EAI Endorsed Transactions
on Pervasive Health and Technology
Research Article EAI.EU

Quantitation of Body Movement in a Motor Physical Therapy for Parkinson's Disease

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Abstract

The present work shows the quantitation of body movement in a motor physical therapy for Parkinson's Disease (PD). In recent years, many activities of therapy were carried out remotely using common RGB cameras to capture the body movements. We analyze the body movements of 8 subjects with clinical diagnosis of PD, and compare them with a control group of 11 healthy volunteers, processing their respective RGB video recordings with a software that identifies 17 specific body keypoints while subjects perform two motor rehabilitation therapies (cervical and lumbar spine). All videos were analyzed by OpenPose algorithm and angles from keypoints detected were computed to infer the rotation, rate and amplitude of movement of head, shoulder, back and pelvis. The results show that OpenPose algorithm could be used in a home environment specially in follow-up and management of the motor rehabilitation therapy for Parkinson's disease.

Received on 04 May 2023; accepted on 28 August 2023; published on 25 September 2023

Keywords: Remote sensor, Physical therapy, Body movement, Parkinson's disease

doi:10.4108/eetpht.9.3149

1. Introduction

The pace of population aging in recent years has involved an increased and urgent request for rehabilitation therapies to effectively treat important illnesses in old age. Conversely, there has not been an increase of resources in terms of facilities and ad-hoc personnel to address this demand. The reason is at least twofold. First, an assisted rehabilitation process requires significant economic resources to accommodate the growing request for rehabilitation. Secondly, there is insufficient skilled staff to follow up, individually, all the patients in need of rehabilitation [2]. Added to this situation is the fact that in recent years, the consequences of the COVID-19 pandemic meant that many activities were carried out remotely, including medical rehabilitation treatments [3]. Parkinson's disease (PD) is one of the neurodegenerative disorders where remote rehabilitation could have major benefits. PD is considered the second most common chronic neurodegenerative disorder worldwide, clinically characterized by a constellation of motor and nonmotor symptoms that may have a direct effect on daily activities as well as in the patients quality of life [9]. However, a conventional physical therapy program that combines strength, resistance, and flexibility exercises, as well as balance training, could be effective to reduce the degree of motor disability [4, 5, 7]. Attempts are being made to transfer care and rehabilitation of PD from the hospital setting to the patient's home, specifically focusing on: [10]

- Improve the patients quality of life, through a reduction of transfer times and costs.
- Reduce medical costs by increasing the number of patients treated in a single day, or by a single professional unit.
- Expand rehabilitation opportunities using computer-assisted systems.

Therefore, the development of technology allows to expand the treatment capacity beyond the acute phase of the disease and, at the same time, it develops an intervention model aimed at replacing the traditional one, that is, replacing face-to-face

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interaction between patient and physician/therapist. Considering the application of distance medicine in a home environment, there are several reports about systems for the evaluation of body movements from commonly used standard RGB video recordings [6]. Thus, the main aim of this work is to analyze body movements of 8 subjects with clinical diagnosis of Parkinson's disease, and compare them with a control group of 11 healthy volunteers, processing their respective RGB video recordings with a software that identifies 17 specific body keypoints while subjects perform two motor rehabilitation therapies (cervical and lumbar spine).

2. Methodology

2.1. Design.

Nineteen subjects (11 control and 8 with diagnosis of PD) were enrolled to participate in this study. All subjects were informed about the main objective of the study and instructed to follow a protocol for the video capture. A set of 4 body movement therapies (2 for cervical spine and 2 for lumbar spine) were instructed to be followed by all subjects and supervised by physioterapist. All video recordings were analyzed by a specific software that detect 17 body points in order to compute indices of angles of rotation, rate and amplitude of movement for head, shoulder, back and pelvis respectively. A non-parametric statistical analysis was performed in order to quantify the significant differences ($p<0.05$) between groups. The complete view of the study is shown in Fig. 1.

