Non-linear dynamical feature of center of pressure extracted by approximate entropy in people with various stages of Parkinson’s Disease

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Abstract

Introduction: Postural instability, one of the most important features of Parkinson’s Disease (PD), is associated with increased falls and loss of independence in these population. It is postulated the abilities of individuals to adjust to environmental perturbation for postural control is different in various stages of PD. The aim of current study is to investigate the non-linear dynamical feature of COP in various stages of PD and in different environmental challenges.

Method: 38 persons with PD (mild PD =19, moderate PD =6 and severe PD =13) and 33 healthy aged, gender, weight and height matched subjects were asked to stand on force plate in four test conditions included: 1) Rigid Surface with Opened Eyes, 2) Rigid Surface with Closed Eyes, 3) Foam Surface with Opened Eyes, and 4) Foam Surface with Closed Eyes. COP velocity and Approximate Entropy (ApEn) in both Anteroposterior (AP)/Mediolateral (ML) directions were calculated. A Mixed ANOVA 4*2*2 (Group*Vision*Surface) test was applied for statistical analysis.

Results: Both COP velocity and COP ML ApEn were significantly higher in participants with PD in comparison to healthy individuals. Moreover, COP ML ApEn increased by eye closure in all studied groups but the amount of this increase was lesser in PD groups. For COP velocity, vision, surface and group interaction was significant in all directions (P ≤ 0.016). For COP ApEn, vision, surface and group interaction (P = 0.002) were statistically meaningful in only ML direction.

Conclusion: Balance system irregularity is more in people with PD compared to healthy matched individuals. In addition, their adaptive capacity of the postural control system in response to environmental perturbation is reduced. PD induced complexity of the postural control system is associated with the loss of adaptive behavior that is organized over the confluence of constraints of the individual, environment and task.

Introduction

Parkinson’s Disease (PD) is the most common neurodegenerative disease of elderly with impairment of central nervous system (1). Static and dynamic instability is one of the important movement disorders and the principle manifestation of the PD which certainly increases risk of falling (2, 3). It may also influence the Activity Daily Living (ADL) of the individuals, decrease their Quality of Life.
(QoL) and cause disability (4, 5). The pathophysiological aspect of the PD is not well known, however some factors such as reduced postural reflexes, impaired central sensory information processing, non-adjustability of postural reflexes, postural malformation, interference effect of bradykinesia, akinesia, rigidity and frizzing gait of persons may affect their postural stability (6-8).

By far there are many studies on static postural stability of PD population using force platform and linear Center Of Pressure (COP) parameters (e. g. excursion, velocity and path length) (9-15). These traditional measures report quantitative information about the magnitude of postural sway but they are not able to show qualitative properties of COP oscillations whereas efficiency of the postural control system is ascribed to its potential of adjustability in different stability conditions and the quality of its response to environmental perturbations. Obviously, non-linear parameters of COP are more functional for this mean (16, 17). In fact the non-linear COP variables represent a various appearance of postural control thus it seems use of them and linear ones together may help in more comprehensive understand of postural control system integrity and efficiency (18, 19). Non-linear measures indexing the regularity of COP fluctuations, such as entropy and RQA (Recurrence Quantification Analysis), have been successfully applied to study the postural control system (20-24). Results of a research showed that the PD individuals not only had significantly greater COP excursions in comparison to healthy people but also their COP pattern was more complex (higher Approximate Entropy (ApEn)) in both Anteroposterior (AP) and Mediolateral (ML) directions (9). However, in this study different stages of PD were not compared and it was not possible to evaluate postural stability system variations in the face of environmental changes because of only one test condition (standing on rigid surface with opened eyes). Another investigation revealed significant higher value of linear (path length) and non-linear (RQA) COP measures in PD participants who had clinical instability (Hoehn/Yahr Scale (25): 3-4) in comparison with healthy matched individuals and showed a less random and more deterministic dynamic pattern of COP in people with PD. The sensory (visual) manipulation did not differentially affect the two groups. Authors proposed if normal postural control strategies or mechanisms are unavailable to PD individuals, producing a more deterministic (and perhaps more predictable) pattern of sway could allow for more efficient control of balance in these
inflexible, stereotyped and rigid subjects (11). In addition, COP ApEn in mild PD population was not different in comparison to healthy participants in other survey and visual deprivation (eyes closing) did not have a different effect on postural control of two groups (26).
Postural control system could change during progression of PD (individual constraints) and its ability in facing various constraints from the environment would be affected. While some studies have investigated the linear sway measures of individuals with PD, no study has yet reported the non-linear structure of postural sway (using entropy) in various stages of PD (according to H/Y scale, which classifies persons not only regarding the affected body side and severity of symptoms but also based on observation of clinical instability at retropulsion test) in varied stance environmental conditions (regarding the amount of correct proprioceptive and visual feedbacks). Therefor the aim of this study was to investigate the non-linear dynamical features of COP as a good representative of postural control system in various stages of PD.

