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Limb-Kinetic apraxia of legs in Parkinson's disease: Prospective clinical investigation

Yacov Balash [a,b,*], Evelin D. Mate [a], Riyad Idries [a], Anda Eilam [a,b], Amos D. Korczyn [c]

[a] Department of Neurology, Kaplan Medical Center, Rehovot, 76100, Israel
[b] The Hebrew University of Jerusalem, Jerusalem, 91120, Israel
[c] Departments of Neurology and Physiology and Pharmacology, Faculty of Medicine, Tel-Aviv University, Tel-Aviv, 6997801, Israel

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ABSTRACT

Background: The study of dynamic organization of motor acts is important for investigation of motor impairment, and a possible sign of a disorder of fronto-parietal areas of the brain in Parkinson's disease (PD). We aimed to prospectively investigate whether limb-kinetic apraxia in legs (LKA-L) is a heretofore unrecognized manifestation of PD independent of bradykinesia and rigidity.

Methods: Patients with PD and healthy controls (HC) performed bipedal reciprocal coordination (BRC) and monopedal reciprocal coordination (MRC) tests as a foot modification of the Oseretzky exam (originally alternate antiphase clenching and unclenching of the fists of the right and left hands). While MRC allowed for alternating movements of one leg per unit of time, BRC required synchronous movements of both legs in antiphase. Leg movement rates and their quality were measured by video recording and compared statistically between the groups of PD and HC.

Results: The cohort consisted of 31 PD patients (mean age 69.3 ± 7.1 years,16 males) and 12 HC (mean age 69 ± 6.2 years, 6 males). No differences between PD and HC groups were identified in MRC rate of performance, which were used as a measure of legs movement speed, although the quality of MRC movements was poorer in PD patients ($p = 0.022$). BRC rate and its performance quality were significantly flawed in PD compared to controls ($P = 0.002$ and $P = 0.003$, respectively).

Conclusions: Testing for dynamic organization of LKA-L revealed disorder in individuals with PD. LKA-L analyses should be considered in the diagnosis of leg movements and gait disorders in PD.

1. Introduction

A considerable number of patients with Parkinson's disease (PD) have difficulties with walking and gait because of bradykinesia, hypokinesia, rigidity, postural instability, camptocormia, and freezing of gait. Some authors even consider gait disorders as a hallmark of PD [1]. Additional manifestations include small steps [2] and increased step-to-step variability [3]. These disorders result from dysfunction of the basal ganglia-thalamo-cortical loops, which are controlled by the frontal lobes [4,5]. In 1931, Oseretzky [6] proposed tests for reciprocal coordination of arms in order to investigate limb-kinetic apraxia (LKA) as a disturbance of the dynamic organization of the motor act, characteristic of damage to the premotor areas of the frontal lobes. Luria subsequently popularized these tests [7].

While some of those manifestations of PD are considered as being cardinal, others are less obvious. For example, limb-kinetic apraxia (LKA) of the arms is rarely mentioned, and leg and gait apraxia was not considered as being relevant [8]. Leg apraxia in PD has since been suggested as possibly representing an underestimated effect on locomotion affecting quality of life in PD patients [9]. With this in mind, we now modified two of these tests to examine the legs. The monopedal reciprocal leg coordination test assessed the influence of bradykinesia and rigidity on leg movements by allowing the patient to focus upon sequential movements of one leg per unit of time, whereas the bipedal reciprocal coordination test required simultaneous bilateral performance of highly coordinated leg movements, which required the simultaneous involvement of both hemispheres and their coordination.

The purpose of this study was to determine whether patients with PD have limb-kinetic apraxia in legs (LKA-L) and, if so, to what extent this phenomenon is associated with bradykinesia and rigidity. We

* Corresponding author at: Department of Neurology, Kaplan Medical Center, 1, Pasternak Street, Rehovot 76100, Israel.
E-mail address: yacovbalash@gmail.com (Y. Balash).

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hypothesized that if apraxia plays a role in the dynamic organization of motor acts in PD, there would likely be differences in the rate and the quality of performance of these tests, since bipedal reciprocal coordination (BRC) requires greater attention and concentration. Contrarily, if the organization of motor acts in PD depends mainly upon bradykinesia and rigidity, it would follow that there should be no significant differences between the monopedal and the bipedal tests.

2. Methods

2.1. Study design, and participants

We conducted a prospective, cross-sectional, observational, one-visit open pilot study involving consecutive PD patients who visited the neurological outpatient clinic of the Kaplan Medical Center and healthy volunteers who served as controls. During the examination, the PD participants continued to receive their usual medical treatment. Inclusion criteria for the patients was PD diagnosed according to the UK PD Society Brain Bank clinical standards [10]. Exclusion criteria were a Montreal Cognitive Assessment (MoCA) [11] score < 26. The inclusion criteria for the HC group were self-reported absence of severe neurological, psychiatric, or somatic diseases, normal findings on a neurological exam, and age ≥ 60 years.