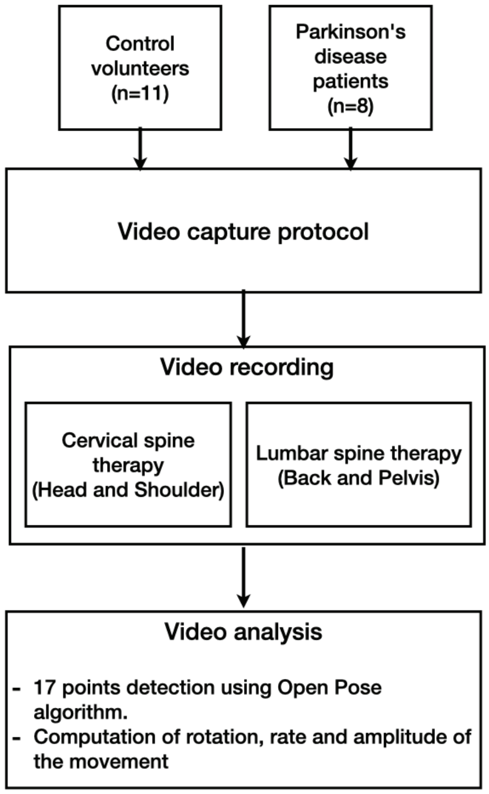


Figure 1. Schematic representation of the study.

2.2. Participants.

Two subject groups were considered in this study: 11 healthy control volunteers (9 males, 2 females; 21.02 ± 3.29 years old) and 8 subjects with clinical diagnosis of Parkinson's disease (6 males, 2 females; 57.64 ± 9.04 years old). All subjects signed a responsability letter to participate in the study according to the Helsinki declaration [1] and approved by the ethics committee of the Hospital General de México "Dr. Eduardo Liceaga" (DI/22/601/04/17), and only subjects with PD received economical compensation for their participation involvement.

2.3. Video capture protocol.

The advantage of the camera-based approach is the ability to detect motion from any regular RGB video, however specific considerations (like space, background, clothes, luminosity, field of view, image resolution, etc.) must be considered in a video capture protocol before the video acquisition. To facilitate the key-points detection, the video capture protocol consisted of:

- Selection of a large place as possible and free of obstacles to prevent falls during the evolution of the therapy exercises.
- Subjects wore clothes that allow them to stand out from the rest of the objects in the background.
- The lighting was directed towards the front of a person, in such a way that it illuminates its face and does not create a shadow.
- There was no other person in the area and large photos or portraits of people were avoided.
- A support for the video capture device was used in all acquisition.
- The floor plane was the reference for the video capture image.
- The resolution of video was 1920x1080 pixels with 24 frames per second and the format of the capture space was 16:9.

Each video was verified to validate that the entire trainee's body was in a correct position at the field of view throughout the recording. At the same time, manual categorization into specific groups was done by a single rater. Border cases were excluded from the analysis.

Table 1. Relationship between therapy and the specific target evaluated.

Target	Code	Therapy
Cervical spine	CS01 CS02	-Left lateral tilt of only the head -Right lateral tilt of only the head
Lumbar spine	LS01 LS02	-Hands on the waist and lateral flexion of the trunk -Arm contralateral to flexion extended to the sides of the trunk above the head

2.4. Physical therapy.

A physical therapy was designed by medical specialist in rehabilitation in order to evaluate specific angles related to the preservation of joint mobility and gross motor coordination. These angles were quantified after video recording by a small camera embedded into a micro-controller board (OpenMV Cam H7 plus, OpenMV) with capabilities to run a neural network and identify 17 points of the body (shoulders, hips, elbows, wrists, knees and ankles). Table 1 shows the target evaluated while the subject performs a specific therapy.

2.5. Video analysis.

In order to perform the rehabilitation therapy, the body segments that belong to the appendicular skeleton are very often measured [11]. These segments allow for translational movement of the body targets through repeated cyclic movements as described in section 2.4. Video recordings of control and PD subjects were analyzed by OpenPose algorithm [8] and angles from keypoints detected were computed to infer the rotation, rate and amplitude of movement of head, shoulder, back and pelvis. Table 2 shows a schematic representation of the computed angles while a subject perform an specific therapy.

