Studying Facial Activity in Parkinson's Disease Patients Using an Automated Method and Video Recording

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Abstract— **Main objective of this research is studying facial activity of Parkinson's disease (PD) patients using an automated method for assessing facial movements based on action units (AUs) detection with calculating the received movement signal kinematic characteristics. 16 PD patients and 16 participants in the control group have been recorded using 2D video camera while performing 4 facial tests: closing the eyes, raising the eyebrows, smiling with an effort (grin), moving the eyebrows. 11 kinematic parameters have been calculated for each signal of AU intensity of each patient. There is decrease in the facial movements frequency and speed. Consequently, there is increase in the duration of the performance of facial tests in PD patients group compared to the control group. Only some AUs also showed a decrease in the amplitude of facial movements in PD patients group compared to the control group. Statistical differences in the largest number of kinematic parameters have been obtained for the action units AU12 and AU14 recorded during the smile with effort test, and AU04 recorded during the eyebrow moving test.**

I. Introduction

Parkinson's disease (PD) is a slowly progressive neurodegenerative disease. One of the most important movement manifestations of PD, necessary for the diagnosis, is hypokinesia which represents decrease in the speed and amplitude of movement [1]. Clinically, hypokinesia is assessed during movements in the limbs, trunk (axial hypokinesia) and in the face muscles (hypomimia). Hypomimia is manifested by decrease in the amplitude and slowing down of facial movements in various parts of the face. While the facial expression decreases, the face becomes "masked" [2, 3]. Hypomimia can manifest itself in the early stages of PD and its severity degree correlates with the rate of further progression of the disease [4].

Previous studies of facial expressions in PD patients show a depletion of emotional expressions and a decrease in spontaneous facial expressions [5-8]. Moreover; hypokinesia leads to impairment of speech and articulation [9]. Such impairments significantly reduce the quality of patient's life [10]. Facial expression is a source of non-verbal information during communication, thus; manifestation of hypomimia causes difficulties in communication since the interlocutor cannot always evaluate the patient's facial expressions behind a masked facial expression. As a result, social adaptation worsens. It has been shown that adopting dopaminergic therapy leads to a notable decrease in hypomimia and other movement symptoms [11]. Therefore; earlier detection of movement disorders in PD contributes to their correction. As a result, this leads to maintaining a normal standard of life.

Currently, clinical assessment of facial activity is carried out on the basis of the Movement Disorder Society's Unified Parkinson's Disease Rating Scale (MDS-UPDRS) according to the 5-point system [12]. In section 3.2, facial expression is assessed according to the following criteria: eyes blinking rate, maskiness of the face or expression loss, spontaneous smile, and lip-seal. Clinical assessments of UPDRS vary from expert to another[13]. However; they refer to the lack of objectivity. Moreover, the UPDRS performance evaluations provide only an integral idea of a specific disorder. They do not reveal the full picture of changes in movement manifestations and they do not report the most significant changes' characteristics of PD patients. Determination of the most important parameters of hypomimia in PD is an important aspect for studying PD and for expanding the clinical performance of the disease.

One of the techniques for assessing facial expressions is the Facial Action Coding System (FACS). FACS is a technique for identifying individual action units (AUs), presented on the face, and assessing their intensity [14]. AUs represent the basic movements performed by individual muscles or muscle groups. Analysis of facial activity based on FACS makes it possible to assess the action activity of separately selected facial muscles. It also makes possible to more accurately assess the impairment degree of facial expression in terms of qualitative and quantitative characteristics.

The rest of this work is organized as in the follows. Section II describes works on automated assessment of facial expressions in PD. Section III describes the methods and means used to obtain quantitative characteristics of the facial movements parameters. Section IV presents the work results and their discussion. Section V contains conclusions.

II. Related works

Automated methods are increasingly used to assess disorders in PD [15–19]. As for the face, the use of instrumental automated methods for assessing facial movements allows, more objectively, identifying movement disorders in certain parts of the face based on the measurement of certain kinematic parameters.

To date, a number of researches have been published using the FACS system in studying facial expression in PD patients [20 - 22]. Wu et al. noticed decrease in facial expression by assessing intensity and frequency of AUs in the analysis of emotional expressions while watching videos [20]. M. Bologna et al. provided an assessment of the velocity and amplitude of action units manifested during natural expression of 6 basic emotions in PD patients [21]. Differences in the occurrence frequency of AUs for action units AU4, AU12 were described by Langevin et al. during facial recording while performing tasks for movement activity of hands from part 3 of MDS-UPDRS and speaking tasks [22].

Despite the large number of facial activity studies in PD patients, there is no unified automated method for investigating hypomimia. Previous studies of hypomimia in PD, based on the AUs analysis, studied spontaneous or posed facial expressions of various emotions. At the same time and in the process of performing tasks by a patient, no requirements were imposed on the intensity, speed and other parameters of movement. As a result of this movement, individual manifestations of facial expressions made a great contribution to the overall assessment. In this work, automated method for studying facial activity in PD patients has been proposed based on the assessment of AUs in the process of 2D video recording of the face when performing special movement tests for the activation of certain AUs with 10-fold repetition of each facial movement with maximum speed and amplitude.

