Revista CEFAC

eISSN 1982-0216

DOI: 10.1590/1982-0216/20232564723 | Rev. CEFAC. 2023;25(6):e4723

Original articles

Use of the diadochokinetic index DDKCCVP% in the detection of articulatory inaccuracies in Parkinson's disease: a preliminary exploratory study

Marcela Sanhueza-Garrido[1]
Carlos Rojas-Zepeda[1]
Virginia García-Flores[1]

[1] Universidad del Bio-Bío, Chillán, Región de Ñuble, Chile.

ABSTRACT

Purpose: to explore whether the diadochokinetic index of syllable production variability (DDKcvp%) is useful for the detection of articulatory inaccuracies in different stages of Parkinson's disease (PD).

Methods: a diadochokinetic speech task of the consonant-vowel type [pa-pa-pa] was applied to 18 people with PD (classified in stages of progression from 1 to 5 according to the Hoehn & Yahr scale) to determine their diadochokinetic performance. Records of the study group were compared to a reference value obtained from a control group made up of 40 subjects.

Results: 77.78% of the study group showed articulatory inaccuracies. The DDKcvp% index allowed to detect articulatory difficulties from stage 1 of PD, and its variation showed that articulatory deficits were permanent from stage 2 onwards. A significant and direct correlation was obtained between the increase in the DDKcvp% index and the increase in the stage of evolution of the participants.

Conclusion: DDKcvp% index evaluated by means of a simple and fast consonant-vowel diadochokinetic task [pa-pa-pa], could be useful to determine articulatory inaccuracies in different stages of PD, although it is suggested that investigation of this index in larger sample sizes be conducted.

Keywords: Parkinson Disease; Speech; Articulation Disorders; Dysarthria

A study conducted at Universidad del Bio-Bío, Chillán, Chile.

Financial support: This study is funded by the Department of Health Rehabilitation Sciences and the Performance Agreement 2022, Faculty of Health Sciences and Food, Universidad del Bio-Bío, Chile.

Conflict of interests: Nonexistent.

Corresponding author:
Marcela Sanhueza-Garrido
Andrés Bello #720
Zip Code: 3820572 - Chillán, Ñuble, Chile
E-mail: mlsanhueza@ubiobio.cl

Received on: September 4, 2023
Accepted on: October 4, 2023

INTRODUCTION

The prevalence of Parkinson's disease (PD) has increased globally over the past 26 years, from 2.5 million people in 1990 to 6.1 million in 2016[1]. PD is a neuromotor disorder clinically expressing itself with resting tremor, rigidity and bradykinesia[2], affecting the entire musculature of the body, including speech. It has been described that people with PD present alterations in different basic motor processes of speech. In prosody, for instance, monotony, mono-intensity and inappropriate silences are observed[3,4]; in phonation, rough (or blown) voice and phono-respiratory discordances stand out; in articulation, imprecision of articulatory movements of vowels and consonants are predominant characteristics along with phonemic repetitions at the beginning of the utterance or after a pause. This pattern of neuromotor alterations result in a reduction of speech intelligibility[5-7], is classified with the diagnostic label of Hypokinetic Dysarthria.

Aviñó-Farret[8] proposes that at a clinical-perceptual level this condition can be accurately diagnosed from stage 3 of the disease (intermediate stage of evolution)[1,2] according to the Hoehn & Yahr (H&Y) scale, when functional disorders have fully manifested. However, Skodda[5] suggests that dysarthric symptoms may appear at any stage, even in stage 1 (early stage of evolution)[1,2], worsening towards the end of the disease. For these reasons, speech evaluation (perceptual or instrumental) must be coherent with the characteristics of each person with PD and sufficiently sensitive to detect alterations that could be generated from the beginning of the disease[9].

Nowadays, assessment methods of dysarthria and articulatory inaccuracies in PD are varied and mainly perceptual[10]. Pommé[11] shows that these methods may differ in several aspects, for instance: 1) overall structure of speech assessment (dimensions assessed); 2) assessment tasks used for each dimension; and 3) speech (audio) recording procedure. With this in mind, Rumbach[12] describes that in the assessment methods there is a lack of standardization of procedures and protocols, considering that most of the tests performed in current clinical practice are perceptual, generating a bias related to the "subjectivity" of the evaluator, especially because the definitions and scoring criteria are prone to interpretive variability[11]. In turn, there is also no clear consensus regarding the "objectivity" of instrumental measurements (a poorly executed acoustic analysis can generate errors). This can be seen at a clinical level because the recording methods used vary widely, compromising the reliability of acoustic measurements. For example, the instructions given by the evaluators are flexible, leading to a great variability in the measurements, along with the recording modalities being dissimilar and the devices used not standardized; thus, finding that some evaluators use high quality microphones, while others prefer to use equipment that is accessible and does not require additional investment[11].

Consequently, Pommé[11] points out that few evaluators seem to feel comfortable with speech assessment using acoustic parameters, as they probably have limited knowledge of them. Even though it has been suggested that the use of this kind of tools could complement and enhance perceptual assessment[13], it is necessary to develop standardized or calibrated protocols with clear instructions on the assessment environment, how to record responses and assess them, as well as suggestions regarding the recording equipment that can be used.

One task that to be used for both perceptual and instrumental analysis of speech articulatory accuracy is syllable repetition. Here, the speaker is instructed to produce a sequence of syllables as quickly and uniformly as possible[14]. When the same syllable is repeated consecutively, as [pa-pa-pa], the task is called rate of alternating movement or diadochokinesis of speech (DDK). Considered a test of maximum demand, it requires the best performance of the speaker's articulatory system; additionally, it would be sensitive to temporal and energetic irregularities in speech production[15]. A parameter to be analyzed from a diadochokinetic performance task is the so-called percentage variability in CV (consonant+vowel) syllable production over time (DDKcvp%). Specifically, this parameter would measure, in percentage terms, the degree of variation in the average number of syllables produced per second[16,17]. It has been described that in a population without underlying neurological pathology being both young (<40 years old) and healthy, the values of the DDKcvp% index - repeated with little variation in a unit of time- are close to a variability of 5.48%; therefore it would be considered within the normal range. In turn, values above this index would show a greater variation in syllable production, and could therefore be classified as inadequate or altered[16].