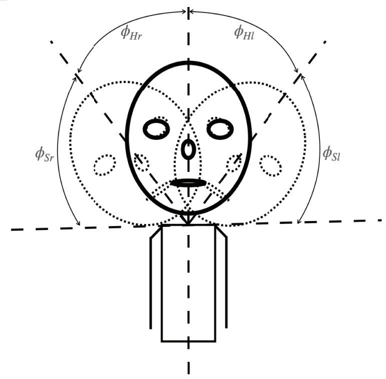
Motion indices (rotation, rate and amplitude) of head, shoulders, back and pelvis were computed for all subjects after performing the therapies for cervical and lumbar spine respectively and were defined as follow:

- Rotation of the head was the angular change of an horizontal imaginary plane formed by keypoints detected for the mouth. Maximum negative rotation values were computed when the head had a maximum tilt to the left and maximum positives values were computed for maximum tilt to the right.

- Rotation of shoulders was the angular change of an imaginary horizontal plane formed by detected keypoints from left and right shoulders.

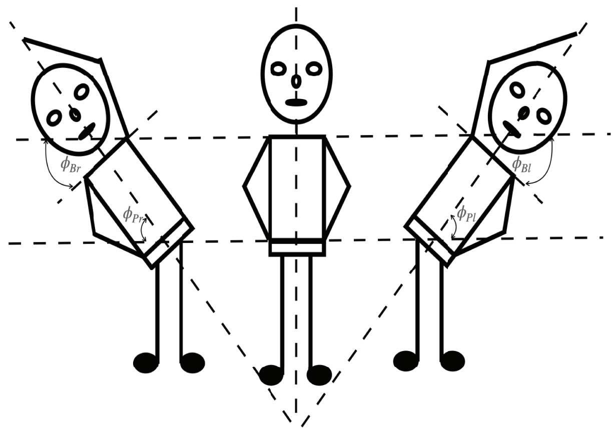
Table 2. Identification and nomenclature of the angles used in continuous monitoring.

Computed angles for cervical spine



ϕ_{Hr} = Angle of the head rotation during CS02.
ϕ_{Sr} = Angle of the shoulder rotation during CS02.
ϕ_{Hl} = Angle of the head rotation during CS01.
ϕ_{Sl} = Angle of the shoulder rotation during CS01.

Computed angles for lumbar spine



ϕ_{Br} = Angle of the back rotation during LS02.
ϕ_{Pr} = Angle of the pelvis rotation during LS02.
ϕ_{Bl} = Angle of the back rotation during left LS01.
ϕ_{Pl} = Angle of the pelvis rotation during left Ls01.

- Rotation of back was the angular change of the trunk (a perpendicular imaginary plane that starts in the midpoint between the femur greater trochanters ending at the midpoint between shoulders).

- Rotation of pelvis was the angular change of an imaginary horizontal plane of left and right trochanters.

- In all cases rate was defined by the number of cycles per minute computed from rotation signal.

- In all cases amplitude was the absolute difference between consecutive minimum and maximum values of the rotation signal.

3. Results and Discussions

In this work we compare motion indices of 8 subjects with clinical diagnosis of Parkinson's disease with those computed for 11 healthy control volunteers to infer the control motion parameters of two specific motor rehabilitation therapies (cervical spine and lumbar spine).

Table 3 depicts the keypoints computed by OpenPose software for a control volunteer during an specific therapy. Angles for head, shoulder, back and pelvis are displayed overlaid on the image (see Table 2 for reference and nomenclature). As observed, OpenPose software has a high sensitivity to identify and follow 11 keypoints of face and 17 keypoints of trunk, lower and upper extremities during the proposed therapies. To achieve these results it is mandatory to follow the video capture protocol described in subsection 2.2.