III. Methods and Materials

A. Participants

2 groups of participants have been selected to participate in the study: a group of patients with Parkinson's disease (PD) and a control group including healthy volunteers (HC). PD patients were recorded in the Federal State Budget Scientific Institution "Scientific Center of Neurology". HC volunteers have been recorded in the Research and Educational Medical-Technological Centre of Bauman Moscow State Technical University. The PD group included 16 patients (6 women, 10 men), average age is 58.3 ± 13.5, disease duration is 8.2 ± 4.8, and average stage value according to Hoehn & Yahr stage is 2.5 ± 0.6. The HC group included 16 patients (13 women, 3 men), mean age is 49.2 ± 10.1. Among the PD group, 1 patient is with the first stage of the disease according to Hoehn & Yahr, 6 patients are with the second stage, 1 patient is with stage 2.5, and 8 patients are with the third stage. Informed consent was obtained in accordance with the Declaration of Helsinki.

B. Facial expressions assessment

Participants in this study have been asked to perform 4 facial expression tests: closing the eyes(E), raising the eyebrows(U), smiling with an effort (grin)(S), and moving the eyebrows(B). Each test is a series of facial movements performed 10 times with maximum possible amplitude and speed (by analogy with the assessment of hypokinesia in the arms and legs when performing part 3 of the MPS-UPDRS scale). Sets of AUs involved in each test are shown in Table I.

TABLE I. Compliance of test items and AU

Designation	Task	Number of repetitions	The involved AU
E	Closing eyes	10	4,6,7
U	Raising eyebrows (to wrinkle the forehead)	10	1,2
S	Smiling with an effort (grin)	10	6,12,14
B	Moving the eyebrows	10	4

The correspondences of each investigated AU and facial muscles in accordance with the FACS system are presented in Table II.

TABLE II. AUs and the corresponding facial muscles

AU	AU name	Muscle base
AU01	Inner eyebrow lifter	frontalis muscle (medial part)
AU02	Outside eyebrow lifter	frontalis muscle (lateral part)
AU04	Eyebrow depressor	procerus muscle; muscle that lowers the eyebrow; muscle that wrinkles the eyebrow
AU06	Cheek lifter	circular eye muscle (orbital part)
AU07	Eyelid stretcher	circular eye muscle (secular part)
AU12	Lip corner lifter	zygomaticus major muscle
AU14	Dimple	buccinator muscle (Trumpeter muscle)

C. Video recording procedure

During the performance of facial tests, each study participant has been recorded on a 2D video camera. Recording was carried out under normal conditions, and the face was evenly illuminated. For the facial video recording, the patient has been positioned opposite the camera at a distance of 0.7-1.2 m and the camera has been fixed on a tripod at the level of the patient's eyes. 2D images have been recorded using a Logitec C920 webcam. Each of the 4 tests has been performed in turn. Recording began at the researcher's command and ended after performing 10 movement actions. Before recording, the study participants were instructed to perform each facial expression task with maximum effort and as fast as possible. Correctness of the assignments has been monitored visually by an expert. Thus, total number of video recordings that make up the research database was 128, i.e. 4 entries for each participant.

D. Signal processing

Algorithms for analyzing facial expressions [23-25] based on automated detection AUs open up further prospects for their use. For automated detection of AUs on each video frame, the OpenFace free access software has been used [26]. OpenFace has a good correlation between the AUs when checked on public databases with different facial expressions. The average correlation value at this time is 0.73 across all AUs [26].

OpenFace is able to determine the degree of manifestation (from 0 to 5) of AU for (AU 1, 2, 4, 5, 6, 7, 9, 10, 12, 14, 15, 17, 20, 23, 25, 26, 28, 45) by 2D face image. AUs are determined by the facial key points and using regression and

classification methods. For each AU, its presence or absence is determined by the parameter AU_c (the parameter AU_c, has a value of 0 or 1) and the degree of manifestation (the parameter AU_r, has a value from 0 to 5).

The intensity (A) of action unit on each frame of the video has been calculated using the following method [23]: $A = AU_r \times AU_c$. To plot the AU changes, the intensity has been marked depending on the frame number. Each received signal has been automatically marked with maximum and minimum points using the built-in Python libraries. Moreover; manual correction of the placed points has been performed, where it was necessary. The AU intensity A in exercise B (eyebrow moving) for the HC and PD groups is shown in Fig. 1.

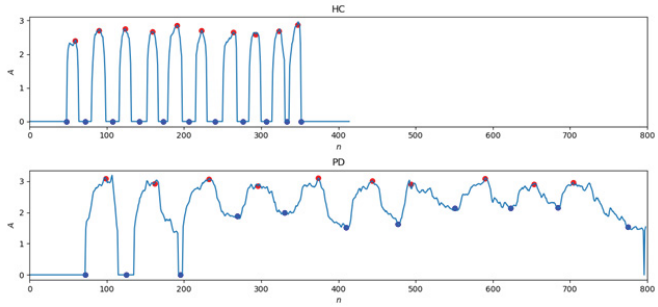

Fig. 1. AU intensity graph during exercise B. The horizontal axis represents the frame number (n) while the vertical axis represents the intensity (A) of the action unit AU04

For each exercise, graphs which represent changes in the intensity of AUs have been constructed and presented in accordance with Table II.

E. Kinematic characteristics

For each signal, 11 kinematic parameters have been calculated (Table III). The calculation has been carried out on the marked points of the signal extremum in accordance with [27, 28] on the basis of important movement indicators: frequency (1), opening phase speed (2), closing phase speed (3), amplitude (4). Signal marking has been carried out using the built-in Python libraries. There has been also manual correction of points where it was needed. A schematic representation of the signal for calculating the kinematic parameters is shown in Fig. 2.