According to Skodda's preliminary study[5], specific articulatory tasks in PD would exhibit significant irregularities compared to typical speakers, where syllables could vary in duration and consonant production might

be imprecise[5,18]. A different study[19] suggests that certain indicators such as the percentage of syllable duration and the variation of syllable duration (assessed by a diadochokinetic task), would allow distinguishing between speakers with PD and healthy conditions with 93% accuracy (age and sex matched). Karlsson[14] even suggests that articulatory tasks would allow establishing future speech difficulties in PD, although they are not concrete enough to be used as markers of dysarthria on their own. In turn, diadochokinesis tasks have shown that it would be possible to predict articulatory deficits during text reading based on articulatory sequence performance[14]. Now, considering that articulatory inaccuracy is one of the main dimensions affected in PD, and that the assessment and diagnosis of dysarthria is a multifactorial process[7], there is a need to determine whether any specific diadochokinetic index, such as the DDKcvp% index, would facilitate fast and accurate detection of articulatory inaccuracies at any stage of disease progression, complementing the perceptual diagnosis of dysarthria, even in the initial (stage 1) or intermediate stage of the disease (stages 2 and 3), when the deficit and articulatory inaccuracies can be compensated by the person[7] and the perceptual judgment of the evaluator requires a high level of expertise[11,20,21].

Despite the fact that articulatory inaccuracies in PD have been the focus of interest in recent years, it is believed to be relevant to explore whether the DDKcvp% index, assessed by a simple diadochokinetic task, could behave as a quantitative parameter to detect articulatory inaccuracies at different stages of the disease, even at the beginning, considering the clinical and therapeutic advantages of early detection, documentation of the progression of dysarthria, monitoring of the disease and the effects of treatment[14]. Now, the present study explores by means of a diadochokinetic speech task how articulatory accuracy is affected in elderly people with a clinical diagnosis of PD, who are in the initial (stage 1), intermediate (stages 2 and 3) and advanced stages of the disease (stages 4 and 5)[1,2], compared with a control group homologous in age and cognitive normality.

METHODS

The present study was authorized by the Bioethics Committee of the Universidad del Bío-Bío (DIUBB code 1229213R), Chile. A sample of 18 elderly subjects with a clinical diagnosis (confirmed) of PD was secured. All individuals voluntarily participated in the study and signed an informed consent form. Ages ranged from 58 to 89 years old (M=74.28, SD=10.02), 9 men and 9 women. The inclusion criteria applied: being 50 years of age or older, having 8 years of education or more, receiving medical control for PD at least twice a year, receiving pharmacotherapy for PD, normal or corrected vision and hearing, and living within the urban radius. Exclusion criteria: evidence indicating cerebrovascular, psychiatric or other neurodegenerative diseases, presenting dementia risk score in the cognitive screening protocol Mini-Mental State Evaluation (MMSE <23 points). Only 18 of the 43 participants originally contacted met the criteria. Participants were contacted by the means of a connection between the University and two Family Health Centers. Objectives and benefits of the study were explained to the authorities of both centers. Afterwards, those willing to collaborate underwent a brief anamnesis to verify inclusion and exclusion criteria and to evaluate cognitive performance. Finally, the selected participants were invited to the Speech and Oral Motor Laboratory of the sponsoring University for clinical evaluation of PD stage of evolution and speech diadochokinesis.

As for materials and design, the Hoehn & Yahr scale[22] was used to classify participants according to the stage of PD evolution, complemented with a functional kinesthetic assessment protocol, the UK Parkinson Disease Society Brain Bank Diagnostic Criteria (UKPDSSB), the Katz index and the Barthel index. By using these protocols, participants were classified into stage 1 (early stage of PD evolution), stages 2 and 3 (intermediate stage) and stages 4 and 5 (advanced stage of the disease).

On the contrary, to establish the DDKcvp% index, a diadochokinetic task was performed, consisting of measuring the ability to execute in an alternating, rapid and organized manner speech articulation exercises from the emission of a repeated series of CV-type syllables. Specifically, participants had to articulate the CV sequence [pa-pa-pa] in a fluent, rapid and constant manner for 12 seconds[16]. The CV syllable pattern selected is justified in that the [pa pa pa pa] sequence demonstrated utility for articulatory assessment in people with PD[5,23]. Moreover, the CV pattern [pa-pa-pa-pa] is sensitive to variations in the amplitude of the oral emission during articulation[19], facilitating the exploration of the DDKcvp% index. There is evidence that the emission of the oral, occlusal and bilabial phoneme [p] generates greater articulatory difficulty at the beginning of the motor act[14], corresponding to one of the main motor symptoms described in people with PD.

Records were analyzed using the Motor Speech Profile (MSP) software, getting and examining speech and voice parameters in normal people or those with neurological pathologies. The MSP provides 11 study directory, including the percentage of variability in CV syllable production over time (DDKcvp%), whose high clinical applicability in various populations[16] and greater sensitivity to variation in CV production type [pa-pa-pa][19] makes it an appropriate index for the detection of articulatory inaccuracies in people with PD.

Procedure

Each participant was contacted the day before the evaluation to confirm attendance and to remind them to take the medication prescribed by the treating physician 60 minutes before the session began, with the purpose of evaluating the participant in the "on" moment of pharmacological effect, defined as the best period of motor response achieved after an optimal dose of levodopa[24]. The anamnesis and motor evaluation was carried out by a professional kinesiologist with expertise in neurorehabilitation. The functional kinesthetic assessment protocol, UKPDSBB criteria and Katz and Barthel indices were applied to each of the participants in a single session of approximately 45 minutes. With these data, each participant was classified in stages 1 to 5 according to the H&Y scale.

Finishing the functional motor evaluation, a 20-minute rest was given and then the speech diadochokinesis evaluation was performed. This stage of the procedure was carried out in an individual, illuminated and acoustically isolated box. Five high-fidelity audio recordings were made using Tascam DR-40 professional recording equipment at a sampling rate of 44.1 kHz. Each participant was coached to repeat the syllabic sequence CV [pa-pa-pa], in a stable, fast, sustained manner and at normal intensity for 12 seconds. To begin the recording, a test exercise of only 5 seconds was performed (in order to not fatigue the participant). Once the instruction was comprehended, the participant was asked to perform the task 5 times, with a 20-second rest interval between each recording.