The first row of Table 3, concerning to cervical spine target therapy, we observe at the central column the reference (0 degrees of head rotation), and the maximum rotation to right and left at the first and third columns respectively. In maximum rotations can be observed a slight difference between left and right keypoints for shoulders (horizontal plane), despite of the indication for this therapy is that the subject only rotates the head.

In the second and third rows of Table 3, corresponding to lumbar spine target therapy, we can observe in the central column the reference (0 degrees of rotation for pelvis and back), and the maximum rotation in the first and third columns. Imaginary planes for shoulders, back and pelvis are more evident and how it change according to therapy.

Fig. 2 and Fig. 3 depicts the comparison indices among of head and shoulders (rotation, rate and amplitude) between a control subject and a PD patient during the cervical spine therapy. Instantaneous rate (in cycles per minute) and the instantaneous amplitude (in grades) were computed using the minimum and maximum peaks in the rotation plots (red points). For head and shoulder the Control subject make 15 cycles in 30 seconds while the PD patients makes only 10 cycles in 26 seconds. It means that instantaneous rate of the PD patient is lower than the Control subject, as can be observed in the second row of both figures. Instantaneous amplitude for PD patients is bigger than the Control subject in the middle of the exercise and decreases suddenly at the end of the exercise. Rate and amplitude behaviour can be explained by the stiffness of movement as a consequence of PD. As previously explained, despite the therapy indicates that the subject only turns his head, we can observed that shoulders have a similar pattern for rate although a marked difference in amplitude. This results confirm the high sensitivity of OpenPose algorithm to detect and follow slight changes in the motion parameters. Special care must be taken to quantify speed and amplitude of the movement at the beginning or at the end of the exercise, since, being of lower amplitude, there are limitations to identify the maximum and minimum peaks, so these parameters can be overestimated.

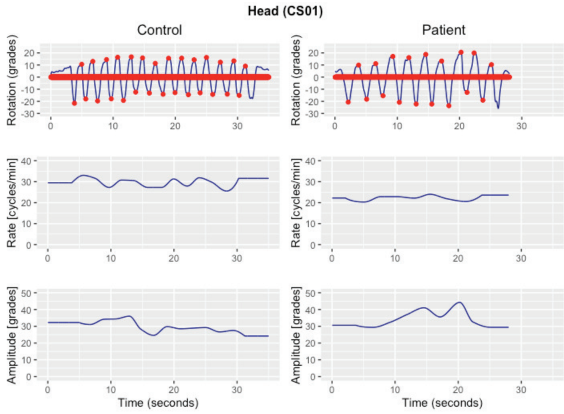


Figure 2. Rotation, rate and amplitude of the head while a Control and a PD patient exercises their cervical spine (CS01).

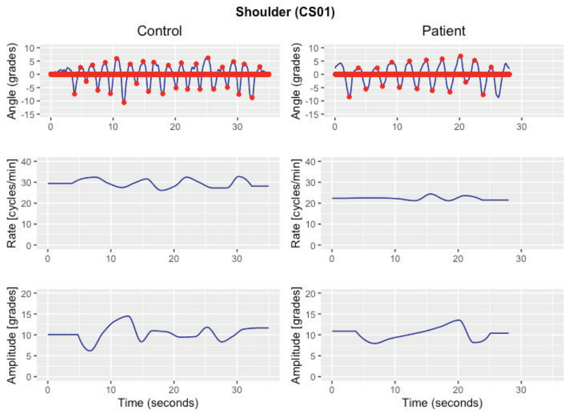


Figure 3. Rotation, rate and amplitude of shoulders while a Control and a PD patient exercises their cervical spine (CS01).

Table 4 summarize the motion parameters for head and shoulders for all subjects after perform the cervical spine therapy. Non-significant differences were found in all parameters between PD and Control groups, however all indices had a wider range for PD patients than Control subjects. Distribution of the instantaneous rate of head in PD patients was lower than Control subjects (15.00-51.43 for PD vs 21.18-45.57 for Control in CS01, and 8.78-53.33 for PD vs 17.14-50.00 for Control in CS02), showing the effects of stiffness

Table 3. Keypoints and computed angles for a control volunteer in all therapy excercises.