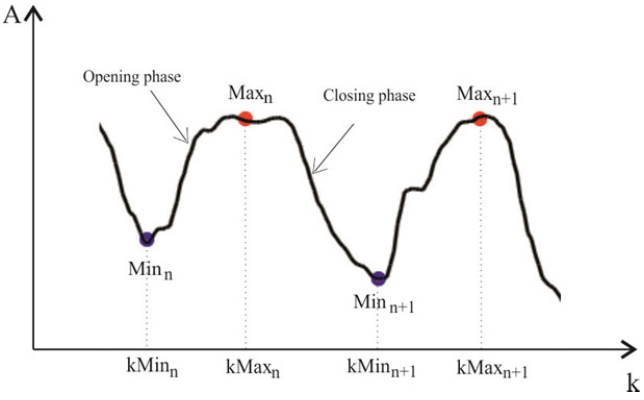

Fig. 2. Schematic representation of the AU movement graph. The horizontal k-axis represents number of extreme points. the vertical A-axis represents the intensity value of the movement signal

$$F_n = \frac{1}{\mathrm{kMax_{n+1}} - \mathrm{kMax_n}} \quad (1)$$

$$Vopen_n = \frac{\mathrm{Max_n} - \mathrm{Min_n}}{\mathrm{kMax_n} - \mathrm{kMin_n}} \quad (2)$$

$$Vclose_n = \frac{\mathrm{Max_n} - \mathrm{Min_{n+1}}}{\mathrm{kMax_n} - \mathrm{kMin_{n+1}}} \quad (3)$$

$$A_n = \frac{(\mathrm{Max_n} - \mathrm{Min_n}) + (\mathrm{Max_n} - \mathrm{Min_{n+1}})}{2} \quad (4)$$

Amplitude decrement magnitude of each movement has been calculated as the ratio of the subsequent movement amplitude to the previous. To calculate the amplitude decrement magnitude according to the signal, all ratios that are less than one have been summed up as $1 - \mathrm{A_{n+1}}/\mathrm{A_n}$, where n is the movement number. Speed decrement has been calculated similarly where speed has been calculated as $\mathrm{V_n} = \mathrm{Mean}\,(\mathrm{V_{close}}, \mathrm{V_{open}})$. To detect rhythm disturbances, speed variation, amplitude, and frequency have been calculated. Variation is defined as the ratio of standard deviation to the mean value multiplied by 100.

TABLE III. KINEMATIC PARAMETERS

№	Parameter	Definition	Presentation
1	AvgFrq	Average frequency	mean($\mathrm{F_n}$)
2	VarFrq	Variation of frequency	(std($\mathrm{F_n}$)/ mean($\mathrm{F_n}$))*100
3	AvgVopen	Average opening speed	mean($\mathrm{Vopen_n}$)
4	AvgVclose	Average closing speed	mean($\mathrm{Vclose_n}$)
5	AvgA	Average opening amplitude	mean($\mathrm{A_n}$)
6	VarA	Variation of Amplitude	(std($\mathrm{A_n}$)/ mean($\mathrm{A_n}$))*100
7	VarVopen	Variation of opening speed	(std($\mathrm{Vopen_n}$)/ mean($\mathrm{Vopen_n}$))*100
8	VarVclose	Variation of closing speed	(std($\mathrm{Vclose_n}$)/ mean($\mathrm{Vclose_n}$))*100
9	Length	Number of movements	$\mathrm{kMin_n} - \mathrm{kMin_1}$
10	DecA	Amplitude decrement	sum($1 - \mathrm{A_{n+1}}/\mathrm{A_n}$)
11	DecV	Speed decrement	sum($1 - \mathrm{V_{n+1}}/\mathrm{V_n}$)

It is expected to obtain values which show decrease in the amplitude AvgA, the speed AvgVopen, AvgVclose, the frequency of movements AvgFrq. The same obtained values would show increase in the values of the amplitude variability parameters VarA, the speed VarVopen, VarVclose, the frequency of movements VarFrq, the increase in decreasing, i.e. decay of the DecA amplitude and DecV rate by the end of the recording in the group of patients with PD compared to the values obtained in the HC group.

F. Calculating the statistical significance of differences between groups

In this study, a nonparametric test has been used to calculate the statistical values. Mann-Whitney test has been chosen to assess the statistical significance of the differences between HC and PD groups. Initially, the null hypothesis of the absence of differences between the samples is accepted. The significance level at which the null hypothesis is rejected is set to $p < 0.05$.

Data in which there are statistically significant differences between the groups are highlighted in the tables.

IV. Results and discussions

When analyzing the received signals of changes in the AU intensity, it has been noticed that not all patients had a 10-fold movement of the selected AUs. Moreover; not all the data of the16 patients of each group have been used in the calculations. The tables show the HC / PD ratio elaborating number of people in each group who had facial movements of the selected AU at least 8 times. Patients for whom the selected AU was not recorded or the number of performed facial movements in one series was less than 8, have been excluded from the sample used for calculating statistical values. Results of the statistical calculation, average value, and standard deviation are shown in tables 5, 6, 7, 8 for each movement parameter.