Materials And Methods
38 participants with PD (62.54±9.1 years) and 33 healthy (60.47±8.9 years) age, gender, weight and height matched subjects recruited into the study by nonrandom convenient sampling. Table 1 shows demographic characteristics of individuals. All subjects were provided written consent for the participation. An ethics approval was obtained from Isfahan University of Medical Sciences Human Research Ethics Committee. Inclusion criteria for PD group were as followed: idiopathic PD, stage 1 to 3 of H/Y scale, use of levodopa and dopamine agonists, MMSE (Mini Mental State Exam (27)) ≥24. Participants were screened to exclude subjects with history of diabetes, orthopedic or any other neurologic disorders, psychological or mental impairment, foot dyskinesia, no corrected visual or auditory deficits, a recent injury or other condition affecting postural control.

Table 1. Demographic characteristics of participants

| Groups          | Age (Year) | Height (Cm) | Weight (Kg) | Sex (Male: Female) |
|-----------------|------------|-------------|-------------|-------------------|
| PD stage 1 (n=19) | 57.58±9.9  | 164.6±6.3   | 76.5±13.8   | 14:5              |
| PD stage 2 (n=6)  | 64.83±8.1  | 168.3±8.1   | 78.0±14.6   | 6:0               |
| PD stage 3 (n=13)| 65.23±9.3  | 159.5±9.1   | 68.5±7.8    | 12:1              |
| Control (n=33)   | 60.47±8.9  | 167.0±7     | 75.7±10.1   | 28:5              |
| P-value          | 0.102      | 0.017       | 0.176       | ---               |

PD: Parkinson`s disease, Difference of groups demographic characteristics considers significant at P-
value $\leq 0.05$. Only the difference of PD stage 3 group and Control group height was significant (P-value = 0.015)

PD subjects were examined in their best ON state (1-2 hour post medication). Individuals were asked to stand on force plate (kistler 50*60 Cm$^2$) with the head facing forwards and a shoulder width stance for 60 seconds, refraining voluntary movements or talking. Foot distance on force plate was consistence in all test trials by drawing footprint for each subject. Test conditions included 4 random states: standing on 1) Rigid Surface with Opened Eyes (RSOE), 2) Rigid Surface with Closed Eyes (RSCE), 3) Foam Surface with Opened Eyes (FSOE), and 4) Foam Surface with Closed Eyes (FSCE) and each condition was repeated 3 times. The participant’s eyes were focused on a "X" target (at approximately eye-level) located 2 m from the center of the force plate during the OE conditions. A 12 cm height latex foam was placed on the force plate for FS conditions by the purpose of proprioceptive manipulation. Proprioceptive signals are less reliable during standing on noncompliant surface (28). Security of PD persons were provided by placing a heavy wide frame like a walker round the force plate and subjects were asked to reach out for it if they were at risk of falling, also one assistant were standing behind them to prevent their falling from posterior. Trials which participants grasped the frame were excluded. The frame was used for tests of healthy subjects too.

Sampling frequency was 120 Hz and data were filtered with a Butterworth low pass filter with cutoff frequency of 10 Hz. Postural stability was measured by linear (Velocity) (29) and non-linear (ApEn) (30-32) COP parameters in AP and ML directions.

COP sway velocity was calculated as below:

\[
\text{(1) Vel X (mm/min)} = \frac{\sum_{i=1}^{n-1} \sqrt{(x_{i+1}-x_i)^2}}{t} \\
\text{(2) Vel Y (mm/min)} = \frac{\sum_{i=1}^{n-1} \sqrt{(y_{i+1}-y_i)^2}}{t}
\]

In present study ApEn was defined as ApEn (m,r,N), where m is the length of compared runs, r is a tolerance, and N is input data points. It was calculated by use of following equation:
\[ \Phi^m = \frac{1}{N-m+1} \sum_{i=1}^{N-m+1} \log C_i^m \]
\[ \Phi^{m+1} = \frac{1}{N-m} \sum_{i=1}^{N-m} \log C_i \]
\[ \text{ApEn}(m, r, n) = \Phi^m - \Phi^{m+1} \]

Since parameters had a normal distribution the parametric Mixed ANOVA 4*2*2 (Group*Vision*Surface) test was applied for final analysis. Significance level for all tests was set at \(\alpha \leq 0.05\). All statistical quantifications were performed using SPSS (v. 16; USA).