MSP analysis and calibration of the DDKcvp% index

Prior to the MSP analysis, it was necessary to check the acoustic quality of each recording by using Praat software. All the selected recordings met the appropriate quality standards to be edited and selected the time segment in which the participants actually performed the articulatory task. After completing the previous process, they were entered into the MSP software, delivering the DDKcvp% syllable variation indices for each of the participants.

Due to the fact that the MSP software does not have standardized parameters for the target population, it was necessary to perform the calibration procedure of the DDKcvp% index in people without PD between 50 and 89 years old (control group). Therefore, this value was used as a reference parameter for the group of users with PD in the present study. To conduct the calibration procedure, a universe of 87 people was used. A probabilistic sample of 40 persons (95% confidence, 5% error) was collected who met criteria such as: age between 50 and 89 years old, both male and female, MMSE scores >23 and who were not diagnosed with PD or any other neurological condition. Each of them underwent the diadochokinesia task to determine the DDKcvp% index. The selecting, cleaning and editing procedure of the recordings was identical to that performed with the PD group, although in this case only 3 recordings were made per participant.

Data analysis

A database was created in IBM SPSS25 software. With it, the variables of the control group and the PD group (DDKcvp%, H&Y stage, years of PD evolution and age) were recorded. Then, a descriptive statistical analysis of the control group was performed to establish the baseline DDKcvp% index. Afterwards, these values were calculated for each of the participants with PD and for each of the H&Y stages established. To perform the inferential analysis of the data, the Shapiro-Wilk normality test was run for the DDKcvp% values of the PD group and the control group. Since the data did not present normality in any of the groups, the nonparametric Mann-Whitney U test (Wilcoxon) was used for the comparison of means between the DDKcvp% index for each H&Y stage (5 groups) with respect to the control group. Finally, to establish the level of correlation between the DDKcvp% index and the variables H&Y stage, years of PD evolution and age, respectively, Spearman's Rho test was used for nonparametric data.

RESULTS

The calibration procedure of the DDKcvp% index in the control group yielded homogeneous values in the 40 participants of this group, who averaged a syllable production variation index DDKcvp% of reference M=5.369% and SD=2.977% (Table 1).

Table 1. Mean performance of the diadochokinetic index of variability in syllable production in the control group

Subject	MMSE	Mean DDK(cvp%)	SD	Min.	Max.	Mean standard Error
1	27	4.518	0.333	4.23	4.88	0.192
2	24	4.728	0.207	4.55	4.96	0.120
3	25	5.779	4.736	1.13	10.60	2.735
4	30	4.493	0.645	3.75	4.93	0.373
5	29	6.047	5.471	2.23	12.31	3.158
6	28	4.106	0.595	3.46	4.64	0.344
7	27	3.265	0.902	2.37	4.17	0.520
8	30	6.512	1.918	5.26	8.72	1.107
9	29	4.930	2.065	2.55	6.23	1.192
10	28	4.266	1.991	2.37	6.34	1.149
11	27	4.535	2.079	2.16	6.03	1.200
12	25	7.928	3.404	4.03	10.29	1.965
13	26	3.301	0.693	2.59	3.97	0.400
14	26	4.224	1.537	2.84	5.88	0.888
15	26	6.418	2.010	4.30	8.29	1.160
16	29	6.733	2.624	3.95	9.17	1.515
17	30	9.232	5.071	5.77	15.05	2.928
18	29	5.571	1.374	3.99	6.46	0.793
19	28	3.187	1.046	2.37	4.37	0.604
20	30	4.260	1.630	3.26	6.14	0.941
21	25	4.538	1.861	2.66	6.38	1.075
22	25	6.363	0.450	5.98	6.89	0.271
23	27	7.362	4.283	2.45	10.33	2.473
24	27	4.200	1.125	2.96	5.16	0.650
25	29	5.799	2.038	3.58	7.59	1.177
26	28	5.281	1.851	3.16	6.59	1.069
27	25	3.222	0.568	2.64	3.78	0.328
28	25	5.392	1.469	4.00	6.93	0.848
29	27	12.007	9.322	5.06	22.60	5.382
30	28	8.794	3.725	4.87	12.29	2.151
31	29	5.601	3.684	3.39	9.85	2.127
32	30	7.349	1.873	5.46	9.21	1.081
33	28	2.295	1.058	1.39	3.46	0.611
34	26	3.271	1.235	1.86	4.17	0.713
35	27	4.967	0.618	4.27	5.43	0.357
36	26	5.570	3.055	3.33	9.05	1.764
37	25	5.528	4.112	2.50	10.21	2.374
38	27	3.591	1.572	2.36	5.36	0.908
39	29	5.693	2.775	3.28	8.72	1.602
40	29	3.905	1.010	2.97	4.97	0.583
		5.369	**2.977**	**1.13**	**22.60**	**0.272**

Captions: MMSE: Mini-Mental State Evaluation Score; Med. DDK(cvp%): Mean performance of the diadochokinetic index of variability in syllable production; SD: standard deviation; Min: minimum value recorded; Max: maximum value recorded.

Regarding the variation of the DDKcvp% index for each of the participants with PD, Table 2 is presented. Now, 14 people (77.78%) showed articulatory inaccuracies by obtaining syllable production variation values above the reference range, of which 2 people were categorized in stage 1 H&Y (early stage of evolution), 8 in stages 2 and 3 (intermediate stage) and 4 in stages 4 and 5 (advanced stage). In contrast, only 4 individuals (22.22%), all categorized in stage 1 H&Y, presented DDKcvp% values within the reference range.