A. Results of statistical calculation for the test :smiling with an effort (grin) (S)

To analyze differences between the groups, 3 action units which appear during this test: AU06, AU12, AU14 have been used.

When performing the test: smiling with an effort (grin) (S), manifestation of the AU06 action unit in the groups differ in the following parameters are: AvgFrq, AvgVopen, AvgVclose, Length (Table IV), with the manifestation of the AU12 action unit: AvgFrq, VarFrq, AvgVopen, AvgVclose, Length (Table V), and with the manifestation of the AU14 action unit: AvgFrq, AvgVopen, AvgVclose, AvgA, VarVclose, Length (Table VI).

TABLE IV. Kinematic parameters when performing the test smiling with an effort for AU06

AU	**AU06**		
HC/PD	15/15		
Group	HC	PD	p
AvgFrq	**1.27 ± 0.16**	**0.99 ± 0.27**	**0**
VarFrq	11.14 ± 5.46	11.84 ± 5.58	0.35
AvgVopen	**5.55 ± 1.45**	**3.9 ± 1.67**	**0.01**
AvgVclose	**6.92 ± 1.65**	**4.62 ± 1.79**	**0**
AvgA	2.28 ± 0.55	2.01 ± 0.54	0.13
VarA	13.41 ± 6.26	20.56 ± 16.44	0.18
VarVopen	22.3 ± 7.93	28.17 ± 12.91	0.15
VarVclose	20.03 ± 7.9	23.87 ± 10.75	0.16
Length	**7.92 ± 1.13**	**10.86 ± 2.77**	**0**
DecA	0.48 ± 0.2	0.71 ± 0.53	0.12
DecV	0.65 ± 0.19	0.86 ± 0.43	0.1

TABLE V. Kinematic parameters when performing the test smiling with an effort for AU12

AU	**AU12**		
HC/PD	16/15		
Group	HC	PD	p
AvgFrq	**1.31 ± 0.22**	**0.99 ± 0.27**	**0**
VarFrq	**10.84 ± 3.85**	**14.84 ± 5.96**	**0.01**
AvgVopen	**5.96 ± 1.25**	**4.55 ± 1.71**	**0.01**
AvgVclose	**8.01 ± 1.96**	**5.22 ± 1.75**	**0**
AvgA	2.48 ± 0.59	2.34 ± 0.56	0.28
VarA	12.87 ± 8.83	19.6 ± 17.31	0.12
VarVopen	26.21 ± 10.89	30.04 ± 13.45	0.19
VarVclose	20.95 ± 8.57	27.84 ± 17.09	0.11
Length	**7.74 ± 1.24**	**11.07 ± 2.77**	**0**
DecA	0.44 ± 0.33	0.66 ± 0.51	0.11
DecV	0.67 ± 0.22	0.82 ± 0.43	0.25

TABLE VI. Kinematic parameters when performing the test smiling with an effort for AU06

AU	**AU14**		
HC/PD	15/15		
Group	HC	PD	p
AvgFrq	**1.31 ± 0.22**	**0.96 ± 0.29**	**0**
VarFrq	16.93 ± 9.09	19.01 ± 13.99	0.34
AvgVopen	**4.69 ± 1.69**	**2.61 ± 1.15**	**0**
AvgVclose	**4.8 ± 1.84**	**2.97 ± 1.45**	**0**
AvgA	**1.71 ± 0.51**	**1.36 ± 0.55**	**0.05**
VarA	20.2 ± 9.7	27.06 ± 15.53	0.12
VarVopen	35.5 ± 14.84	36.25 ± 16.82	0.5
VarVclose	**27.15 ± 11.61**	**37.54 ± 12.2**	**0.02**
Length	**8.06 ± 1.39**	**11.97 ± 4.24**	**0**
DecA	0.64 ± 0.31	0.82 ± 0.53	0.25
DecV	0.91 ± 0.37	1.04 ± 0.47	0.22

The AvgFrq parameters show a decrease in the frequency of movement in PD patients group. At the same time, there are differences in the parameters of the movement speed AvgVopen, AvgVclose, i.e. the speed of the beginning and end of movement in PD patients is lower than its value in the control group. The Length parameter indicates that PD patients take longer to complete the effortful smile task (S). No differences in the movements amplitude have been found for the action units AU06 and AU12. AU14 has showed decrease in the amplitude of the movement end in the PD group. Also, statistically significant differences are present for the variability parameters VarFrq, VarVclose. The value of the frequency variability parameter VarFrq is higher in the PD group for AU12, and the value of the closing phase speed variability parameter VarVclose is higher in the PD group for AU14, this indicates changes in the rhythm of movement.

B. Results of statistical calculation for the parameters of eyes closing test (E)

To analyze the differences between the groups, 3 action units which appear during this test: AU04, AU06, AU07 have been used.

When performing the eyes closing test (E), manifestation of the action unit AU07 in the groups differed in the following parameters: AvgVopen, AvgVclose. Speed of the beginning and the end of the exercise in PD group was lower than its value in HC group (Table VII). There were no differences in the movement parameters for AU04 during the exercise E and number of people, who recorded AU06 during this exercise in each group, was less than half. Therefore; this number doesn't provide statistical calculations for AU06 (Table VIII).