<table>
<tr><th>Target</th><th colspan="3">Keypoints and angles</th></tr>
<tr><td>Cervical spine</td><td>
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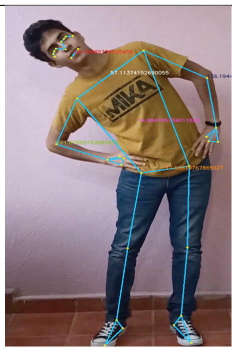
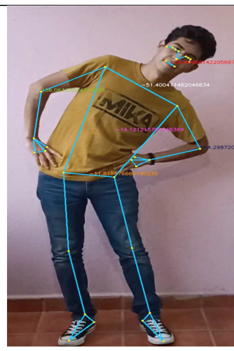
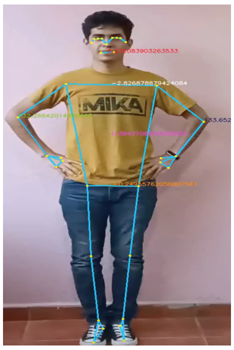
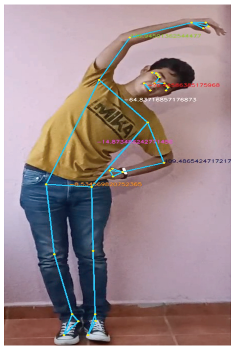
<tr><td rowspan="2">Lumbar spine</td><td></td><td>
</td><td></td></tr>
<tr><td></td><td>
</td><td></td></tr>
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movement as a consequence of the disease. Distribution of instantaneous amplitude of head in PD patients was greater than control subjects (14.19-65.50 for PD vs 14.36-53.75 for Control in CS01, and 5.17-65.67 for PD vs 7.04-49.56 for Control in CS02), showing that PD patients have a less control of the movement. Similar results can be observed for indices of shoulder, which suggest that PD patients tend to have a less control of the movement with lower instantaneous rate and greater instantaneous amplitude, however they were in different stages of the disease such that they were non-statistically different from the control group.

Fig. 4 and Fig. 5 depicts the comparison indices among of back and pelvis (rotation, rate and amplitude) between a control subject and a PD patient during the lumbar spine therapy. In both figures can be observed that PD patient make 10 cycles in 60 seconds while the PD patients makes 8 cycles in 30 seconds. These results confirm that instantaneous rate of the PD patient was lower than the Control subject but a less variability of the trace can be observed too. For back, instantaneous amplitude of the PD patient was lower than the Control subject in all the exercise, having a tendency to increase at the end. However, for pelvis instantaneous amplitude of PD patient was almost equal than Control subject at the end of the exercise. These results suggest that for lumbar therapy, PD patient had a lower amplitude of movement (back) and a less balance during the exercise reflected as an increase of the amplitude in the pelvis.

Table 5 summarize the motion parameters of back and pelvis for Control subjects and PD patients after perform the lumbar spine therapy. Non-significant differences were found in all parameters between PD and Control groups, however values of back rotation were wider for Control subjects than PD patients (-51.79-49.40 for Controls vs -18.20-14.96 for PD patients in LS01, -52.99-50.91 for Controls vs -19.96-17.82 for PD patients in LS02) and similar results were

Table 4. Indices of movement for head and shoulder during cervical spine therapy.