Results
All major statistical results are provided in Table 2 and 3.

Velocity:
Mixed analysis of variance showed significant vision (\(P = 0.000\)), surface (\(P = 0.000\)) and group (\(P \leq 0.005\)) effects in both AP and ML directions. Where vision, surface interaction was statistically meaningful in only AP direction (\(P=0.005\)); vision, surface and group interaction was significant in all directions (\(P \leq 0.016\)).

ApEn:
Main effects of vision and surface were significant in AP and ML directions (\(P = 0.000\)) but group effect (\(P = 0.004\)) and vision, surface and group interaction (\(P = 0.002\)) were statistically meaningful in only ML direction. In AP direction two interactions (Surface*Group (\(P = 0.008\)), Vision*Surface (\(P = 0.014\))) were significant.

Table 2. Main and interaction effects of groups, surface and vision on parameters of postural sway
|                  | VelX(mm/min) | VelY(mm/min) | ApEnX  | ApEnY  |
|------------------|--------------|--------------|--------|--------|
| **Vision effect**|              |              |        |        |
| F                | 57.133       | 43.763       | 73.572 | 43.496 |
| P-value          | **0.000**    | **0.000**    | **0.000** | **0.000** |
| **Surface effect**|              |              |        |        |
| F                | 2.702        | 2.018        | 4.287  | 1.689  |
| P-value          | **0.005**    | **0.016**    | **0.008** | **0.008** |
| **Vision*Surface interaction** |              |              |        |        |
| F                | 8.352        | 0.150        | 6.431  | 0.341  |
| P-value          | **0.005**    | **0.016**    | **0.005** | **0.016** |
| **Vision*Group interaction** |              |              |        |        |
| F                | 6.189        | 3.666        | 0.976  | 5.382  |
| P-value          | **0.005**    | **0.005**    | **0.000** | **0.002** |
| **Group effect** |              |              |        |        |
| F                | 4.722        | 7.002        | 2.029  | 4.933  |
| P-value          | **0.005**    | **0.000**    | **0.005** | **0.004** |

VelX: Velocity in Anteroposterior direction, VelY: Velocity in Mediolateral direction, ApEnX: Approximate Entropy in Anteroposterior direction, ApEnY: Approximate Entropy in Mediolateral direction. The amount of P-value ≤ 0.05 is considered significant.

### Table 3. Parameters of Postural Sway in Different Test Conditions

| Group | Test Condition | VelX (mm/min) | VelY (mm/min) | ApEnX  | ApEnY  |
|-------|----------------|---------------|---------------|--------|--------|
| **Control** |                  |               |               |        |        |
| OERS  | 448.28±39.82    | 283.25±37.79  | 0.289±0.021   | 0.160±0.021 |
| CERS  | 535.39±61.47    | 296.14±74.44  | 0.352±0.022   | 0.176±0.024 |
| OEFS  | 924.81±90.54    | 485.32±50.76  | 0.485±0.017   | 0.298±0.023 |
| CEFS  | 1448.00±111.61  | 670.17±64.38  | 0.540±0.013   | 0.391±0.022 |
| **PD1** |                  |               |               |        |        |
| OERS  | 486.93±51.68    | 271.71±49.81  | 0.298±0.028   | 0.152±0.028 |
| CERS  | 658.93±79.77    | 323.05±98.11  | 0.376±0.030   | 0.191±0.032 |
| OEFS  | 1006.00±117.50  | 564.34±66.90  | 0.486±0.022   | 0.344±0.030 |
| CEFS  | 1465.00±144.85  | 784.66±84.85  | 0.541±0.017   | 0.415±0.029 |
| **PD2** |                  |               |               |        |        |
| OERS  | 647.57±91.97    | 358.57±88.64  | 0.401±0.049   | 0.221±0.050 |
| CERS  | 865.62±141.96   | 475.39±174.59 | 0.481±0.053   | 0.278±0.057 |
| OEFS  | 1704.00±209.09  | 857.43±119.05 | 0.507±0.039   | 0.427±0.053 |
| CEFS  | 2160.00±257.76  | 1121.00±151.00| 0.506±0.029   | 0.456±0.052 |
| **PD3** |                  |               |               |        |        |
| OERS  | 743.52±262.48   | 498.10±60.22  | 0.387±0.033   | 0.308±0.034 |
| CERS  | 956.42±96.44    | 833.33±118.61 | 0.430±0.036   | 0.350±0.039 |
| OEFS  | 1402.00±142.05  | 942.44±80.88  | 0.507±0.026   | 0.449±0.036 |
| CEFS  | 1408.00±175.11  | 907.19±102.58 | 0.524±0.020   | 0.443±0.035 |