TABLE VII. Kinematic parameters when performing the eyes closing test for AU07

AU	**AU07**		
HC/PD	14/12		
Group	HC	PD	p
AvgFrq	1.6 ± 0.48	1.34 ± 0.46	0.11
VarFrq	13.21 ± 5.39	16.88 ± 8.37	0.18
AvgVopen	**7.76 ± 2.98**	**5.29 ± 3.12**	**0.03**
AvgVclose	**8.13 ± 2.91**	**5.09 ± 2.92**	**0.01**
AvgA	2.53 ± 0.89	1.85 ± 0.75	0.08
VarA	21.63 ± 12.76	29.77 ± 14.32	0.09
VarVopen	24.11 ± 11.15	33.73 ± 17.66	0.09
VarVclose	28.44 ± 14.25	35.93 ± 15.0	0.17
Length	6.75 ± 1.54	8.65 ± 3.84	0.12
DecA	0.74 ± 0.5	1.01 ± 0.51	0.05
DecV	0.76 ± 0.46	1.0 ± 0.45	0.11

TABLE VIII. KINEMATIC PARAMETERS WHEN PERFORMING THE EYES CLOSING TEST FOR AU04

AU	**AU04**		
HC/PD	15/16		
Group	HC	PD	p
AvgFrq	1.66 ± 0.48	1.38 ± 0.41	0.1
VarFrq	14.06 ± 6.25	14.33 ± 7.64	0.46
AvgVopen	6.57 ± 3.75	5.6 ± 3.63	0.21
AvgVclose	7.23 ± 3.6	5.49 ± 3.53	0.1
AvgA	1.9 ± 0.59	1.9 ± 1.04	0.46
VarA	25.32 ± 16.76	29.39 ± 23.18	0.37
VarVopen	34.17 ± 13.89	41.66 ± 33.71	0.43
VarVclose	31.74 ± 18.87	32.27 ± 23.42	0.44
Length	6.38 ± 1.58	8.07 ± 2.88	0.05
DecA	0.77 ± 0.58	0.89 ± 0.64	0.31
DecV	0.98 ± 0.58	1.03 ± 0.63	0.49

C. *Results of statistical calculation for the parameters of moving the eyebrows test (B)*

To analyze the differences between the groups, 1 action unit which appears during this exercise: AU04 has been used. During exercise of moving the eyebrows (B), manifestation of the action unit AU04 in different groups differed in the following parameters: AvgFrq, AvgVopen, AvgVclose, AvgAopen, AvgAclose, Length, DecV (Table IX).

The differences show decrease in the frequency of movements AvgFrq and consequently, increase in the duration of the exercise Length in PD patients. Moreover; there is decrease in the speed of the beginning and end of the repetition of each movement AvgVclose, AvgVopen, increase in the variability of the closing phase speed VarVclose, decrease in the amplitude of movements AvgA, and increase in the variability of the amplitude VarA. DecV parameter indicates that PD group, patients had the largest deceleration in speed with each subsequent movement in comparison with its value in the control group.

TABLE IX. KINEMATIC PARAMETERS WHEN PERFORMING THE EYES CLOSING TEST FOR AU04

AU	**AU04**		
HC/PD	16/16		
Group	HC	PD	p
AvgFrq	**1.37 ± 0.19**	**1.02 ± 0.24**	**0**
VarFrq	14.95 ± 7.57	19.39 ± 10.25	0.12
AvgVopen	**6.51 ± 2.09**	**4.25 ± 2.29**	**0**
AvgVclose	**7.29 ± 2.42**	**4.44 ± 3.41**	**0**
AvgA	**2.39 ± 0.59**	**1.97 ± 0.92**	**0.03**
VarA	**19.39 ± 11.74**	**33.04 ± 21.52**	**0.04**
VarVopen	**28.09 ± 16.12**	**44.25 ± 18.15**	**0**
VarVclose	28.06 ± 12.07	37.2 ± 20.95	0.15
Length	**7.78 ± 1.05**	**11.33 ± 4.05**	**0**
DecA	0.71 ± 0.4	1.0 ± 0.63	0.13
DecV	**0.97 ± 0.35**	**1.25 ± 0.49**	**0.04**

D. *Results of statistical calculation for the eyebrow raising test (U) parameters*

To analyze the differences between the groups, 2 action units which are manifested during the performance of these exercises: AU01, AU02 have been used. During raising the eyebrows (U) exercise, manifestation of the action unit AU01 in different groups differed in the following parameters: AvgFrq, Length (Table X). Manifestation of AU02 differed in the parameters: AvgFrq, AvgVopen, AvgVclose, Length (Table XI).

TABLE X. KINEMATIC PARAMETERS DURING THE EYEBROW RAISING TEST FOR AU01

AU	**AU01**		
HC/PD	14/12		
Group	HC	PD	p
AvgFrq	**1.54 ± 0.22**	**1.22 ± 0.32**	**0**
VarFrq	18.19 ± 18.04	18.37 ± 14.1	0.35
AvgVopen	5.71 ± 2.48	5.06 ± 2.63	0.23
AvgVclose	5.37 ± 2.48	5.42 ± 2.76	0.47
AvgA	1.59 ± 0.77	1.91 ± 0.77	0.21
VarA	16.79 ± 9.37	19.7 ± 16.86	0.49
VarVopen	51.91 ± 36.2	38.41 ± 33.46	0.05
VarVclose	24.67 ± 14.54	26.19 ± 19.38	0.45
Length	**6.59 ± 1.21**	**8.85 ± 2.32**	**0**
DecA	0.69 ± 0.47	0.64 ± 0.62	0.21
DecV	1.03 ± 0.49	0.9 ± 0.78	0.13