Table 2. Mean performance of the diadochokinetic index of variability in syllable production per participant with Parkinson's disease

PD Subject	Stage H&Y	MMSE	Mean DDK(cvp%)	SD	Min.	Max.	DDK difference control group
1	1	27	5.256	0.931	4.56	6.68	-0.113 (rango)
2	1	24	5.980	1.721	3.28	7.81	0.611 (rango)
3	1	25	16.694	1.580	15.05	18.64	11.325
4	1	30	23.460	7.960	11.96	32.10	18.091
5	1	29	6.564	1.368	4.480	8.02	1.195 (rango)
6	1	28	6.161	2.268	4.22	9.83	0.792 (rango)
7	2	27	17.038	1.529	14.46	18.42	11.669
8	2	30	28.865	10.128	16.96	39.40	23.496
9	2	29	13.152	2.216	10.48	15.59	7.783
10	3	28	27.705	3.314	24.13	31.04	22.336
11	3	27	16.462	1.746	14.80	19.16	11.093
12	3	25	26.123	1.686	24.23	28.18	20.754
13	3	26	31.299	1.984	28.99	33.74	25.93
14	3	26	19.268	6.779	13.67	29.02	13.899
15	4	26	21.617	7.826	10.19	28.71	16.248
16	4	29	52.715	29.892	37.74	106.06	47.346
17	4	30	45.771	35.150	26.49	108.36	40.402
18	5	25	91.333	10.419	79.72	107.32	85.964

Captions: PD subject: participants with Parkinson's disease; Stage H&Y: stage of progression of Parkinson's disease according to Hoehn & Yahr scale; MMSE: Mini-Mental State Evaluation Score; Mean. DDK(cvp%): mean performance of the diadochokinetic index of variability in syllable production; SD: standard deviation; Min: minimum value recorded; Max: maximum value recorded.

When analyzing the DDKcvp% index by each of the H&Y stages, it was observed that participants categorized in stage 1 of the disease (early stage) presented dissimilar performances (Figure 1). For example, 4 individuals in this group (participants PD1, PD2, PD5 and PD6) exhibited no articulatory inaccuracies, with syllable production variations within the reference range. However, the same was not true for participants PD3 (M=16.694%) and PD4 (M=23.460%) who showed a significant increase in articulatory inaccuracies, with a variation of the DDKcvp% index higher (on average) than that observed in the control group.

As for the participants categorized in stage 2 (intermediate stage), the motor restrictions generated by the progression of the disease caused all participants in this group to exhibit a large number of articulatory inaccuracies (Figure 1) compared to the control group, although with a slightly better performance for participants PD7 (M=17.038%) and PD9 (M=13.152%) compared to PD8 (M=28.865%).

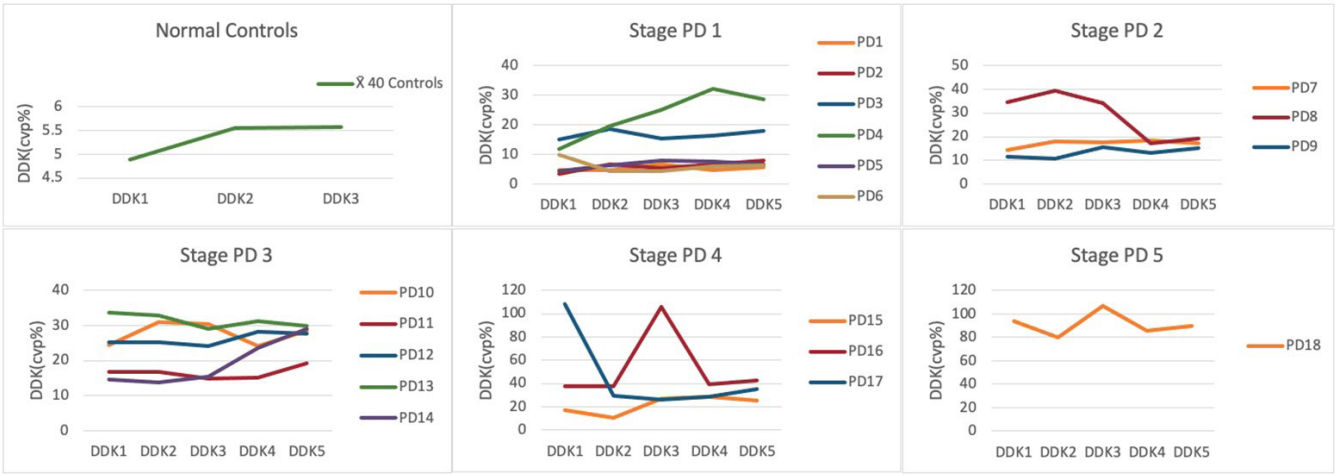

Figure 1. Diadochokinetic performance on variability in syllable production for each utterance by participants in the control group and study group (grouped by Hoehn & Yahr stage of evolution)

In addition, Figure 1 shows that all participants classified in stage 3 (intermediate stage) and stages 4 and 5 H&Y (advanced stage) present a large variation in syllable production, systematically increasesing as motor restriction and rigidity progress. For example, the DDKcvp% behavior of the participants classified in stage 3 yielded a DDKcvp% variability index of M= 24.171%, which increased to M=40.035% during stage 4 of evolution (Figure 2), and which doubles upon reaching stage 5 with an articulatory imprecision M=91.333% (although it should be considered that this reference only corresponds to one participant in the study).

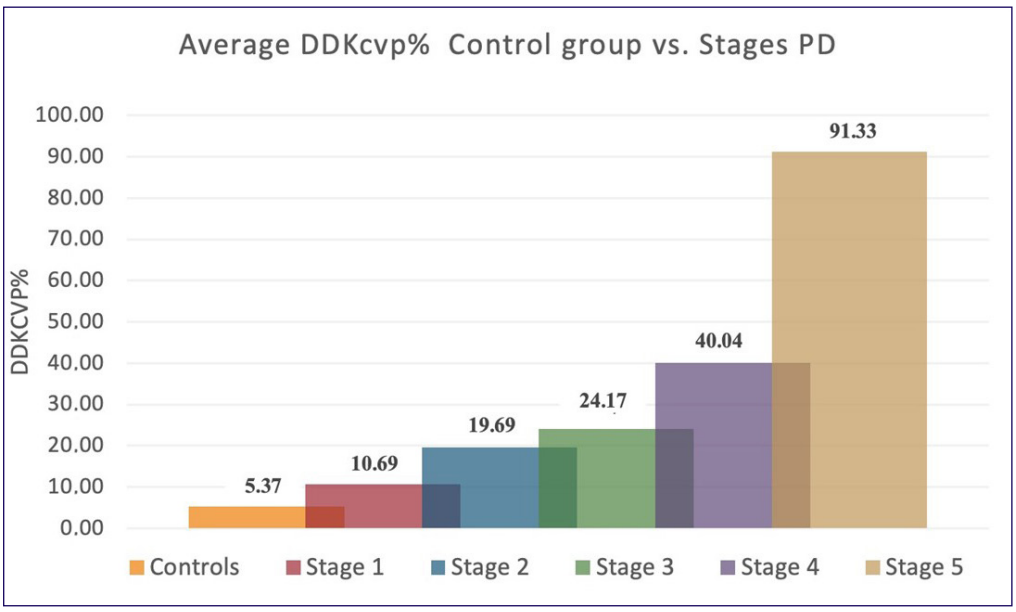

Figure 2. Diadochokinetic performance means of variability in syllable production for the control group and each of the Hoehn & Yhar stages of evolution

When comparing the DDKcvp% means for each of the H&Y stages in connection to the control group (Table 3), the Mann Whitney U test states that all stages presented significant differences compared to the control group (stage 1: z=-4.529, p=.000; stage 2: z=-6.164, p=.000; stage 3: z= -7.789, p=.000; stage 4: z= -6.238, p=.000; stage 5: z=-3.780, p=.000).