PD: Parkinson`s disease. OERS: Opened Eyes Rigid Surface, CERS: Closed Eyes Rigid Surface, OEFS: Opened Eyes Foam Surface, CEFS: Closed Eyes Foam Surface. VelX: Velocity in Anteroposterior direction, VelY: Velocity in Mediolateral direction, ApEnX: Approximate Entropy in Anteroposterior direction, ApEnY: Approximate Entropy in Mediolateral direction.

### Discussion
This study examined linear and non-linear features of COP in persons with various stages of PD and age, gender, weight and height matched healthy subjects in varied sensory conditions and demonstrated more COP velocity and ML ApEn in people with PD. Furthermore, we found that PD
population ability to re-weight their dependence upon sensory information in response to changes in surface and visual inputs is not only less than that of healthy individuals but also different in various disease stages.

In the following section, Group effect, Surface*Group, Vision*Surface and Vision*Surface*Group interactions on COP measures will be discussed in details:

Group Effect:
As shown in Figure 1. a, ML ApEn of COP was higher in people with PD in comparison to healthy group without considering subgroups of the studied PD population (p≤0.004). This means that balance system irregularity in individuals with PD is more than healthy age matched subjects and their neuromuscular mechanism is degraded (33). However, the difference of postural control irregularity between each subgroups of PD people with healthy persons, regardless of vision and surface conditions were not significant except for group of subjects with PD stage 3 (Figure 1. a). This finding highlights the importance of sensory challenging condition in quiet stance stability measurement so that early and moderate stages of PD could be discriminated from controls using COP ML ApEn measure. More system complexity and irregularity by the increase of disease severity could be indicative of postural control system decadence during disease progression, which is consistent with a previous study results that showed a positive correlation between COP ApEn values and PD severity, based on UPDRS (Motor) scale (34) ($r^2=0.516$) (9). Similarly, mean values of linear COP parameters (AP/ML COP Standard deviation and Path length) were significantly higher in PD group (H/Y scale:3) and their COP time series showed deterministic dynamic pattern in other investigation, however the non-linear COP parameter was RQA (11). In contrast, another research revealed no significant difference of COP path length between PD people and healthy subjects, of course the PD participants were at early stage of disease (10).

It should be mentioned that postural stability of persons with PD is influenced by disease severity and it relates to On/Off state of subjects at examination time so researches which evaluated PD individuals in their On state and has mentioned the stage of disease are compared in the current study.
According to our study, COP velocity and ApEn in ML direction in participants with PD stage 2 are not different from that of subjects with PD stage 1 and 3; however, individuals with PD stage 1 and 3 differ significantly (p≤0.040) (Figure 1. a, b). This interesting observation points out the progress of PD2 to instability as their balance system irregularity does not increased as much to differ from two end of postural control continuum which is related to PD1 and PD3.

The between group difference of COP velocity in AP direction is significant only between PD stage 2 and control group (p≤0.005) but AP ApEn is not significantly different between them and this could highlights the importance of nonlinear COP analysis for our judgment about standing stability of PD individuals using COP parameters. If we considered the COP linear parameter (COP AP velocity), PD stage 2 persons would be the least stable group in our study, whereas the COP nonlinear measure (COP AP ApEn) shows more normal behavior for them which verifies the result of the clinical balance test (retropoulsion test in PD stage 2 is negative according to H/Y scale).

It could be concluded by the last two paragraphs that COP velocity and ApEn in ML direction are more sensitive than those in AP direction, in detection of quiet stance stability between various stages of PD. Likewise, it has been proposed that increased ML COP sway and COP area in quiet stance with eyes closed could be instability indicators of PD which may serve to quantify a tendency to fall and are highly correlated by disease severity (12).

Surface*Group Interaction:

COP AP ApEn increases significantly in all studied groups by standing on foam surface compared to rigid surface (p≤0.008) although the amount of the increase is more in healthy subjects in comparison to PD participants (surface group interaction effect in control group≥ PD stage 1≥ PD stage 3).