TABLE XI. KINEMATIC PARAMETERS DURING THE EYEBROW RAISING TEST FOR AU02

AU	**AU02**		
HC/PD	14/10		
Group	HC	PD	p
AvgFrq	**1.42 ± 0.27**	**1.21 ± 0.34**	**0.05**
VarFrq	16.6 ± 8.94	19.71 ± 11.81	0.35
AvgVopen	**1.28 ± 0.62**	**0.77 ± 0.32**	**0.01**
AvgVclose	**1.34 ± 0.61**	**0.84 ± 0.4**	**0.02**
AvgA	0.37 ± 0.18	0.28 ± 0.08	0.14
VarA	47.48 ± 10.81	48.4 ± 7.94	0.42
VarVopen	69.9 ± 29.65	63.09 ± 19.03	0.33
VarVclose	50.16 ± 11.95	56.95 ± 26.25	0.49
Length	**6.64 ± 1.39**	**8.6 ± 2.62**	**0.01**
DecA	1.76 ± 0.41	1.74 ± 0.69	0.42
DecV	1.73 ± 0.5	1.94 ± 0.69	0.21

The AvgFrq parameter indicates a decrease in the frequency of movements in the PD patients group. Accordingly; duration of the exercise Length in this group is of greater importance for AU01 and AU02. Also, speed of starting movement is lower in the PD group when the action unit AU02 is activated.

E. *Determination the most significant AUs and discussion*

For visual assessment, as an example, a diagram of the distribution by the Length parameter has been built for each exercise. The diagram is shown in Fig. 3.

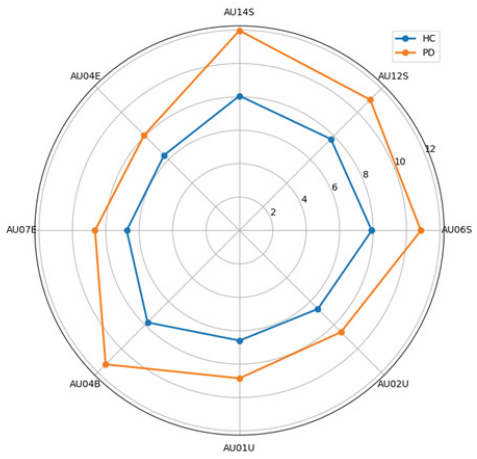

Fig. 3. Diagrams of the Length parameter values distribution for the action units of each exercise

Having analyzed all the obtained differences between the PD and HC groups, it can be concluded that the most common differences are in such parameters as AvgFrq, AvgVopen, AvgVclose and Length. Therefore; there is a decrease in the speed of each movement repetition and a decrease in the frequency of movements. Consequently; there is increase in the duration of the exercise in the PD patients group. Differences in the amplitude AvgA and DecV rate decrement were much less common. This can be explained either by the fact that the facial movements speed during PD decrease to a greater extent and at earlier stages of the disease as compared to the amplitude, or by the fact that the patients favored amplitudes movements during the exercise while losing the speed of execution. Also, differences in the VarFrq, VarA and VarVclose parameters are rare. This indicates that the variability of frequency, amplitude and speed is not a key sign of differences in the way the task is performed, i.e. rhythm disturbance is not significant in general. It can be assumed that more repetitions are needed to estimate the variability in the parameter values. Besides; there is no difference anywhere in the DecA amplitude decrement and the variability of the opening phase speed VarVopen.

Difference between the groups of participants in this study is about 10 years. In [29], it has been noticed that with this difference, age does not affect facial expressions when expressing emotions. Accordingly, there is no reason to assume that there are significant differences in facial expressions depending on the age when performing the selected 4 tests.

In this work, the AU04 has been evaluated twice and depending on the test, different results have been obtained. For the AU04 action unit, no statistically significant differences have been found in the eye closing test in contrast to the eyebrow moving test. Probably, the lack of differences in the eye closing test is due to the fact that this action unit is auxiliary when closing the eyes.

To select the most informative tests and AUs, the number of statistically significant differences obtained for each AU have been estimated as well as the number of participants in each group in whom the selected AU has been recorded. In the course of the study, not all the participants have 10 movement repetitions determined using the automated method. No assumptions have been made for justifying the reasons why this happened. It is possible that the participants have performed some movements with a small intensity which was not enough to recognize changes in the AU.

Thus, the most informative AUs can be called AU12, and AU14, recorded during smiling with an effort (grin) (S) test, and AU04, recorded during the eyebrows moving (B) test. These AUs have been selected since they were recorded in all participants in the experiment and the number of parameters showing statistically significant differences are more than the differences for the other AUs.

The obtained results show the possibility of quantitative assessing the parameters of speed, frequency of movement, duration of exercise, and other important indicators of facial muscle activity in hypomimia. Therefore; a more complete picture of disorders have been got taking into account localization of movement disorders in various parts of the face. In future, studying the capabilities of this method in the early stages of PD for a larger number of patients can contribute to the creation of a system to support decision-making about the presence of the disease. Moreover; an objective and automated assessment of facial expressiveness opens up the possibility of monitoring the dynamics of changes in facial expression in patients with PD against the background of anti-Parkinsonian therapy.

