Original Article

THE COMBINED INFLUENCES OF VISUAL INFORMATION, SPATIAL WORKING MEMORY AND PROPRIOCEPTIVE FEEDBACK ON POSTURAL STABILITY OF INDIVIDUALS WITH PARKINSON'S DISEASE : A DOUBLE-BLIND RANDOMIZED CONTROLLED TRIAL

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ABSTRACT

Background and Objectives: Disturbance in the processing of proprioception contributes to characteristic Parkinson's disease (PD) postural instability which can be cited as a fourth core feature of PD in addition to the early emerging gait abnormalities. This study is aimed at measuring the combined influences of visual information, spatial working memory, and proprioceptive feedback on the diminished postural control in PD.
Design: A double-blind randomized controlled trial.
Participants and settings: Twenty six patients with PD participated in this study. They were randomly assigned to either group one (G_1) who received proprioceptive training with task related visual biofeedforward/back using a force platform in addition to a traditional physical therapy program or group two (G_2) who received only the traditional physiotherapy program.
Outcome measures: Rhythmic weight shift, sit to stand and tandem gait examination protocols of the computerized dynamic posturography were used to measure the sensorimotor performance.
Results: Significant improvements were observed ($P \leq 0.05$) in on-axis velocity, directional control, weight transfer, rising index, center of gravity sway, step width, speed, end sway. In G_2 a significant improvement is only observed with sit to stand test.
Conclusion: Long term training based on integrated proprioceptive and spatial visual information has a positive effect on the sensorimotor performance and postural instability caused by the PD. The results also support that motor relearning abilities is retained in subjects with PD.

KEYWORDS: Parkinson's disease; Postural instability; Proprioceptive training; Visual feed forward/back; Motor relearning.

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INTRODUCTION

Postural instability is a major problem of patients with Parkinson's disease (PD) that causes difficulties with transfers, gait disorders, hesitancy to live independently at home and usually leads to frequent falling as well as hospitalization.[1,2,3] A falling rate of about 38% found among 100 PD patients, among these 13% felt down more than once a week, was reported.[4] Effective postural control requires both perception and action. Perception is the ability to detect and integrate sensory information to evaluate the position and motion of the body with respect to the environment while action refers to the body's ability to produce forces for controlling body position.[5] In cases of PD, there is growing evidence that the patho-physiology of movement disorders includes changes in sensory processing as well as a cortically mediated decline in attentional capacity and delay in the motor programming.[6,7,8] Additionally, individuals with PD are dependent on kinesthetic input which affect their ability to maintain balance especially when the eyes are occluded and visual information is lost.[9,10,11]

Several studies have examined the direct effects of biofeedback on balance in healthy subjects and in patients with postural deficits. [6,7,12,13] Auditory [12], vibrotactile [13], or multi-modal feedback increased postural stability in both young and elderly healthy subjects.[6,7] Experiments on this theme employed functionally decorrelated and really non-applicable techniques for inducing auditory, tactile feedback. Moreover, utilization of a moving visual cues or moving body with stabilization of the visual surround during normal stance or walking[17, 18] may induce visual vertigo because of a mismatch between the visual sensation of movement and vestibular and somatosensory inputs.[19] The application of 2 different cues that are not related to a functional task at the same time may divide the patient's attention between the two cues, resulting in a slight decrement in performance[21] or makes the patient hooked to the visual information even if inappropriate. [22]

