

Virtual Functional Mobility Test: A Potential Novel Tool for Assessing Mobility of Individuals With Parkinson's Disease in a Multitask Condition.

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Abstract

Background: There are few instruments available for evaluating functional mobility during multitasking in people with Parkinson's Disease. Virtual Reality is a potentially tool capable of aiding in the evaluation of functional mobility. The purpose of this study is to verify the potential of the Virtual Functional Mobility Test (VFMT) as a clinical tool to assess functional mobility of people with PD during multitasking condition.

Method: 25 people with PD and 25 people without PD, matched for age and sex, were recruited. Participants were evaluated through the Trail Making Test, Timed "UP and GO" test, Timed "UG and GO" in dual task and through the VFMT, composed of 1) a simple task, involving exclusively motor skills and 2) a complex task, involving multitasking. The groups' performances on the clinical and VFMT tests were compared to verify the virtual test's sensitivity. It was evaluated the correlations between VFMT tasks and existing clinical tests, the reliability intra-rater and the users' perception.

Results: The VFMT and clinical tests were sensitive to differentiate the groups, except the trail making test part B ($p= 0.332$) and complex task ($p= 0.052$). Strong correlations were observed between parts A and B of the trail making test ($r=0.75$) and complex task ($r=0.72$); Moderate correlations between Timed Up and Go test and Timed Up and Go in dual task test with simple task ($r=0.47$) and complex task ($r=0.55$), respectively, was found. The complex task and simple task showed excellent and moderate reliability intra-rater, respectively.

Conclusion: It was concluded that the novel VFMT is feasible, sensible, reliable and has potential as an instrument for the evaluation of functional mobility during multitasking in people with PD.

Introduction

Parkinson's disease (PD) is marked by four typical motor symptoms (MS) – tremor, rigidity, bradykinesia, and postural instability. As a consequence of disease, gait disorders are a major challenge with a characteristic pattern such as trunk flexion, reduced arm swing, narrowed base of support and reduced range of motion and gait velocity [1]. Non-motor symptoms (NMS) are also present in PD. Dysfunctions in cognitive domains like memory, language, attention, visuospatial capacity, and executive functions (EF) are some examples of NMS [2, 3].

The NMS, mainly the EF and attention [4, 5] interact negatively with gait, especially during the performance of simultaneously tasks [6, 7]. A reduction in gait speed, stride length and gait stability are observed during these simultaneous conditions [8]. The functional mobility of people with PD is, consequently, impacted in this case [7] and reportedly simple daily life tasks are more difficult for this population. For example, when people have to walk while they do another cognitive task, such as counting backwards, gait becomes more difficult. Therefore, a reduction in quality of life and an increase in fall risk can be observed [4].

Thus, the functional mobility assessment in people with PD is necessary and, due to the negative interaction between the MS and NMS, it should be performed in varied dual task (DT) conditions [7]. Although, specific instruments to assess functional mobility during the performance of simultaneous tasks are scarce, especially when referring to instruments that approximate real-life demands. In the literature, the Timed-Up and Go test (TUG) is the gold standard test to assess functional mobility in people with PD [9]. The Timed-Up and Go cognitive test (TUG-cog) assesses functional mobility in simultaneous task conditions by adding a cognitive task, for example counting backwards. However, the tasks usually added to the TUG do not resemble tasks required in the daily life. Furthermore, many times we are faced with more than two tasks simultaneously.

In this way, we hypothesize that virtual reality (VR) could be an effective functional mobility assessment tool. VR simulates real life environments and objects, providing multisensory stimulus. This enables users to interact in real time [10] through body movements [11]. VR is safe, portable, and easy to use [12].

Thus, the aim of the present study is to verify the potential of the Virtual Functional Mobility Test (VFMT) as a clinical assessment tool of the functional mobility of people with PD, during multitasking.

Methods

Study design

The present study used a cross-sectional design. It was approved by the ethic committee and research of the Faculty of Ceilândia – University of Brasília, Brasília, Federal District, Brazil (approval 2.139.454). All participants provided written informed consent prior to begin the study. The study was conducted at the physiotherapy laboratory facilities of the Faculty of Ceilândia—University of Brasília, Brazil.