F. Statistical results for the early and extended PD stage.

In clinical practice and for convenience, they apply stages combination, according to the severity, and distinguish 3 stages [30]:

1) Early stages (stages 1–2.5 according to Hoehn-Yahr);

2) Extended stages (3rd stage according to Hoehn-Yahr);

3) Late stages (4-5th stage according to Hoehn-Yahr).

To assess the change in parameters depending on the stage of the disease, the most informative selected action units are: AU04, AU12, AU14.

For statistical analysis, 2 analysis groups have been formed: patients with early stages of the disease (PD early) and patients with advanced stages (PD extended) of the disease. The results of statistical analysis are presented in Table XII, XIII, XIV. The analysis shows that no statistically significant differences have been found between the patients of the early and advanced stages.

TABLE XII. KINEMATIC PARAMETERS OF PATIENTS WITH EARLY AND ADVANCED STAGES FOR AU04

AU	**AU04**		
PD early/ PD extended	8/8		
Group	PD early	PD extended	p
AvgFrq	1.09 ± 0.28	0.94 ± 0.17	0.08
VarFrq	20.87 ± 10.96	17.91 ± 9.25	0.25
AvgVopen	5.07 ± 2.65	3.43 ± 1.46	0.13
AvgVclose	5.51 ± 4.0	3.37 ± 2.23	0.06
AvgA	2.19 ± 1.04	1.75 ± 0.72	0.36
VarA	24.27 ± 18.19	41.82 ± 21.01	0.09
VarVopen	42.4 ± 20.52	46.11 ± 15.2	0.16
VarVclose	28.89 ± 12.4	45.5 ± 24.22	0.11
Length	11.03 ± 5.31	11.62 ± 2.09	0.08
DecA	0.71 ± 0.51	1.3 ± 0.59	0.06
DecV	1.12 ± 0.41	1.38 ± 0.52	0.19

TABLE XIII. KINEMATIC PARAMETERS OF PATIENTS WITH EARLY AND ADVANCED STAGES FOR AU12

AU	**AU12**		
PD early/ PD extended	8/7		
Group	PD early	PD extended	p
AvgFrq	1.05 ± 0.29	0.92 ± 0.22	0.34
VarFrq	16.06 ± 5.84	13.44 ± 5.79	0.23
AvgVopen	4.91 ± 2.06	4.13 ± 1.03	0.26
AvgVclose	5.54 ± 2.09	4.86 ± 1.14	0.26
AvgA	2.32 ± 0.62	2.37 ± 0.47	0.48
VarA	15.72 ± 11.96	24.03 ± 21.02	0.3
VarVopen	26.58 ± 8.38	34.0 ± 16.66	0.23
VarVclose	23.77 ± 9.55	32.48 ± 21.94	0.19
Length	10.56 ± 2.54	11.66 ± 2.9	0.39
DecA	0.57 ± 0.4	0.76 ± 0.6	0.39
DecV	0.72 ± 0.3	0.94 ± 0.52	0.23

TABLE XIV. KINEMATIC PARAMETERS OF PATIENTS WITH EARLY AND ADVANCED STAGES FOR AU14

AU	**AU14**		
PD early/ PD extended	8/7		
Group	PD early	PD extended	p
AvgFrq	1.05 ± 0.31	0.89 ± 0.24	0.3
VarFrq	13.68 ± 4.64	23.68 ± 17.36	0.09
AvgVopen	3.05 ± 1.04	2.22 ± 1.1	0.11
AvgVclose	3.3 ± 1.32	2.68 ± 1.5	0.26
AvgA	1.45 ± 0.39	1.28 ± 0.65	0.26
VarA	26.59 ± 18.21	27.47 ± 12.71	0.39
VarVopen	34.14 ± 18.79	38.1 ± 14.63	0.23
VarVclose	34.16 ± 11.0	40.5 ± 12.44	0.26
Length	10.62 ± 2.62	13.16 ± 4.97	0.26
DecA	0.86 ± 0.63	0.78 ± 0.41	0.5
DecV	1.08 ± 0.43	1.01 ± 0.5	0.48

For a visual assessment of the parameter values dependence on the disease progression, diagrams of the average values distribution of the kinematic parameters have been constructed for the control group of patients and patients with early and advanced stages of PD. Parameters of the control group have been presented as single values. Parameters of the early and advanced stage patients, have been presented as a ratio of the early and advanced stages patients parameters to the parameters of the control group. Distribution diagrams for AU04, AU12, AU14 are shown in Fig. 4, 5, 6 respectively.

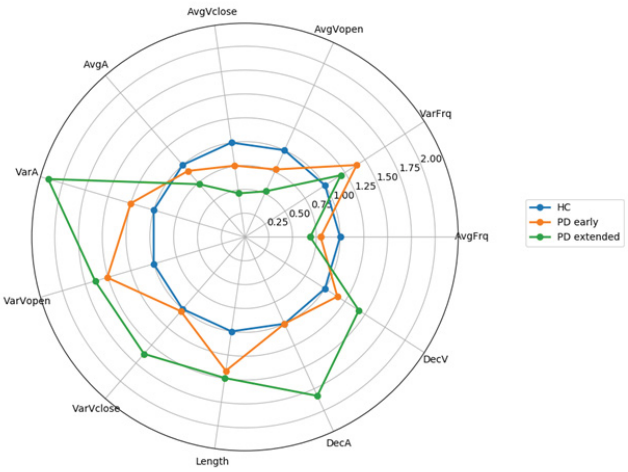

Fig. 4. Diagram of the parameter average values distribution depending on the stage of PD for the action unit AU04

For AU04, progressive deterioration in facial expressions with an increase in stage is characteristic of the following parameters: AvgVopen, AvgVclose, AvgA, VarA, VarVopen, VarVclose, Length, DecA, DecV, AvgFrq.