The amount of COP measures changes in studied groups is proportional to weighting changes of sensory senses and their manipulation.

Not only more COP sways velocity but also less increase of ApEn (by going to more difficult conditions and reduction of reliable sensory inputs) are indicators of postural instability in PD population. In fact, the amount of irregularity increase and resulted adjustability potential in mentioned conditions in the
PD people are less than healthy individuals and it decreases by progression of disease (11). In other words, our study shows that PD individuals cannot decrease their reliance on proprioception in response to reduction of reliable proprioceptive inputs although a recent research reported that subjects with PD could re-weight sensory information like age matched healthy individuals and did not find significant correlation between disease severity and impairment of sensory organization (35). However, the mentioned study examined a small sample size of PD (8 participants, H/Y scale mean score: 2 (in On state)) using SOT (Sensory Organization Test) with support surface and visual surround rotations for rendering somatosensation and visual sense inaccurate.

Vision*Surface Interaction:
COP AP ApEn increases by eye closure during standing on both rigid and foam surfaces (0.066 increase p≤0.000, 0.031 increase p≤0.001); however, the amount of this rise is more while standing on rigid surface, approximately twofold (Figure 2. a).
COP AP velocity increases by eye closure during standing on both rigid and foam surfaces (172.89 mm/min increase p≤0.000, 360.08 mm/min increase p≤0.000), however, the amount of this rise is more while standing on foam surface, approximately twofold (Figure 2. b).
It is evident that the behavior of these two linear and non-linear measures of COP following sensory manipulation is not similar and changes in quantity and quality variables of COP movement are in different directions (36, 37). This indicates that non-linear measures would reveal new aspects of the data that were not disclosed by means of the conventional parameters.

Vision*Surface*Group Interaction:
In control group: the increase of COP ML velocity, COP path length in relation to test duration, is significant by eye closure only while standing on foam (p≤0.000) (Figure 3. a). The changes of COP ML ApEn are the same (p≤0.000) (Figure 4. a). Healthy individuals have the capacity of controlled COP sways rising in difficult balance conditions (eye closure while standing on foam) and they control COP sways in not difficult balance conditions (eye closure while standing on rigid surface) properly as these sways do not increase considerably. Indeed, healthy group could react against environmental challenges appropriately which could be the obvious sign of an efficient balance system freedom (16,
In PD stage 1: the increase of COP ML velocity is significant by eye closure only while standing on foam (p≤0.001) (Figure 3. b), whereas COP ML ApEn increases significantly by eye closure while standing on both foam and rigid surface (p≤0.011) (Figure 4. b). Despite the fact that COP linear parameter is similarly influenced by the test condition in PD stage 1 and control group, its nonlinear measure changes in a different manner in mild PD, which could shows subclinical instability in PD stage1. In fact, the balance system is going to pathologic irregularity and gradual deterioration (36). Conversely, a previous research reported no difference of postural sways complexity between individuals with mild PD and healthy adults while standing on rigid surface. Of course, stance surface was not manipulated in this study (26).

In PD stage 2: in the group of individuals having bilateral symptoms but no clinical instability, the increase of COP ML velocity and ApEn following eye closure is significant while standing on foam (p≤0.017) and rigid surface (p≤0.037), respectively (Figure 3. C, Figure 4. c). It should be mentioned that mean value of COP ML ApEn in FSOE condition is 0.42 (0.08 more than same value in PD stage 1 and 0.13 more than same value in control group). The concurrent significant increase of COP ML ApEn and no raise of COP ML velocity by eye closure while standing on rigid surface, increase of irregularity even in undemanding condition, could be interpreted that these subjects seem going to lose their self-control ability. Despite the fact that the amount of postural stability system irregularity in these persons is considerably more than healthy subjects, their complexity change after closing eyes is not significant (while standing on foam). Therefore, one possibility is that the postural sway irregularity in this group of individuals while standing on foam reached the maximum value (i.e., Ceiling effect) and could not be more irregular following eye closure as it would cause problem (39) and lead to observable instability and falling.

In PD stage 3: in the group of PD participants with clinical instability, COP ML velocity increases significantly by eye closure while standing on rigid surface (p≤0.001) and decreases nonsignificantly while standing on foam (Figure 3. d). This strict control of COP sways during standing on foam surface could be due to increase of cocontraction in this stage of PD. COP ML ApEn changes show that COP
complexity and its dynamic pattern of irregularity is intensified in uncomplicated test condition 
(p≤0.023) because of sever impairment of motor control system. However, it could not vary after eye 
closure in difficult test condition as its value is close to end of the irregularity continuum (maximum 
irregularity) (Figure 4. d).