Participants

A convenience sample of 25 participants ($61,08 \pm 9,67$ years) diagnosed with PD, according to UK Brain Bank criteria [13], in stages I to III of the Hoehn & Yahr classification [14] were included in the Parkinson's Disease group (PG) and 25 people without PD ($60,40 \pm 9,11$ years) matched by age and sex to the people with PD, were included in the health people group (HG). People with PD had to be in stable treatment with Levodopa, did not present any other neurologic problem and, if they were involved in other rehabilitation programs, these programs should ongoing for more than four months.

All participants were required to have preserved or corrected visual and hearing acuity (glasses or hearing aid), a minimum score of 24 on the Mini Mental State Exam (MMSE), an education level ≥ 4 years and score less than 6 on the Geriatric Depression Scale (GDS). Participants who were unable to stand independently or any physical limitations that could affect the proposed activities were excluded.

Participants were recruited from the local community and surrounding areas via media, flyers, television, and telephone contact to volunteers in local health services.

Virtual Functional Mobility Test (VFMT)

The VFMT was developed specifically for this study with the purpose to create a virtual environment able to mimic a daily life activity of people with PD. It was developed by a research group from San Antonio Virtual Environments (SAVE) Lab, in Texas, in partnership with a physiotherapy research group from University of Brasília. It was developed with Unity™ software, usually used to create games in 2D and 3D that can be exported to many platforms like Xbox, Android, IOS, Windows, Linux, Mac, and PlayStation.

VFMT set up

A movement sensor, Microsoft Kinect® V2 (Microsoft Corp., Redmond, Washington) was used to detect the participant movements and a multimedia projector was used to project the virtual environment. Both were connected to a notebook (Windows 8.1 with a USB port 3.0) where the VFMT software was installed. The images were projected in white screen placed 1.50 m from the Kinect V2 sensor and the participants were positioned 1 m from the movement sensor.

VFMT Virtual Environment

In the VFMT, participants control an avatar – a 3D virtual human - to move through a simulated house and interact with various everyday objects. To move the avatar forward, participants had to perform a stationary gait. To turn on the corridors, participants had to lean to the left or right, respectively, depending on the corridor of interest. To grab an object, participants had to reach out their hand, performing a shoulder flexion, until the avatar's hand intersected with the object. The VFMT house consists of a main corridor (FIGURE 1.A) from where two side corridors come out to the right and left, which lead, respectively, to a telephone (FIGURE 1.B) and a door (FIGURE 1.C). At the end of the main corridor there was a table with some bottles on top of it, with different colors, representing medicine bottles (FIGURE 1.D).

VFMT tasks

The VFMT is composed by two tasks: a Simple Task (ST) and a Complex Task (CT). The ST requires only motor skills from the participant while CT requires to perform multiple tasks simultaneously, similar to real activities of daily living.

A familiarization with the virtual environment and the required body movements was performed previously to the start. Before the beginning of each task, instructions were read clearly and loudly. To ensure only motor skills were used in the ST, the physiotherapist in charge guided the participant by voice command, through the task. For example: "*Please, walk to that first door, and open it*", "*Turn to the right and answer the phone*", "*Now, go back to the main corridor and turn to the right*", "*Take the red medicine bottle*". "*Go back to where you started*".

In order to make sure that multiple tasks would be required on the CT, the physiotherapist read the task instruction and reinforced that no verbal command or help would be given during the task. The instructions were read till the participant understood them. In CT, the participant was told a time (9:00 am

or 2:00 pm). The time defined the color of the medicine bottle that needed to be picked up - If it was 9:00 am, the red bottle had to be picked and if it was 2:00 pm, the yellow bottle. On the way to the medicine table a doorbell or telephone sound would ring. If a doorbell ringed, the participant had to turn in the left corridor and open the door. If a telephone ringed, the participant had to turn to the right corridor and answer the phone. After that, participants had to go back to the main corridor, pick up the medicine bottle, according to the time told at the beginning, and then they had to go back to the start spot.

VFMT cognitive and motor demands

The motor demands in the ST and CT were: *stationary gait*, to make the avatar walk through the environment; *shoulder flexion*, to open the doors and to grab the phone or medicine bottle; and *lateral trunk flexion*, to make the avatar turn.