For AU12, progressive deterioration in facial expressions with an increase in stage is characteristic of the following parameters: AvgVopen, AvgVclose, VarA, VarVopen, VarVclose Length, DecA, DecV, AvgFrq.

For AU14, progressive deterioration in facial expressions with an increase in stage is characteristic of the following parameters: AvgVopen, AvgVclose, AvgA, VarA, VarVclose, Length, AvgFrq.

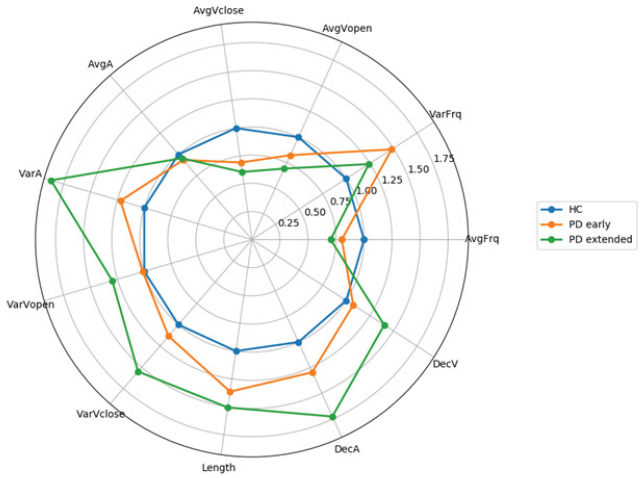

Fig. 5. Diagram of the parameter average values distribution depending on the stage of PD for the action unit AU12

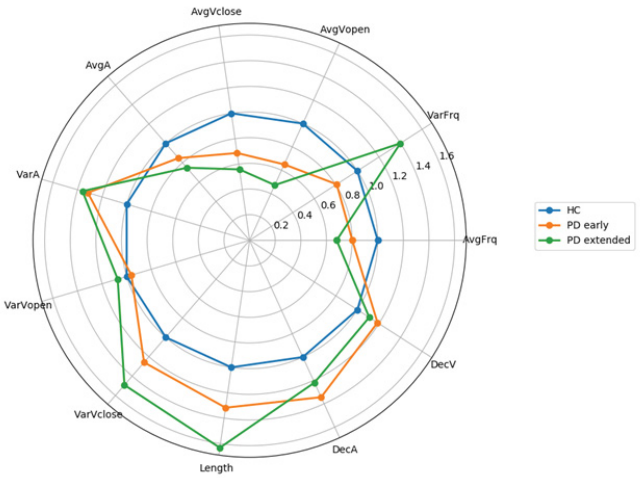

Fig. 6. Diagram of the parameter average values distribution depending on the stage of PD for the action unit AU14

The literature notices that it is difficult to initiate movements in PD patients [31]. However; in this study no differences between the speed of the beginning and end of movements have been seen.

General parameters for action units AU04, AU12, AU14 showing changes in facial activity depending on the stage are the following parameters: AvgVopen, AvgVclose, VarA, VarVclose, Length, AvgFrq. Thus, when the disease progresses, there is a decrease in the speed of movements, an increase in variability of the amplitude and the closing phase speed of movements, a decrease in the frequency of movements, and an increase in the duration of the movement test depending on the stage according to Hoehn - Yahr.

V. CONCLUSION

In this work, a quantitative assessment of movement parameters has been carried out for several facial tests: closing the eyes(E), raising the eyebrows(U), smiling with an effort (grin)(S), and moving the eyebrows(B) and revealed differences between groups in some movement parameters. The tools used

are a 2D camera and OpenFace to analyze facial expressions in PD patients. The calculated kinematic parameters reflect features of movement which are implicitly used by neurologists to assess facial expression activity but not noticed by them quantitatively since Section 3.3 MDS - UPDRS assumes only a general assessment of facial expression.

Based on the analyzed action manifestations of the selected AUs, it can be concluded that a reduced frequency of movements, a reduced speed of facial movements, a decrease in amplitude can be recorded in patients with PD when performing exercises smiling with effort (S), raising eyebrows (U), moving eyebrows (B), and eyes closing (E) tests. The most common differences have been found in the parameters of beginning and end of movement speed, frequency of movement, and duration of the exercise. The most informative recognized AUs are as AU12, AU14 recorded during the exercise smiling with an effort (S) and AU04 recorded during the exercise eyebrows moving (B). Changes in parameters for patients with early and advanced stages of the disease have been shown, progression of hypomimia has been noticed. These parameters are as follows: a decrease in the speed of movements, an increase in variability of the amplitude and the closing phase speed of movements, a decrease in the frequency of movements, and an increase in the duration of the movement test.

The ability to quantitatively assess the parameters of facial expression using available tools using an automated method provides ample opportunities for further use in tracking disease dynamics, epidemiological controlling, and telemedicine.

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