Head					
		CS01		CS02	
		Controls	Patients	Controls	Patients
Rotation (grades)	Range:	-35.12 to 27.52	-51.64 to 57.58	-26.12 to 44.11	-48.87 to 54.94
	1st. Quartile:	-9.52	-11.76	-8.40	-8.53
	Median:	-0.06	1.35	-1.40	-2.18
	3rd. Quartile:	9.24	10.01	9.01	9.56
Rate (cycles/min)	Range:	21.18 to 45.57	15.00 to 51.43	17.14 to 50.00	8.78 to 53.33
	1st. Quartile:	25.00	22.17	24.00	21.64
	Median:	27.30	27.71	26.49	25.71
	3rd. Quartile:	33.00	32.00	34.60	29.96
Amplitude (grades)	Range:	14.36 to 53.75	14.19 to 65.50	7.04 to 49.56	5.17 to 65.67
	1st. Quartile:	24.99	26.74	21.28	26.58
	Median:	28.76	31.21	34.43	32.35
	3rd. Quartile:	37.33	39.84	40.60	38.23
Shoulder					
		CS01		CS02	
		Control	Patients	Control	Patients
Rotation (grades)	Range:	-13.06 to 10.88	-30.10 to 38.07	-9.52 to 14.13	-29.66 to 29.18
	1st. Quartile:	-1.64	-3.18	-1.59	-2.30
	Median:	0.10	0.81	0.09	-0.23
	3rd. Quartile:	2.23	3.29	1.89	2.76
Rate (cycles/min)	Range:	19.31 to 52.50	15 to 48	16.07 to 55.38	9.79 to 49.65
	1st. Quartile:	25.45	21.82	23.33	20.28
	Median:	27.54	27.30	26.19	25.71
	3rd. Quartile:	30.52	32.00	33.87	29.38
Amplitude (grades)	Range:	0.29 to 21.11	3.61 to 31.11	0.93 to 18.16	3.19 to 34.66
	1st. Quartile:	4.31	6.43	3.65	6.10
	Median:	8.38	9.51	6.40	8.32
	3rd. Quartile:	11.64	20.99	11.10	14.79

found for instantaneous amplitude, meaning that head amplitude of movement during the lumbar therapy was lower for PD patients.

Values of the instantaneous rate of back were similar between groups for LS01 but wider in PD patients in LS02, suggesting that PD patients made a great effort to follow the activity in LS02. Distribution of instantaneous amplitude of back in PD patients was lower than Control subjects (median of 17.16 for PD patients vs 32.28 for Control subjects in LS01, and 20.11 for PD patients vs 36.06 for Control subjects in LS02), showing that PD patients have a less control of the movement.

Instantaneous amplitude of pelvic movement was greater in PD patients than Control subjects (median of 28.60 in PD vs 17.74 in LS01 and 25.50 vs 11.93 in LS02), which suggest that PD patients tend to have a less control of the movement.

4. Conclusion

There have been many recent publications describing the possibility of using RGB video recordings for home rehabilitation. In this work we propose to quantify the body movement of cervical and lumbar spine motor therapies for Parkinson's disease using indices like rotation, instantaneous rate and instantaneous amplitude of head, shoulders, back and pelvis. Based on our findings, we can say that OpenPose algorithm is a sufficiently robust algorithm that is capable of detecting slight motion parameters of an specific rehabilitation therapy, that could facilitate their use in a home environment specially in follow-up and management of the motor rehabilitation therapy for Parkinson's disease. In the Control subjects quantitation of motion parameters were similar in amplitude and rate regardless of whether the exercise therapy is to the right or to the left. However for PD patients the estimated motion parameters suggested that PD