[Insert table 3 here]

Table 3. Mean performance of the diadochokinetic index of variability in syllable production by stage of evolution Hoehn & Yahr

Stage H&Y	Mean DDK(cvp%)	SD	Min.	Max.	z	Asymptotic S. (p value)
1	10.686	7.765	3.28	32.10	-4.529	0.000*
2	19.686	8.900	10.48	39.40	-6.164	0.000*
3	24.171	6.519	13.67	33.74	-7.789	0.000*
4	40.035	28.568	10.19	108.36	-6.238	0.000*
5	91.333	10.419	79.72	107.32	-3.780	0.000*

Captions: Stage H&Y: stage of Parkinson's disease progression according to Hoehn & Yahr scale; Mean DDK(cvp%): mean performance of the diadochokinetic index of variability in syllable production; SD: standard deviation; Min: minimum value recorded; Max: maximum value recorded; z: approximation to normal according to Mann-Whitney U-test.
Statistical test: Mann-Whitney U test (Wilcoxon) for non-parametric data. Statistical significance: p< 0.005.

At last, when correlating the DDKcvp% index of all participants with PD with the variables H&Y stage, years of disease evolution and age, respectively, Table 4 shows a significant, direct, positive and moderate correlation between the upsurge in articulatory variation (DDKcvp% index) and the increase in H&Y stage in which the participants were. This effect was not observed for the year indicators of PD evolution and age, which were not correlated with the DDKcvp% index.

Table 4. Correlation between the performance of the diadochokinetic index of variability in syllable production with Hoehn & Yahr stage of evolution, years of disease evolution and age of participants

Variable	N	Bilateral S.	Correlation Coef. DDK(cvp%)
Stage H&Y	90	0.000	0.732**
PD years of evolution	90	0.938	-0.008
Age	90	0.607	0.055

Endnote: N: number of records obtained; Bilateral sig.: degree of compatibility between variables; DDK(cvp%) correlation coefficient: correlation coefficient of the variables with the diadochokinetic index of variability in syllable production according to Spearman's Rho test.
Statistical test: Spearman's Rho bivariate correlation for non-parametric data. Statistical significance: p< 0.005.
** Correlation is significant at the 0.01 level (bilateral).

DISCUSSION

The objective of this study was to explore the usefulness of the syllable production variation index (DDKcvp%) for fast and accurate detection of articulatory inaccuracies in different stages of PD. For this purpose, a simple CV-type diadochokinetic task [pa-pa-pa] was used to assess how speech articulation is affected in elderly people with a clinical diagnosis of PD who were classified as PD stages 1 to 5. These results showed that the index of articulatory variation over time (DDKcvp%) is useful for the detection of articulatory inaccuracies at different stages of disease progression, including stages 1 and 2 (early and intermediate stages). Moreover, the variation of the DDKcvp% index showed that articulatory inaccuracies in the study sample are permanent from stage 2 of evolution and increase as the disease progresses. On the contrary, a meaningful, direct and positive correlation was obtained between the increase of the

DDKcvp% index and the increase of the H&Y stage in which the participants were.

While multiple perceptual and instrumental parameters such as articulation rate[18], vowel articulatory accuracy[25], speech intelligibility[26], articulatory quality of vowels and consonants, tongue movement, production of occlusal phonemes, and speech synchronization[27] among others; have shown that people with PD in intermediate (stages 2 and 3) and advanced stages of the disease (stages 4 and 5) show significant articulatory deficits; yet, there is still no instrumental tool or index of greater sensitivity in early and intermediate stages of the disease, when the perceptual assessment depends largely on the expertise of the evaluator. In this matter, this investigation explored articulatory performance with the DDKcvp% parameter, described as a useful index for articulatory assessment in people with PD as it is a temporal sequence parameter[28].

These results support the use of the DDKcvp% index for the assessment of articulatory inaccuracies. It detected articulatory deficits in 77.78% of the sample, with distinct restrictions from stage 2 onwards, and revealed inaccuracies in two of six people with PD at stage 1 H&Y, when the motor deficit was still subtle and unilateral. Unlike other specific articulatory parameters such as maximum syllable repetition speed or vowel holding time, the DDKcvp% index assesses in an integrated and functional way aspects frequently altered in people with PD, such as amplitude, precision, speed and variability of lip, tongue and jaw movements[26,29]. According to these findings, difficulties could be present from stage 1 of the disease, which may give an important diagnostic advantage to this index, and especially on perceptual parameters that require advanced clinical knowledge.

Generally, there are several factors contributing to articulatory disorders in people with PD, such as bradykinesia and rigidity, characterized by a drastic decrease in the range of motion of the musculature involved in phonoarticulation[25,30]. These difficulties are visualized mainly from stage 3 of the disease, where there is greater axial impairment[31], facilitating the clinical perceptual diagnosis of hypokinetic dysarthria. Meanwhile, in stages 1 and 2 of PD a majority presence of functional but not structural alterations has been described, supporting the theory that functional changes precede structural alterations in the progression of PD[32]. This, in a certain way, could complicate the clinical perceptual diagnosis in case of mild articulatory alterations in stages 1 and 2, requiring a high degree of knowledge on the part of the evaluator, and generating the need for instrumental tools sensitive to such functional alterations[9,11,33]. In this view, this research presented a simple articulatory task (repetition of the sequence [pa-pa-pa]), as close as possible to articulatory functionality, fast, easy to apply and inexpensive, which proved capable of detecting syllabic variations outside the norm, even in people with PD stages 1 and 2 (possibly without structural alterations).