It should be recalled that the amount of COP ML ApEn increase after changing sensory environments 
(eye closure and making vision unavailable, standing on compliant foam and rendering 
somatosenstion inaccurate) is lower in PD individuals compared to healthy participants and it 
decrees concurrent to disease progression (0.093 increase in control group (standing on foam), 0.072 
increase in PD stage 1 (standing on foam), 0.039 increase in PD stage 1 (standing on rigid surface), 
0.057 increase in PD stage 2 (standing on rigid surface), 0.042 increase in PD stage 3 (standing on 
rigid surface)) (Table 3). More irregularity in control group could express higher adaptation capacity of 
healthy postural control system to environmental conditions alteration and sensory challenging 
situations (40); as such, variability not only could not be the instability indicator but also could be the 
refractor of important information about a balance system health (39). The interesting point is that 
this strategy is observed while standing on foam surface (the most difficult test condition) in healthy 
group, on both rigid and foam surfaces in PD stage 1 and only on rigid surface (the easiest test 
condition) in PD stage 2 and 3, which could mean that more sever groups of PD people are challenged 
even in easy balance situations because of their inefficient postural control system and limited 
capacity to face environmental perturbation. The amount of COP ML ApEn in moderate and sever PD 
while standing on foam surface with open eyes is so high that could not increase more by eye closure 
as it might cause clinical instability and falling so these patients show this conservative behavior (not 
significant increase of COP irregularity) in such a high demand condition but its value in mild PD is not 
the maximum in same condition so it would increase by going to more difficult situation. Fear of 
falling could be a reason for such a behavior in individuals with more sever PD (41, 42) which high 
correlation of FES (Falls Efficacy Scale) (43) and H/Y scale scores in this study confirms (p≤0.000, 
Spearman’s Correlation= -0.652). An investigation, using SOT and linear COP measures has 
demonstrated postural instability in those with PD in first three stages of disease, based on H/Y scale,
when in challenging or conflicting sensory conditions necessitating the use of vestibular system (44).

There is a question that how much the optimal amount of variability and complexity is in postural control system. The lack of movement variability lead to abnormal mapping of sensory cortex and motor function would be impaired as a result, whereas adequate amount of variability avoids that abnormal mapping and contributes in needed neuroplasticity for maintenance and achievement of functional skills (39). Thus, it is proposed that optimal movement variability lies between too much variability and complete repeatability (45).

There is some limitations in this study. Firstly, we analyzed the “regularity” of the temporal structure underlying COP trajectories, however, examination of other properties of motor control like dimensionality and local stability (46) in future researches might provide clinically meaningful information in the assessment of balance impairments in people with PD. Also, it should be considered that larger sample sizes across various stages of PD would help interpret the results less cautiously.

Conclusion
As compared to healthy individuals, people with PD demonstrated significantly higher values of COP ML ApEn while standing, indicating more complexity of postural control system. Also the increase of COP ML ApEn in response to environmental challenges was lesser than that of healthy participants, suggesting diminished adaptive capacity of PD people to maintain stance balance. Changes of ApEn due to sensory perturbations give insight about dynamic of postural control system during PD progression and could provide valuable information in the assessment of postural control system in various stages of disease, which might guide clinicians in designing fall prevention exercise programs to reduce risk of falling in this population, additionally help to lower costs in the health care system.

Declarations
Ethics approval and consent to participate An Ethical approval was obtained from Isfahan University of Medical Sciences ethical committee.

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Figures
Figure 1

Group Effect on, a) COP ML ApEn, b) COP ML Velocity. The asterisk indicates significant between group difference (p≤0.05).

Figure 2

Vision*Surface Interaction on, a) COP ML ApEn, b) COP ML Velocity. The dashed line indicates significant difference (p≤0.05). The dotted line indicates more difference (p≤0.05).
Figure 3

Vision*Surface*Group Interaction on COP ML Velocity in a) Healthy individuals group, b) Individuals with PD1, c) Individuals with PD2, d) Individuals with PD3. The dashed line indicates significant difference (p≤0.05).
Figure 4

Vision*Surface*Group Interaction on COP ML ApEn in a) Healthy individuals group, b) Individuals with PD1, c) Individuals with PD2, d) Individuals with PD3. The dashed line indicates significant difference (p≤0.05).