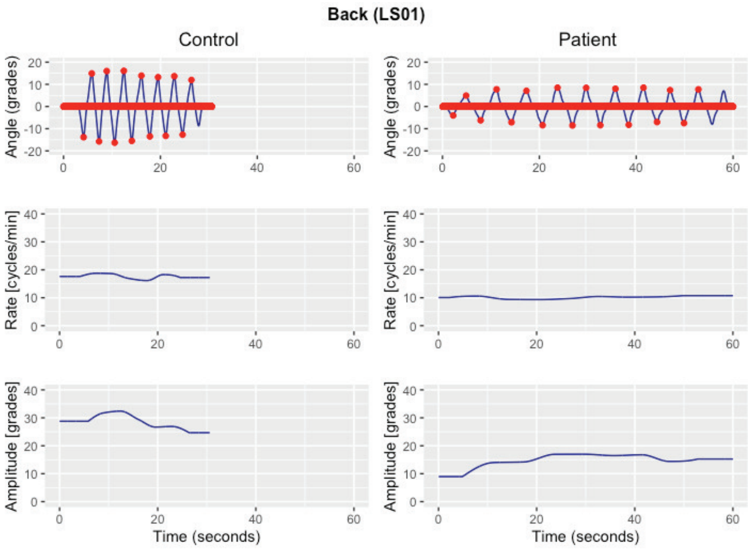

Figure 4. Rotation, rate and amplitude for pelvis and back while a control volunteer exercises their lumbar spine target.

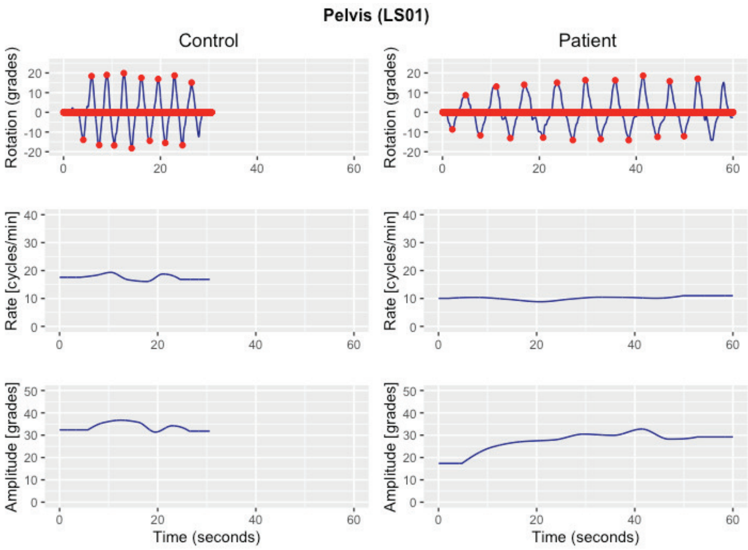

Figure 5. Rotation, rate and amplitude for pelvis and back while a control volunteer exercises their lumbar spine target.

patients tend to have a less control of the movement with tendency of lower instantaneous rate and greater variability in the instantaneous amplitude. It could be explained by the stiffness of movement as a consequence of PD, however all PD patients were in different stages of the disease such that they were non-statistically different from the control group. As future work we will increase the sample size of video recordings considering exercises therapies for another targets like arms, hands, elbows, etc. We will include an analysis of facial expressions to identify patterns of stage in PD and quantify body movement before and after a physical rehabilitation therapy for Parkinson´s disease.

Acknowledgments

This project was partially funded by the program UNAM-DGAPA-PAPIME "PE103323: Herramientas de enseñanza para el desarrollo de dispositivos médicos basados en inteligencia artificial".

References

[1] Association, W.M.: World Medical Association Declaration of Helsinki: Ethical Principles for

Table 5. Back and pelvis parameters of movement during lumbar spine therapy.