2.2. Assessments

The cognitive and affective states of both groups of participants were assessed according to the MoCA and the short version of the geriatric depression scale (GDS-15) [12]. PD stage was evaluated according to the Hoehn and Yahr scale (H&Y) [13], the Unified Parkinsons Disease Rating Scale (UPDRS) (Fahn and Elton, 1987) [14], the Clinical Gait and Balance scale (GABS) [15] and the Schwab and England activities of daily living assessment [16]. LKA-L was examined by the two Oseretzky tests [6] for arms modified for legs: monopedal reciprocal coordination (MRC) of leg movements and bipedal reciprocal coordination (BRC) of leg movements. The seated patient without shoes was asked to tap the right foot twice and then the left foot once at a fast pace, moving from one foot to the other (RT-II, LT-I; RT-II, LT- I; etc.). Two sets of movements were performed, each consisting of six cycles, after which the order of the foot taps was reversed. The rate of the movements were set by the subject. (2) The seated patient was asked to place his/her legs so that the toes of one foot and the heel of the other foot rested on the floor. Then he/she was asked to simultaneously and quickly switch the positions of the feet to the opposite one. Two sets of such movements were performed, each of which consisted of six cycles (see video segments).

The performance of these tests was recorded on videos for subsequent assessment. Two authors (YB and EDM) independently calculated the speed of foot movements as the number of movements per second and rated the quality of test performance.

Following the methodology of van Heugten et al in testing levels of apraxia, scoring was performed as follows: 3 = the performance of each trial is correct and appropriate; 2 = the overall performance resembles the correct response but is clumsy slow, or performed with errors; 1 = the performance only slightly resembles the correct response; 0 = the performance is incorrect or does not resemble the correct response [17]. Intraclass correlation coefficients (ICCs) were calculated to test the strength of associations and examine rating consistency.

The patients were instructed to take their usual doses of levodopa 2.0–2.5 h before the study. Each of the examined patient confirmed before the study that he/she was in his/her best motor state, (not in OFF state as well as not in ON state with dyskinesias interfering with the trial).

2.3. Analysis

The resulting data were entered into a Microsoft Excel 2016 spreadsheet. The results were expressed as means with standard deviations (SD) or as medians with interquartile ranges (IQRs). The data on the PD patients' responses were compared with those of the HC using a Mann Whitney *U* test for independent samples. The data were analyzed with SPSS 27 for Windows (SPSS, Chicago, IL). The results were considered significant at a P level < 0.05.

2.4. Data availiability

Data will be available from the corresponding author upon reasonable request.

3. Results

The mean age of the 31 PD patients (16 males, 51.6 %) was 69.3 years (SD = 7.1, range 54–84 years). The median PD duration was 5 years, IQR: (3.5–10); median H&Y stage 2.5 (IQR: 2–3), and the mean UPDRS score (motor part, III) was 17.7 ± 7.2, the mean GABS score was 14.7 ± 12.7. The mean Schwab and England activities of daily living score was 78.2 ± 11.3 % (median: 80 % IQR:] 70–90]). The PD group was compared with 12 HC (6 males), mean age 69 years, range 59–80.5 years (SD = 6.2, median = 70, IQR: [65.5–70]) (Table1).

The cognitive state of the PD patients according to MoCA was significantly worse than that of the HC, although both scores remained within the normal range (26.5 ± 3.1 vs. 28.8 ± 0.09, respectively, $P = 0.002$). The affective state of the PD patients according to GDS-15 indicated borderline depression (5.1 ± 3.5 vs. 0.3 ± 0.8 for controls, $P < 0.001$) (Table1).

Table 1
Demographic data, cognitive and affective cognition, motor state, activities of daily living and dynamic organization of leg movements in PD patients and healthy controls.