The cognitive demands in the CT were: *working memory* (to memorise the task given via verbal instructions); *planning* (to plan the tasks needed to complete global task); *decision-making* (to allow the participant to select a motor action against two or more possible options); *inhibitory control* (to interrupt the motor plan actually in course); and *divided, sustained and selective attentions* (to be able to perform dual tasks).

Procedures

The participants were assessed in two moments by the same trained physiotherapist. On the first meeting, cognition and functional mobility were evaluated and the VFMT was performed. The second meeting was performed thirty days after the first meeting and the participants were given the VFMT again.

Cognition was assessed by means of the Trial Making Test (TMT), parts A and B, commonly used for the assessment of executive functions in people with PD [15] and by the Montreal Cognitive Assessment (MoCA); Functional mobility was assessed by the TUG, which is a valid and reliable test to quantify the functional mobility in elderly and people with PD [16]. The TUG-cog was also applied, being a valid and reliable test to assess functional mobility in dual tasks [7]. The VFMT usability was assessed by means of the System Usability Scale (SUS) [17], translated to the Portuguese language [18].

Analyses

The data were analysed using Statistical Package for the Social Sciences (SPSS- version 22.0). Data normality was confirmed by the Shapiro-Wilk test. A descriptive analysis was done to summarise and characterize the sample, as mean and standard deviation, frequency and percentage to classify the disease course. The Mann-Whitney test was used to verify the sensitivity of the VFMT by the differentiation of the groups and the magnitude of effect was given by Cohen's d effect-size. It was considered as small effect-size when d is equal or less than 0.5, moderate when d is between 0.5 to 0.7 and large when d is greater than 0.8. The Spearmann correlation was used to analyse the correlation between the clinical tests and the VFMT on the DP group, using Callegari-Jacques [19] cut offs where null correlations are when r equals 0; weak between 0 to 0,3; moderate between 0,3 to 0,6; strong between 0,6

to 0,9; very strong between 0,9 to 1; and perfect when it is 1. Considering that the VFMT data were not normally distributed, to analyse the test-retest reliability intra rater in the DP group, the Wilcoxon signed rank test was used to assess systematic differences between tests moments and Spearman correlation coefficients to indicate reliability. Results were considered statistically significant when $p < 0.05$.

Results

The participant's characteristics are presented in Table 1. According to the Hoehn and Yahr scale 56% of our sample was in stage I of the disease, 40% in stage II and 4% in stage III.

Table 1
Sample characteristics.

	PG (N = 25), Mean(SD)	HG (N = 25), Mean(SD)	<i>p</i>
Age	61.08 (9.67)	60.40 (9.11)	.763 ^b
Sex (M/F)	18/6	18/6	-
MMSE	27.16 (2.08)	28.00 (1.23)	.089 ^a
MoCA	24.44 (3.10)	24.88 (2.71)	.550 ^b
GDS	3.48 (2.28)	3.04 (1.80)	.451 ^a
Education level	11.12 (3.81)	12.36 (4.27)	.261 ^b
H&Y	1.64 (0.60)	-	-
UPDRS- II	9.80 (4.43)	-	-
UPDRS-III	12.04 (5.21)	-	-
Diagnostic time	6.68 (3.68)	-	-

Legend: M. Male; F. Female; PG. Parkinson group; HG. Healthy group; MMSE. SD. Standard deviation. Mini Mental State Exam; GDS. Geriatric Depression Scale; H&Y. Modified Hoehn & Yahr Scale; UPDRS. Unified Parkinson's Disease Rating Scale (II- Motor aspects of daily living; III- Motor examination).

^a.Independent t test. ^b .Mann-Whitney test. Significant if $p < 0.05$.

The differences between groups in the tests applied are shown in Table 2. The groups had different performances in all tests except on the TMT part B and CT.

Table 2
Differences between groups on the tests applied.

