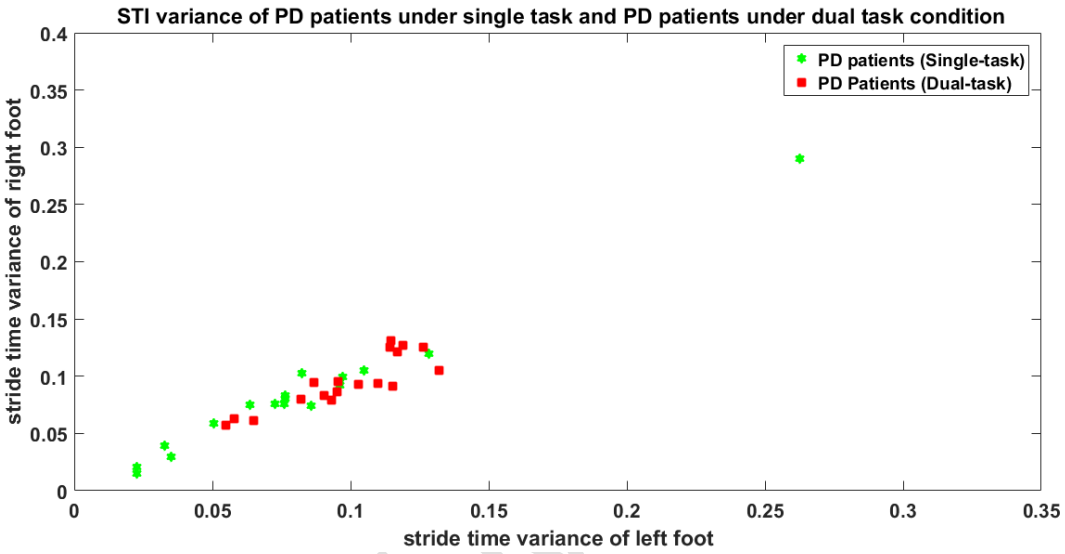

Figure 6. STI variances for patients with PD under single task condition and patients with PD under dual-task condition.

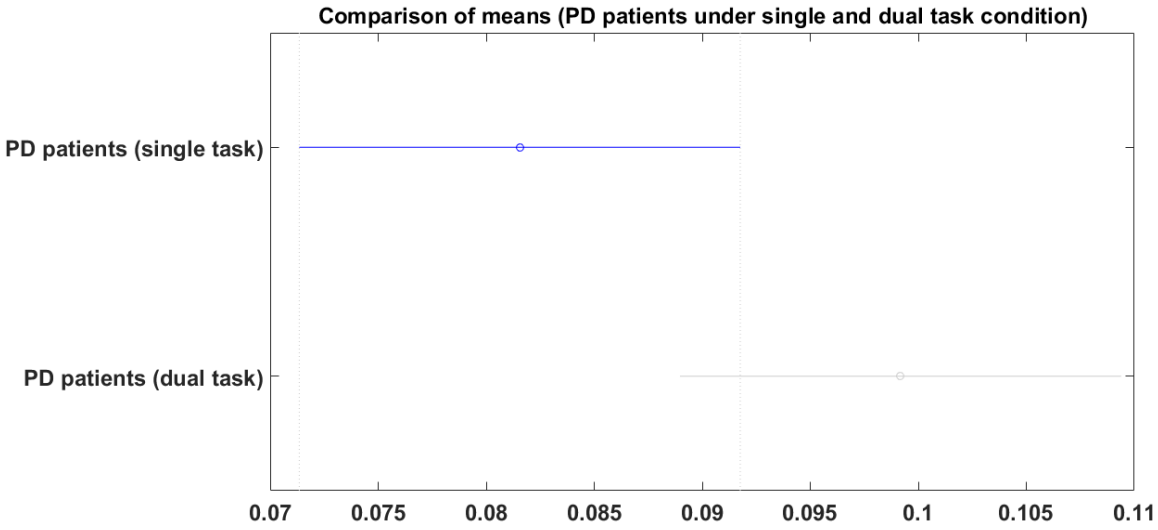

Figure 7. Post hoc analysis result for patients with PD under single task and patients with PD under dual-task condition.

4. Discussion

Human movement is a highly complex motor process that is regulated by the brain. Much remains to be elucidated concerning the neural mechanisms underlying movement control in the brain. CNS diseases can cause problems with control of movements. Such diseases help us to understand the movement control mechanisms better to some extent. Each of these diseases can affect particular areas of the brain; hence, destruction of that particular area reveals its role in control of the movement.

PD is a degenerative disorder of the CNS that mainly affects the motor system. Gait disturbances in PD are motor system disorders that generally get worse over time. The underlying mechanism of gait disturbances in PD has not been elucidated yet. It is thought that early diagnosis and treatment of PD can slow the progression of the disease, and as a result, can postpone the severe stages of the disease. In the present study, attempts were made to evaluate the behaviour of people with PD and present an idea to explain the cause of gait disturbances in order to achieve a better understanding of human movement control mechanisms. If the internal clock function will be specified, we hope this idea be helpful in early diagnosis of PD.