It is noteworthy that within the basic motor speech processes frequently investigated in early (stage 1) and intermediate (stage 2 and 3) stages of PD, articulatory accuracy does not seem to be a priority. What is the reason? There is considerable evidence that within the functional alterations in early stages of the disease, one of the first symptoms of impairment and dysarthria is vocal or phonatory dysfunction, rather than deficits linked to articulatory speech accuracy[34,35]. In this matter, there are reports that 78% of people with PD in stages 1 and 2 (and untreated) present some type of vocal impairment, including vocal harshness, weakness/asthenia, hypophonia and decreased variability of the fundamental frequency[18,35]. It is likely that the fact that the main dysarthric alterations reported in stages 1 and 2 are rather of vocal type[19,23,35], limit further exploration of articulatory inaccuracies. Moreover, people with early and intermediate stage PD often self-report hypophonia as one of the most notorious and disabling symptoms of dysarthria, which evidently increases and prioritizes clinical interest and research on this motor process[36], leaving articulatory inaccuracies in the background (as long as speech intelligibility is maintained).

As for specific studies based on articulatory accuracy, evidence shows that during stages 3, 4 and 5 of the disease, inaccuracy in syllable production would be directly related to the motor axial score on the Unified Parkinson`s Disease Rating Scale[31]. In this light, Skodda[37] through an evaluation of a group of people with PD in early and intermediate stages, reported that performance in tasks of maximum repetition of syllables was similar to healthy controls in terms of rhythm, however, articulatory imprecision was already noticeable in stage 1, coinciding with Rusz[38], who showed that in the prodromal stage of PD, articulatory impairment was evident and characterized by articulatory inaccuracies of consonants and irregular diadochokinesis. In this sense, these results are in line with Skodda, Rusz, Estevo Dias[37,39], since they show that in some people with unilateral motor symptomatology and without structural alterations (stage 1), there is already a

considerable increase in the DDKcvp% variation index. This indicates that the functional difficulties to produce syllables in an alternating, rapid and organized manner could be present when the clinical-perceptual evaluation does not yet show noticeable alterations, and that these increase as the PD stage progresses and axial symptoms appear[31].

With this information, it has been described that vocal-articulatory biomarkers in PD are tools that could offer significant benefits for early diagnosis of the disease (even in the initial phase)[5,11,12,40,41], its progression and evaluation of treatments. In turn, they are non-invasive and relatively inexpensive procedures, facilitating continuous and accurate follow-up[40-42]. Additionally, they reduce the possibility of bias and errors in diagnosis, so they can also be used to evaluate the efficacy of different interventions[40-42]. From this point of view, the evidence provided in the present investigation allowed to corroborate that the use of a simple, fast and inexpensive DDK instrumental acoustic task such as the DDKcvp%, would behave as a true articulatory biomarker for PD, allowing to obtain objective values for the preliminary evaluation and follow-up of the progression of articulatory alterations[19]. In this matter, it is believed that the diagnostic utility that this tool can have from early and intermediate stages of PD would be explained because the DDKcvp% index constitutes a task of maximum articulatory demand, requiring the best performance of the speaker and is sensitive to temporal and energetic irregularities in speech production[15], which seems to be compromised from stage 1 of the disease.

Summarizing, evidence obtained in the present investigation suggests that the evaluation of acoustic phonetic parameters of speech such as the DDKcvp% index could serve as a fast and simple assessment tool and act as a concrete biomarker in the progression of articulatory inaccuracies at different stages of the disease. However, caution is suggested with these findings; therefore, it is advised to project these results as a first exploration for the development of a future screening for articulatory deficits derived from PD dysarthria. Additionally, it is suggest taking into account the various research biases or limitations that may have influenced our results, such as: small sample size, indirect control over the administration of PD drugs prior to the evaluation, properties of the articulatory task applied, and the methodology used in the analysis of the records obtained. In this sense, it is advised that future research in the area could consider a larger sample size (also providing greater validity to the statistical tests); establish a system of direct control over the administration of the PD drug (in such a way as to ensure that all participants are in pharmacological effect prior to the evaluation). Finally, it is suggested to perform other kinds of diadochokinetic tasks[25-27] that combine articulatory points and modes that could also be affected in people with PD, in addition to developing standardized or calibrated protocols with clear instructions about the assessment environment, the way to record and evaluate the responses, and the characteristics of the appropriate instrument for the performance of such diadochokinetic tasks.

CONCLUSION

These results allowed to establish that the diadochokinetic index of variability in syllable production (DDKcvp%) is highly valuable for the detection of articulatory inaccuracies at different stages of PD, even from stage 1 of evolution. At the same time, the index shows a pattern of evolutionary and incremental behavior in the course of PD. These findings are coherent with a previous work[43-45], allowing to argue that the deterioration of speech performance can appear even when the disease has just been diagnosed, being progressive as the stage of the disease progresses, which is explained by the presence of axial symptoms and bradykinesia affecting the labial, mandibular and lingual musculature in people diagnosed with PD. On the contrary, the fact that the DDKcvp% index can detect articulatory deficits from stage 1 of PD would give it a key role -as a diagnostic complement- to perceptual assessments that require the expertise of the evaluator.

Hence, results are consistent with the evidence presented in previous studies revealing the diagnostic use of the DDKcvp% index in people with PD[14,19,46] and allow us to propose that a simple and rapid articulatory diadochokinetic task of the [pa-pa-pa] type could be a good tool for monitoring articulatory inaccuracies at different stages of PD. However, considering the small sample size of the present study, one must be cautious with these findings, so, projecting the results as a preliminary exploration in the use of instrumental tools for the detection of articulatory inaccuracies in PD is suggested.