Tests	PG	HG	<i>p</i>	<i>d</i>
	Mean(SD)	Mean(SD)		
<i>Cognitive</i>				
TMT-A (sec.)	57.91 (22.23)	43.71 (16.88)	0.012*	0.71
TMT-B (sec.)	171.32 (111.34)	125.28 (46.30)	0.332	0.54
<i>Mobility</i>				
TUG (sec.)	9.50 (2.49)	7.57 (1.59)	0.002*	0.92
TUG-Cog. (sec.)	11.66 (2.86)	9.06 (1.75)	0.000*	1.09
<i>VFMT</i>				
ST (min.)	5.16 (2.26)	3.45 (0.88)	0.010*	0.99
CT (min.)	5.48 (1.77)	4.40 (1.53)	0.052	0.65
Legend. PD- Parkinson's disease group. HG- Health group. SD. Standard deviation. TMT-A. Trail making test part A; TMT-B. Trail making test part B; TUG. Timed up and go test; TUG-cog. Timed up and go cognitive test; VFMT. Virtual functional mobility test; ST. Simple task; CT. Complex task. <i>d</i> . Cohen's coefficient. Mann-Whitney test. * <i>p</i> < 0.05.				

The correlations between the clinical tests and the virtual task on the first assessment of the VFMT for the DP group are shown on Table 3. Strong correlations were observed between the performances of the TMT-A and B and CT; moderate correlations between TUG and ST, and TUG-cog and the CT; and weak correlation from MoCA and CT [19].

Table 3
Correlations between the clinical tests and the VFMT tasks.

Clinical tests					
VFMT	TMT-A	TMT-B	MoCA	TUG	TUG-cog
ST (min.)	-	-	-	<i>r</i> = 0.47*	-
CT (min.)	<i>r</i> = 0.75*	<i>r</i> = 0.72*	<i>r</i> = - 0.38*	-	<i>r</i> = 0.55*
Legend. TMT-A. Trail making test part A; TMT-B. Trail making test part B; MoCA. Montreal Cognitive Assessment; TUG. Timed up and go test; TUG-cog. Timed up and go cognitive test; VFMT. Virtual functional mobility test; ST. Simple task; CT. Complex task. <i>r</i> . Spearman correlation test.					
* <i>p</i> < 0.05.					

The test-retest reliability intra-rater for VFMT is shown in Table 4. An excellent and a moderate reliability were showed for CT and ST, respectively.

Table 4
Test-retest reliability intra-rater for the VFMT on the PD group.

Task	1º assessment	2º assessment	p	d	r
	Mean(SD)	Mean(SD)			
ST	5.16 (2.26)	4.26 (1.56)	0.03*	0.46	.63*
CT	5.48(1.77)	5.66 (2.46)	0.46	0.08	.80*

Legend. TMT-A. Trail making test part A; TMT-B. Trail making test part B; MoCA. Montreal Cognitive Assessment; TUG. Timed up and go test; TUG-cog. Timed up and go cognitive test; VFMT. Virtual functional mobility test; ST. Simple task; CT. Complex task. p. Wilcoxon test; d. Cohen's coefficient; r. Spearman correlation. *p < 0.05

The usability was measured by the SUS questionnaire. Twenty-one of twenty-five participants rated the virtual environment above 65% indicating a good usability, and four participants rated below 53%, indicating poor usability.

Discussion

On the authors knowledge this is the first study aiming to develop a clinical assessment tool of functional mobility of people with PD during multitasking by means of VR. Thus, in order to verify the VFMT clinical potential, its sensitivity was tested by the performance's comparison between groups, its feasibility by the correlation between well-established tests, its reproducibility by the intra-rater correlation and the usability by the subjects' perception of the virtual environment.

The results showed significant differences between groups performances not only in the cognitive and motor clinical tests but also in VFMT tests, except on the TMT-B and CT. Furthermore, the performances in the VFMT tasks presented strong correlations with TMT-A and TMT-B, evaluation of performance in the VFMT tasks presented an excellent reproducibility intra-rater for the CT and VFMT had acceptable usability between the people with PD.