	PD patients $n = 31$	Healthy controls $n = 12$	Mann-Whitney U
Sex	15 males	6 males	
Age, y	69.3 ± 7.1	69 ± 6.2	NS
Handedness	26	11	
Right	5	1	
Left			
MoCA	Mean ± SD: 26.5 ± 3.1	Mean ± SD: 28.8 ± 0.9	**0.002**
GDS-15	Mean ± SD: 5.1 ± 3.5	Mean ± SD: 0.3 ± 0.8	**<0.001**
H&Y stage	Median (IQR) 2.5(2.0–3.0)	N/A	
UPDRS motor part (III) score	Mean ± SD: 17.7 ± 7.2	N/A	
GABS score	Mean ± SD: 14.7 ± 12.7	N/A	
Schwab and England activities of daily living score	Median: 80 % IQR: (70–90)	N/A	
MRC rate as number of movements per second	1.35 ± 0.53	1.35 ± 0.19	NS
Quality of MRC performance	Mean ± SD: 2.6 ± 0.7	Mean ± SD: 3.0 ± 0.0	**0.022**
BRC rate as number of movements per second	0.98 ± 0.37	1.37 ± 0.29	**0.002**
Quality of BRC performance	Mean ± SD: 1.7 ± 0.9 or Median (IQR): 1.25(1–2.5)	Mean ± SD: 2.7 ± 0.7 or Median (IQR): 3(2.25–3)	**0.003**

Abbreviations: BRC – bipedal reciprocal coordination; GABS – Clinical Gait and Balance Scale; GDS-15 – geriatric depression scale, short version; H&Y-Hoehn and Yahr stage; MoCA – Montreal Cognitive Assessment; MRC – monopedal reciprocal coordination; N/A- not applicable; NS – non significant; PD- Parkinson's disease; UPDRS – Unified Parkinson's disease Rating Scale;
Bold indicates significant.

The rate of performance of the MRC test did not differ between the PD patients and the HC (1.35 ± 0.53 vs. 1.35 ± 0.19, respectively, $P = 0.361$). Although the quality of the MRC performance among the PD patients scored worse in the analysis of slow motion mode of the video recording (2.6 ± 0.7 vs. 3.0 ± 0, $P < 0.022$), it differed only slightly between the PD patients and the HC (Table 1). The rate of performance of the BRC test and the quality of its performance were significantly reduced in patients with PD compared to the HC (0.98 ± 0.37 vs. 1.37 ± 0.29, $P < 0.002$) and (1.7 ± 0.7 vs. 2.7 ± 0.9, $P < 0.003$), respectively (Table 1). Finally, agreement between raters in assessing test performance was excellent for both MRC (ICC = 0.925, $P < 0.001$) and BRC (ICC = 0.942, $P < 0.001$).

4. Discussion

The results of this analysis revealed that patients with PD performed the MRC test at least as fast as the HC, while their BRC performance was significantly worse. This disparity suggests that patients with PD have LKA-L independent of the akinetic syndrome as measured by the MRC test, but probably dependent upon impairment of higher cortical functions, including central motor planning and bilateral coordination. LKA in arms (or "dynamic apraxia" according to Luria's terminology) is observed with damage to the lower parts of the premotor cortex (Brodmann area 6) and the corpus callosum, and is characterized by the breakdown of the "kinetic melody" and the temporal unfolding of movements [7].

MRC, although requiring planning, is apparently simpler because it allows the subjects to focus upon the movements of one leg while performing the task, i.e., sequentially performing tapping, whereas BRC requires synchronous movements of the feet in antiphase, i.e., bilateral simultaneous involvement of the thalamo-cortical system.

In performing anti-phase movements, Wu et al observed that patients with PD showed less activity in the basal ganglia (BG) and supplementary motor area (SMA), and had more activation in the primary motor cortex, premotor cortex, inferior frontal gyrus, precuneus, and cerebellum compared with HC [18]. Degeneration of the corticofugal tract from the SMA was observed in a study with diffusion tensor tractography in a PD patient with LKA in both arms [19]. It stands to reason, therefore, that dysfunction of the SMA and basal ganglia are associated with abnormal interactions of brain networks and that disrupted attentional networks are probably important contributors to the difficulty of these patients in performing bimanual (and therefore presumably bipedal) anti-phase movements. As a result, PD patients probably required more than regular brain activation and stronger than usual connectivity in the above-mentioned brain regions to compensate for dysfunction of SMA and BG in order to perform bipedal movements correctly.

Similar results had been obtained by Michel et al who studied walking on a treadmill over randomly approaching obstacles, where the bilateral obstacle stepping task performance was worse than the monopedal one among PD patients [20]. In contrast to unilateral obstacle stepping, where they displayed no deficits in performance after task repetition, their bilateral obstacle stepping was poorer compared to healthy subjects [20]. Those authors concluded that performance in the bilateral task can be explained by an impairment in dividing attention between concurrent tasks as well as be influenced by task complexity. Depending upon the investigated task, several authors suggested that dysfunction of the basal ganglia resulted in difficulty to switch between motor programs [21], to transfer acquired performance to different feedback conditions [22], or to synchronize the two limbs [23].

We suggest that the greater difficulty in the bilateral task can also be explained by an impairment in dividing attention between concurrent tasks, an ability that plays a role in all bilateral tasks [24], during walking, and in causing falls [25,26].