REFERENCES

1. Ray Dorsey E, Elbaz A, Nichols E, Abd-Allah F, Abdelalim A, Adsuar JC et al. Global, regional, and national burden of Parkinson's disease, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet Neurol. 2018;17(11):939-53. https://doi.org/10.1016/S1474-4422(18)30295-3 PMID: 30287051.
2. Fahn S. Description of Parkinson's disease as a clinical syndrome. Vol. 991, Ann. N.Y. Acad. Sci. New York; 2003.
3. Dashtipour K, Tafreshi A, Lee J, Crawley B. Speech disorders in Parkinson's disease: pathophysiology, medical management and surgical approaches. Vol. 8, Neurodegenr Dis Manag. 2018;8(5):337-48. https://doi.org/10.2217/nmt-2018-0021 PMID: 30223711.
4. Ramig L, Halpern A, Spielman J, Fox C, Freeman K. Speech treatment in Parkinson's disease: Randomized Controlled Trial (RCT). Mov Disord. 2018;33(11):1777-91. https://doi.org/10.1002/mds.27460 PMID: 30264896.
5. Skodda S, Visser W, Schlegel U. Vowel articulation in parkinson's disease. J Voice. 2011;25(4):467-72. https://doi.org/10.1016/j.jvoice.2010.01.009 PMID: 20434876.
6. Tykalova T, Rusz J, Klempir J, Cmejla R, Ruzicka E. Distinct patterns of imprecise consonant articulation among Parkinson's disease, progressive supranuclear palsy and multiple system atrophy. Brain Lang. 2017 Feb 1;165:1-9. https://doi.org/10.1016/j.bandl.2016.11.005 PMID: 27894006.
7. Freed D. Motor speech disorder diagnosis and treatment. 3th ed. San Diego (CA): Plural Publishing; 2020.
8. Aviñó Farret C, Maneiro Chouza M, Clemente Benaiges I. Neurorrehabilitación en la enfermedad de Parkinson. Neurol Supl. 2007;3(7):22-9.
9. Montaña D, Campos-Roca Y, Pérez CJ. A diadochokinesis-based expert system considering articulatory features of plosive consonants for early detection of Parkinson's disease. Comput Methods Programs Biomed. 2018 Feb 1;154:89-97. https://doi.org/10.1016/j.cmpb.2017.11.010 PMID: 29249350.
10. Munner Altaher A. A report of assesment tools for individuals with dysarthria. Open Public Health J. 2019;12:384-6. https://doi.org/10.2174/1874944501912010384
11. Pommée T, Balaguer M, Mauclair J, Pinquier J, Woisard V. Assessment of adult speech disorders: current situation and needs in French-speaking clinical practice. Logoped Phoniatr Vocol. 2021;47(2):1-17. https://doi.org/10.1080/14015439.2020.1870245 PMID: 33423572.
12. Rumbach AF, Finch E, Stevenson G. What are the usual assessment practices in adult non-progressive dysarthria rehabilitation? A survey of Australian dysarthria practice patterns. J Commun Disord. 2019 May 1;79:46-57. https://doi.org/10.1016/j.jcomdis.2019.03.002 PMID: 30875615.
13. Jankovic J. Parkinson's disease: clinical features and diagnosis. Journal of Neurology, Neurosurgery and Psychiatry. BMJ Publishing Group; 2008;79:368-76. https://doi.org/10.1136/jnnp.2007.131045 PMID: 18344392.
14. Karlsson F, Schalling E, Laakso K, Johansson K, Hartelius L. Assessment of speech impairment in patients with Parkinson's disease from acoustic quantifications of oral diadochokinetic sequences. J Acoust Soc Am. 2020;147(2):839-51. https://doi.org/10.1121/10.0000581 PMID: 32113309.
15. Kent R, Kim H, Weismer G, Kent J, Rosenbek B. Laryngeal dysfunction in neurological disease: amyotrophic lateral sclerosis, Parkinson disease, and stroke. J Med Speech-Lang Pathol. 1994;2:157-75.
16. Pérez H, Fernández R, Oliva C. Valores normativos para el programa de análisis acústico del habla Motor Speech Profile en hablantes de español de Chile. Rev Chil Fonoaudiol. 2015;14:4-14. https://doi.org/10.5354/rcdf.v14i0.37608
17. John J, Ganapathy K, John S, Rajashekhar B. Normative for motor speech profile in kannada-speaking adults. J Voice. 2014;28(1):7-13. https://doi.org/10.1016/j.jvoice.2013.06.009 PMID: 24176300.
18. Rusz J, Cmejla R, Ruzickova H, Ruzicka E. Quantitative acoustic measurements for characterization of speech and voice disorders in early untreated Parkinson's disease. J Acoust Soc Am. 2011;129(1):35-67. https://doi.org/10.1121/1.3514381 PMID: 21303016.
19. Karlsson F, Hartelius L. How well does diadochokinetic task performance predict articulatory imprecision? Differentiating individuals with Parkinson's disease from control subjects. Folia Phoniatr Logop. 2019;71(5-6):251-60. https://doi.org/10.1159/000498851 PMID: 31117108.
20. Pawlukowska W, Szylińska A, Kotlęga D, Rotter I, Nowacki P. Differences between subjective and objective assessment of speech deficiency in Parkinson disease. J Voice. 2018;32(6):715-22. https://doi.org/10.1016/j.jvoice.2017.08.018 PMID: 29122413.
21. Gaballah A, Parsa V, Andreetta M, Adams S. Objective and subjective speech quality assessment of amplification devices for patients with Parkinson's disease. IEEE Trans Neural Syst Rehabil Eng. 2019;27(6):1226-35. https://doi.org/10.1109/TNSRE.2019.2915172 PMID: 31071046.
22. Hoehn MM, Yahr MD. Parkinsonism: onset, progression, and mortality. Neurology. 1967;17(5):427-42. https://doi.org/10.1212/wnl.17.5.427 PMID: 6067254.
23. Eklund E, Qvist J, Sandström L, Viklund F, van Doorn J, Karlsson F. Perceived articulatory precision in patients with Parkinson's disease after deep brain stimulation of subthalamic nucleus and caudal zona incerta. Clin Linguist Phon. 2015;29(2):150-66. https://doi.org/10.3109/02699206.2014.971192 PMID: 25333411.
24. Skodda S, Flasskamp A, Schlegel U. Instability of syllable repetition in Parkinson's disease-Influence of levodopa and deep brain stimulation. Movement Disorders. 2011;26(4):728-30. https://doi.org/10.1002/mds.23439 PMID: 21506151.
25. Rusz J, Čmejla R, Růžičková H, Klempíř J, Majerová V, Picmausová J et al. Evaluation of speech impairment in early stages of Parkinson's disease: a prospective study with the role of pharmacotherapy. J Neural Transm. 2013;120(2):319-29. https://doi.org/10.1007/s00702-012-0853-4 PMID: 22772465.
26. Godino-Llorente JI, Shattuck-Hufnagel S, Choi JY, Moro-Velázquez L, Gómez-García JA. Towards the identification of Idiopathic Parkinson's Disease from the speech. New articulatory kinetic biomarkers. PloS One. 2017;12(12):1-35. https://doi.org/10.1371/journal.pone.0189583 PMID: 29240814.
27. Novotný M, Rusz J, Čmejla R, Růžička E. Automatic evaluation of articulatory disorders in Parkinson's disease. IEEE Trans Audio Speech Lang Process. 2014;22(9):1366-78. https://doi.org/10.1109/TASLP.2014.2329734

28. Tjaden K, Watling E. Characteristics of diadochokinesis in multiple sclerosis and Parkinson's disease. Folia Phoniatr logop. 2003;55:241-59. https://doi.org/10.1159/000072155 PMID: 12931058.