Back					
		LS01		**LS02**	
		Control	Patients	Control	Patients
Rotation (grades)	Range:	-51.79 to 49.40	-18.20 to 14.96	-52.99 to 50.91	-19.96 to 17.82
	1st. Quartile:	-6.57	-3.69	-6.49	-3.69
	Median:	-0.34	-0.12	-0.09	-0.09
	3rd. Quartile:	6.52	3.85	5.64	3.55
Rate (cycles/min)	Range:	10.23 to 19.78	8.42 to 19.45	8.53 to 15.92	5.47 to 48.00
	1st. Quartile:	11.92	10.63	8.95	8.42
	Median:	13.15	12.74	9.46	9.88
	3rd. Quartile:	15.41	15.23	13.39	12.04
Amplitude (grades)	Range:	14.32 to 91.49	8.96 to 25.89	21.41 to 98.44	4.86 to 37.45
	1st. Quartile:	24.68	14.35	28.62	14.32
	Median:	32.28	17.16	36.06	20.11
	3rd. Quartile:	59.83	21.73	67.67	23.69
Pelvis					
		LS01		**LS02**	
		Control	Patients	Control	Patients
Rotation (grades)	Range:	-26.33 to 37.16	-27.65 to 25.72	-24.69 to 27.64	-38.77 to 28.62
	1st. Quartile:	-3.83	-6.97	-2.50	-4.88
	Median:	-0.36	-0.71	0.24	0.37
	3rd. Quartile:	3.29	7.08	2.52	5.38
Rate (cycles/min)	Range:	10.29 to 46.15	8.67 to 20.57	8.61 to 20.57	5.47 to 57.60
	1st. Quartile:	12.43	10.65	9.51	8.42
	Median:	14.44	12.97	12.76	10.89
	3rd. Quartile:	16.82	15.00	17.05	13.45
Amplitude (grades)	Range:	3.67 to 54.40	17.37 to 39.06	1.29 to 50.69	2.16 to 59.97
	1st. Quartile:	13.90	24.31	8.90	17.92
	Median:	17.74	28.60	11.93	24.50
	3rd. Quartile:	31.80	34.06	18.35	28.73

Medical Research Involving Human Subjects. JAMA 310(20), 2191–2194 (11 2013), https://doi.org/10.1001/jama.2013.281053

[2] Baldi, M.M., Mavrodiev, P.A., Galuzzi, B.G., Mantovani, F., Realdon, O., Messina, E.: A decision support system in the context of an applied game for telerehabilitation (2021)

[3] Chen, K.L., Brozen, M., Rollman, J.E., Ward, T., Norris, K.C., Gregory, K.D., Zimmerman, F.J.: How is the covid-19 pandemic shaping transportation access to health care? Transportation Research Interdisciplinary Perspectives 10, 100338 (6 2021)

[4] Crizzle, A.M., Newhouse, I.J.: Is physical exercise beneficial for persons with parkinson's disease? Clinical Journal of Sport Medicine 16 (2006)

[5] Dibble, L.E., Addison, O., Papa, E.: The effects of exercise on balance in persons with parkinson's disease: A systematic review across the disability spectrum. Journal of Neurologic Physical Therapy 33 (2009)

[6] Farulla, G.A., Pianu, D., Cempini, M., Cortese, M., Russo, L.O., Indaco, M., Nerino, R., Chimienti, A., Oddo, C.M., Vitiello, N.: Vision-based pose estimation for robot-mediated hand telerehabilitation. Sensors 16 (2016), https://www.mdpi.com/1424-8220/16/2/208

[7] Gobbi, L.T.B., Oliveira-Ferreira, M.D.T., Caetano, M.J.D., Lirani-Silva, E., Barbieri, F.A., Stella, F., Gobbi, S.: Exercise programs improve mobility and balance in people with parkinson's disease. Parkinsonism Related Disorders 15, S49–S52 (2009), https://www.sciencedirect.com/science/article/pii/S1353802009707801

[8] Hidalgo, G., Cao, Z., Simon, T., Wei, S.E., Joo, H., Sheikh, Y.: Openpose library. CMU-Perceptual-Computing-Lab/https://github. com/CMU-Perceptual-Computing-Lab (2017)

[9] Rodríguez-Violante, M., Cervantes-Arriaga, A., Corona, T., Martínez-Ramírez, D., Morales-Briceño, H., Martínez-Martín, P.: Clinical determinants of health-related quality of life in mexican patients with parkinson's disease. Archives of Medical Research 44 (2013)

[10] Rogante, M., Grigioni, M., Cordella, D., Giacomozzi, C.: Ten years of telerehabilitation: A literature overview of

technologies and clinical applications (2010)
[11] Stirling, D., Hesami, A., Ritz, C., Adistambha, K., Naghdy, F.: Symbolic modelling of dynamic human motions. In: Serra, P.A. (ed.) Biosensors, chap. 16. IntechOpen, Rijeka (2010), https://doi.org/10.5772/7215