The VFMT was sensitive to differentiate the groups during the motor task but, different than expected, the same did not occur for CT. During the ST, the participant was guided by the therapist to ensure that just the motor task was performed. On the other hand, the CT is a motor-cognitive task in which many cognitive domains are required simultaneously with the motor task. Thus, we believe that the CT must have been difficult even for individuals without disease matched by age to the people with PD, since healthy old adults also present decline in automaticity of movements [20] which could impairs the execution of simultaneous tasks. In a pilot study (on going publication), our group compared young

people and people with PD performances, on the VFMT. Young people did not find difficulties in performing the CT. However, more studies are needed to elucidate this question.

Furthermore, similarly to the CT, the TMT part B was not sensitive to differentiate the groups. Coincidentally, in both TMT-B and CT tests, attention and EF are simultaneous with the motor task. Thus, both tests are concurrent high complexity tasks. This supports prior research that suggests higher complexity in concurrent tasks results in a more negative influence of dual tasks for young adults, elderly and people with PD [21, 22, 23].

Furthermore, according to Callegari-Jacques classification [19], in the PG there were strong correlations between the CT and the TMT part A and B. This result was already expected, once both parts of the TMT are predictive of impaired mobility in elderly people [24, 25]. Even though similar results were not found for people with PD, a reduction on gait speed during DT was observed in people with PD and matched controls [26, 27].

On the other hand, the VFMT seems to be as suitable as TUG test for assessing functional mobility, because moderate correlations were found between TUG and TUG-cog and ST and CT, respectively, in PD group. However, even though both tests evaluate functional mobility, they diverge from each other as they require different motor aspects. The TUG test requires movements as sitting to stand and turning, while the VFMT presents trunk lateral flexion. Furthermore, the TUG-cog allows just one cognitive task associated to the motor task, while on the CT, more cognitive tasks are required.

Strong and moderate intra-rater reliability and reproducibility was found for the CT and ST, respectively. We believe that as ST is a less complex task and as participants received simultaneous instructions, they probably presented a learning effect which is an issue usually found in this type of repeated measures [28]. On the other hand, the CT presented an excellent reliability.

The virtual environment of the VFMT was classified as from acceptable to excellent usability [29] by the people with PD, reaching a mean score of 77.4. The SUS questionnaire was applied at the end of the first meeting. According to the users, the VFMT is a tool that, besides the benefits presented by a VR environment, it is easy-to-use, motivating and ecological.

Conclusion

We conclude that the VFMT has potential as an assessment tool of the functional mobility in multitasking conditions in people with PD, showing correlations with clinical tests, reproducibility and feasibility. These findings might be considered as preliminary once future studies are needed to define the cut-offs in the VR environment to make it applicable. Nevertheless, these findings are relevant for bringing to the rehabilitation field a VR environment developed especially to evaluate patients with PD during multiple task conditions by means of simulation of the patients' daily life activity, without the need of large space and with a low cost.

Study Limitations

The present study presented some limitations as the small sample size and the predominance of participants in Hoehn Yahr stages between I to II, which could limit generalizations. Additionally, variables as fatigue and unbalance [30] were not evaluated. Such variables, possibly present in people with PD, could cause increased variability in the study, since these variables can cause a decrease in performance.

Abbreviations

PD - Parkinson´s Disease

MS - Motor symptoms

NMS - Non-motor symptoms

EF - Executive functions

DT - Dual task

TUG - Timed up and go test

TUG-cog - Timed up and go cognitive test

VR - Virtual Reality

VFMT - Virtual functional mobility test

PG - Parkinson´s Disease group

HG - Health people group

MMSE - Mini Mental State Exam

GDS - Geriatric Depression Scale

SAVE - San Antonio Virtual Environments

ST - Simple task

CT - Complex task

TMT - Trail Making Test

MoCA - Montreal Cognitive Assessment

SUS - System Usability Scale

SPSS - Statistical Package for the Social Sciences

TMT-A - Trail making test part A

TMT-B - Trail making test part B

Declarations

Ethics approval and consent to participate

The present study was approved by the ethic committee and research of the Faculty of Ceilândia – University of Brasília, Brasília, Federal District, Brazil, by the approval number: 2.139.454. All participants provided written informed consent prior to begin the study.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

JAM collected, analyzed and interpreted the patients' data, also was a major contributor in writing the manuscript. JCL and MEPP helped designing the study and performed the revision of the manuscript. JPQ provided the development of the RV environment according to our necessity and revised the manuscript. FASM is the main head of the study, creator of the VR environment, helped on the interpretation of the data and on the writing. All authors read and approved the final manuscript.