29. Ackermann H, Ziegler W. Articulatory deficits in Parkinsonian dysarthria: an acoustic analysis. J Neurol Neurosurg Psychiatry. 1991;54(12):1093-8. https://doi.org/10.1136/jnnp.54.12.1093 PMID: 1783924.

30. Fabbri M, Guimarães I, Cardoso R, Coelho M, Guedes LC, Rosa MM et al. Speech and voice response to a levodopa challenge in late-stage Parkinson's disease. Front Neurol. 2017 Aug 22;8(AUG). https://doi.org/10.3389/fneur.2017.00432 PMID: 28878734.

31. Skodda S, Lorenz J, Schlegel U. Instability of syllable repetition in Parkinson's disease-Impairment of automated speech performance? Basal Ganglia. 2013;3(1):33-7. https://doi.org/10.1016/j.baga.2012.11.002

32. Steurer H, Schalling E, Franzén E, Albrecht F. Characterization of mild and moderate dysarthria in Parkinson's disease: behavioral measures and neural correlates. Front Aging Neurosci. 2022; May 16;14. https://doi.org/10.3389/fnagi.2022.870998. PMID: 35651530.

33. Walsh B, Smith A. Basic parameters of articulatory movements and acoustics in individuals with Parkinson's disease. Movement Disorders. 2012;27(7):843-50. https://doi.org/10.1002/mds.24888 PMID: 22729986.

34. Kent RD, Vorperian HK, Kent JF, Duffy JR. Voice dysfunction in dysarthria: Application of the Multi-Dimensional Voice ProgramTM. J Commun Disord. 2003;36(4):281-306. https://doi.org/10.1016/S0021-9924(03)00016-9 PMID: 12837587.

35. Ma A, Lau KK, Thyagarajan D. Voice changes in Parkinson's disease: what are they telling us? J Clin Neurosci. 2020;7(2):7. https://doi.org/10.1016/j.jocn.2019.12.029 PMID: 31952969.

36. Silbergleit AK, Schultz L, Hamilton K, Lewitt PA, Sidiropoulos C. Self-perception of voice and swallowing handicap in Parkinson's disease. J Parkinsons Dis. 2021;11(4):2027-34. https://doi.org/10.3233/JPD-212621 PMID: 34366369.

37. Skodda S. Steadiness of syllable repetition in early motor stages of Parkinson's disease. Biomed Signal Process Control. 2015;17:55-9. https://doi.org/10.1016/j.bspc.2014.04.009

38. Rusz J, Hlavnička J, Tykalová T, Bušková J, Ulmanová O, Růžička E et al. Quantitative assessment of motor speech abnormalities in idiopathic rapid eye movement sleep behaviour disorder. Sleep Med. 2016 Mar 1;19:141-7. https://doi.org/10.1016/j.sleep.2015.07.030 PMID: 26459688.

39. Estevo Dias A, Tonidandel Barbosa M, Papaterra Limongi JC, Reis Barbosa E. Speech disorders did not correlate with age at onset of Parkinson's disease. Arq Neuropsiquiatr. 2016;74(2):117-21. https://doi.org/10.1590/0004-282X20160008 PMID: 26982988.

40. Tracy J, Özkanca Y, Atkins D, Hosseini R. Investigating voice as a biomarker: deep phenotyping methods for early detection of Parkinson's disease. J. Biomed. Inform. 2020;104:103362. https://doi.org/10.1016/j.jbi.2019.103362 PMID: 31866434.

41. Moro L, Gómez JA, Arias JD, Dehak N, Godino JI. Advances in Parkinson's disease detection and assessment using voice and speech: A review of the articulatory and phonatory aspects. Biomed. Signal Process. Control. 2021;66:102418. https://doi.org/10.1016/j.bspc.2021.102418

42. Narendra NP, Schuller B, Alku P. The detection of Parkinson's disease from speech using voice source information. IEEE/ACM Trans. Audio Speech Lang. 2021;29:1925-36. https://doi.org/10.1109/TASLP.2021.3078364

43. Rueda A, Vásquez JC, Orozco-Arroyave JR, Nöth E, Krishnan S. Empirical mode decomposition articulation feature extraction on Parkinson's diadochokinesia. Comput. Speech Lang. 2022;72:101322. https://doi.org/10.1016/j.csl.2021.101322

44. Kumar S, Kar P, Singh D, Sharma M. Analysis of diadochokinesis in persons with Parkinson's disease. J. Datta Meghe Inst. Med. Sci. Univ. 2018;13(3):140-2. https://doi.org/10.4103/jdmimsu.jdmimsu_66_18

45. Karan B, Sahu SS, Orozco-Arroyave JR. An investigation about the relationship between dysarthria level of speech and the neurological state of Parkinson's patients. Biocybern. Biomed. Eng. 2022;42(2):710-26. https://doi.org/10.1016/j.bbe.2022.04.003

46. Lowit A, Marchetti A, Corson S, Kuschmann A. Rhythmic performance in hypokinetic dysarthria: relationship between reading, spontaneous speech and diadochokinetic tasks. J Commun Disord. 2018;72:26-39. https://doi.org/10.1016/j.jcomdis.2018.02.005 PMID: 29471176.

Authors' contributions:

MSG: conception and design of the study, drafting of the article and critical review of the relevant intellectual content;

CRZ: conception and design of the study, data collection, drafting of the article and statistical analysis, final approval of the version to be submitted for publication;

VGF: critical review of the relevant intellectual content and editing of the manuscript.