We proposed a new protocol for gait data acquisition in an بـ8-shaped pathپin our previous study [20]. The participants counted their stride numbers while walking. The results clearly showed its potential value for separating patients with PD from healthy subjects. In the current study we tried to increase the reliability of the results by increasing the sample sizes (20 patients with PD and 18 healthy subjects) and the effects of dual task interference on gait performance were investigated. To this end, in this study, again the healthy subjects and patients with PD were asked to walk in an بـ8-shaped pathپfor 3 minutes and count the number of strides taken while walking. The patients did the same test after resting, without counting or performing any other cognitive tasks. The participantsبtrunk acceleration signals were recorded while they walked. STI signals were extracted from the acceleration signals. Then variances of STI signals were calculated and were considered as features. Statistical analyses results showed that although counting the stride numbers improves screening patients and healthy subjects process, there were no significant differences between the patients under dual task and secondary task conditions. It means that counting doesnبtspecifically alter gait performances in patients but affects the variance and increases the differences between patients and healthy subjects. Therefore, it is helpful in separating healthy subjects from patients. An interesting point to be noted is that the healthy subjects counted the number of their strides correctly; however, most of the patients made glaring errors in counting the stride numbers. Very few studies have been conducted on this topic. It seems that this study may describe the reason for dual task interference in the patients.

Here, the main questions remained are: What are the causes of dual task interference in the patients? Why patients manifested worse gait performance under dual task condition? Why do patients make errors in

counting the numbers? Based on the clinical observations, there is a significant difference between the cognitive performance (counting the number of strides) of the healthy subjects and patients with PD. The bodyپ internal biological clock influences various physical and mental activities throughout the body. It also facilitates synchronization of movements and stabilizes walking. Various disorders may affect any performances of the internal clock including motor control, cognitive performance, alertness, mental health and metabolism [22]. Joundi et. al (2012) showed that BG has a major role in regulating the motor timing [23]. BG has an important role in the production of rhythmically repetitive movements. The internal clock is tuned by BG during finger tapping performance [24]. As proved, PD affects the BG. The results of Perbal et al.پ study in 2005 shows that dopaminergic dysfunction leads to a slowdown in the rate of the bodyپ internal (biological) clock [25]. In 2009, Hausdroff et al. suggested that impairment of بinternal clockپ function lead to gait disturbances [26]. As mentioned, the main reason for synchronization of all actions of the body seems to be the internal biological clock. Indeed, all parts of the CNS regulate their performances timing according to the internal clock in a healthy state. The BG has an important role in planning and regulating motor tasks of the body. PD affects BG and, as a result, timing in motor tasks is disrupted in people with PD.

Our idea is that another clock is established for motor tasks that we name it ιmotor tasks clockبAlso, we can consider a ιcognitive task clockبfor cognitive tasks. These two clocks coincide with the internal clock and they are synchronized in a healthy state. PD affects the BG. So, it cannot regulate its activity based on the internal clock. While, cognitive task clock coincides with the internal clock. Therefore, the synchronization between these two clocks is disrupted in the diseased state. That is why the patients made errors in counting the stride numbers (cognitive task) while walking (motor task). Indeed, these two tasks are regulated according to two inconsistent timing.

A few attempts have been made to study the internal clock role in regulating the bodyپ activities that may confirm this idea. It should be noted that to the best of our knowledge such an idea (inconsistency between the two clocks) has not been presented so far. It should be noted that the role of the BG on motor tasks timing has been studied, but its role on cognitive tasks timing and also, the coordination between cognitive and motor tasks have been less studied. An inconsistent relationship between the timing of a motor task and the timing of a cognitive task may appear in the early stages of the disease [27, 28]. It is possible all the movement disorders in PD are not caused solely by damage to the motor areas of the CNS [29]. Perhaps this timing inconsistency has a larger role in the appearance of movement disorders [30]. Therefore, based on the idea, it may be supposed that this desynchronization is result of the creation two different timing (motor task timing and cognitive task timing). This is due to BG damage and motor timing disruption.

Based on the presented idea, the two clocks don؛t show coinciding component periods under the diseased state. Therefore, it is possible to develop a new theory about the disease disorders appearance. On the other hand, it seems that functional performances of the disease rehabilitation may be explained. For example, some studies have shown the effectiveness of vibratory stimulation on gait in PD [31]. Additionally, deep brain stimulation (DBS) can improve movement disorders of PD [32]. It is possible that regular electrical impulses create a reference clock that coordinates cognitive and motor clocks. In the case of synchronization between the two clocks and tuning of the synchronization with an external resource clock (DBS), the time differences between the two clocks is reduced and as a result the degree of gait disturbances is reduced.

5. Conclusions

The results of this study demonstrate an increase in dual task gait disturbances. This may be appropriate for detection of the disease in its earlier stages. However, it seems that the main cause of the dual tasks interference during gait is related to unsynchronized performances between the motor tasks clock and cognitive tasks clock. One of the major findings of this study is that any cognitive activity that involves the brain besides motor activity will lead to increased effectiveness of screening of patients with PD. It should be noted that the more the brain is involved during motor activities, the more screening will be accurate.

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Conflicts of interest

There is no conflict of interest.