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Figures

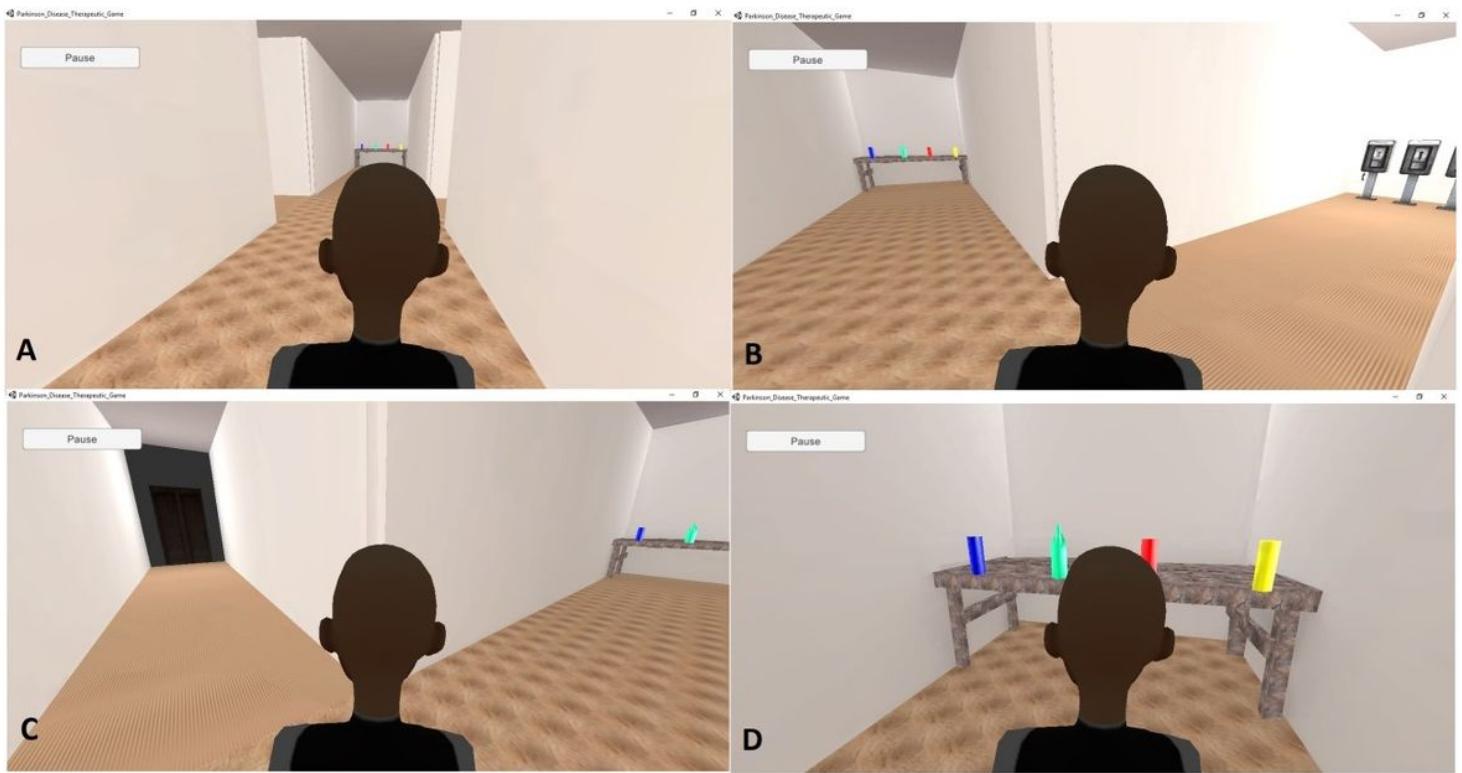


Figure 1

Virtual functional mobility test environment. Legend. A. Main corridor of the virtual house. B. Right corridor which leads to the telephone. C. Left corridor which leads to a door. D. Medicine table disposed at the end of the main corridor.