Diagnosing apraxia is particularly difficult in PD where subtle disturbances of higher cortical functions may be unnoticeable or erroneously attributed to extrapyramidal disorders since the presence of bradykinesia and rigidity further complicates the ability to arrive at the correct diagnosis.

Quencer et al, [27] were the first to overcome this "damnation" of bradykinesia-rigidity by comparing the speed of finger tapping with the speed of coin rotation (CR) in patients with PD and HC. Those authors showed that while the finger tapping speed did not differ significantly between the parkinsonian patients and HC, the CR speed was significantly slower among PD patients, and so they considered this phenomenon as limb-kinetic apraxia in PD. Their claim, however, caused some controversy in the literature [28]. One year later, Gebhardt et al (2008) [29] demonstrated that dopaminergic loading had an only insignificant effect on CR, but definitely accelerated finger tapping in PD patients, thus confirming, "dexterous deficits in PD are related to LKA rather than bradykinesia". Indeed, the CR test had originally been proposed to investigate finger dexterity but turned out to be an obvious correlate of LKA, having coincided with the original description of LKA made earlier by Kleist, the author of the manual LKA concept [30]. Since then, CR has become a classical model for studying manual dexterity and to be applicable for evaluation of fine motor skills of fingers, quality of life, and benefits of rehabilitation in PD [9,31,32].

CR has been used as a standard task in several functional magnetic resonance imaging (f-MRI) studies of the brain to explore the pathogenesis of LKA. Foki et al found significant differences between PD patients and HC with a tendency for the former to display precentral overactivation and postcentral under-activation, which the authors termed "perirolandic dissociation" [33]. Dexterous deficits in PD were associated with enhanced f-MRI activation of the praxis network [34] upstream to primary motor areas. LKA in PD was linked to an intrinsic disruption of the SMA function, which was overcome by compensatory network activation [35]. Furthermore, it was shown that PD patients recruit temporal areas of motor memory as an attempt to compensate for impaired motor skills [36]. In addition, dexterity deficits were shown to be related to an intrinsic dysfunction of the primary somatosensory cortex (S1). Finally, PD patients that were both in ON and OFF medication states showed impaired S1 activation in comparison to HC [31].

In general, the above-mentioned studies confirm that LKA is a disorder affecting the performance of skilled and purposeful movements because of dysfunction of the parieto-frontal circuits in performing a higher level of sensory-motor integration [37].

Our findings suggest that LKA-L in gait disorder studies should take a place similar to that of CR in manual studies of patients with PD.

The limitations of this study include the small number of participants in both groups. In addition, leg dominance and the side of the predominant PD lesion of the PD patients were not taken into account. Also in this study we did not consider other types of apraxia of the legs, such as ideational and ideomotor, since the aim of our study was narrowed to proving the principal possibility of diagnosing limb-kinetic apraxia of the legs in patients with PD.

Finally, since the fundamental features of PD are bradykinesia and movement dysrhythmia [38–40], these disorders in current conditions can be better recorded using contemporary methods, for example, using smartphone apps and other wearable devices with subsequent computer processing of the required parameters, than those used in this work. Therefore, the methods used in this study could be more accurate and, consequently, increase the sensitivity of measurements.

However, in our opinion, the stated limitations did not essentially alter the obtained results and their interpretation which open up new possibilities in understanding the pathophysiology of movement disorders in PD.

5. Conclusion

We have demonstrated the possibility of diagnosing of LKA-L in patients with PD despite their bradykinesia and rigidity. This provides an opportunity to establish the influence of LKA-L on gait disorders in

different H&Y stages of PD and its impact on the patients' quality of life. The diagnosis of LKA-L allows the study of ideational and ideo-motor apraxia in legs and their possible impact on gait disorders in PD.

Contributions

YB: Study concept and design; Analysis and interpretation of data. Medical writing for content.

EDM: Help with data acquisition and processing. This work is part of completion of neurology training.

RI: Help with data acquisition. This work is part of completion of neurology training.

AE: Medical writing for content. Revision of the manuscript for content.

ADK: Study concept and design; Analysis and interpretation of data; Drafting/revision of the manuscript.

CRediT authorship contribution statement

Yacov Balash: Writing – review & editing, Writing – original draft, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Evelin D. Mate:** Validation, Investigation, Data curation. **Riyad Idries:** Investigation, Data curation. **Anda Eilam:** Writing – review & editing, Project administration. **Amos D. Korczyn:** Writing – review & editing, Validation, Supervision, Investigation, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics.

The study was approved by the Kaplan Medical Center Institutional Review Board (protocol number: 0049-22-KMC). All participants provided written informed consent.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.prdoa.2025.100302.

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