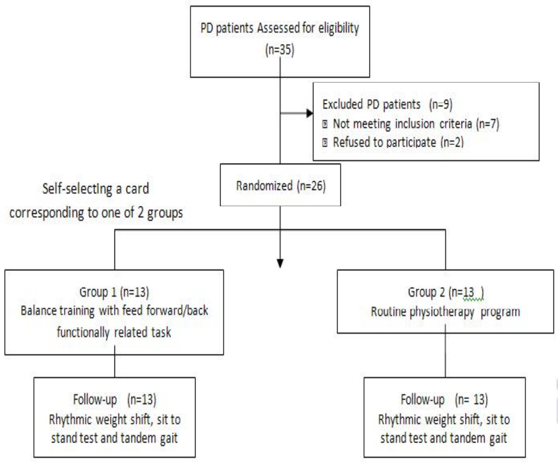
It was suggested that balance training during unperturbed standing has the potential to improve postural corrective responses to unexpected balance perturbation through improved neuromuscular coordination of the involved muscles and adaptive neural modifications on the spinal and cortical levels.[23] A recent study has also shown that gait training performed under functionally related augmented proprioceptive input can improve sensory integrative ability of walking in patients with PD. [24] Moreover, Sidaway et al reported that visual cues was successful in establishing a lasting improvement in gait speed and step length while increasing the stability of the underlying motor control system.[25] On the other hand there are no trials for measuring the effect of an integrated proprioceptive and spatial visual information (Allocentric visual information) on postural instability caused by PD. Stimulated by these multifactorial findings, and the lack of studies that measure the direct effect of an integrated external cues on the postural control of PD we aimed at investigating the effect of training with an emphasis on enhancing task related sensory feed forward/back (visual and proprioceptive) on postural control ability in people with PD.

SUBJECTS AND METHODS

Twenty six PD patients (9 females, 17 males), with age ranging from 45 to 62 years (55.1 ± 4.9 years), represented the sample of the study. The participants were recruited from the Department of Neurology at the Faculty of Medicine, and the Out-patient clinic at the Department of Physical Therapy Neuromuscular Disorders and its surgery, Faculty of Physical Therapy, Cairo University, Egypt. Before signing a participation consent form, the purpose and steps of the study were fully explained to the participants. A clinical neurological assessment was performed by a neuropsychiatrist using the Mini-Exam of Mental Status (MEMS), the Hoehn and Yahr Rating Scale, a motor examination, assessment of activities of daily living using the Unified Parkinson's Disease Rating Scale. All assessments, and treatment were carried out in the morning, in the ''on medication'' state, an hour after participants' first dose of medication. The individuals who suffere from moderate disability according to UPDRS ADL/motor scores with duration of illness ranging from 2 to 5 years and are able to give their informed consent participated in this study. Patients with any of the following criteria were excluded from the study: epilepsy; mental and cognitive impairment; marked rigidity (more than 3 according to the UPDRS rigidity subscale); poor visuo-spatial abilities; dyskinesias; anorexia.[18,19] For all participating subjects, all PD medications were kept stable during the course of the study. The baseline laboratory measurements were done in the same day of the neurological examination followed by randomization. With their eyes closed, the patients were randomly assigned into two equal groups (G_1 and G_2) by self-selecting a card corresponding to one of the 2 groups.

Subjects and examiner were blinded during randomization, except for a nurse who prepared the cards [Figure1]. This study was approved by the research review boards of the Faculty of Medicine, Cairo University, Egypt.

Figure 1: Reporting trials diagram.



Computerized Dynamic Posturography (Balance Master system: Version 7.0.4) of the balance lab located in the Faculty of medicine, Cairo University, Egypt was used for measuring the rhythmic weight shift, a part of the voluntary motor examination protocols, as well as sit to stand (STS) test and tandem Walk (TW) test, parts of the functional limitation examination protocols, for all participants before and after completion of the physiotherapeutic programs. A harness was used to ensure safety for an examinee who is standing on the force plate form facing the system's screen. The rhythmic weight shift test quantifies the participant's ability to rhythmically move his/her center of gravity (COG). The directions are from left to right (lateral) and forward to backward (anterior/ posterior) between two targets. It measures "on-axis velocity" and "directional control" parameters. The test consists of six trials, conducted in the following order left/right, slow (three seconds transitions), left/right, medium (two seconds transitions), left/right, fast (one seconds transitions), forward/backward, slow transitions, forward /backward, medium and forward/backward, fast. Participant was asked to control his/her COG which represented by the cursor on the screen through smooth weight shifting synchronized with direction and speed of the cursor. Sit to Stand (STS) test measures the participants' ability to rise from a sitting to a standing position. The main components of this task include shifting the body's COG forward from an initial position over the seat to a location centered over the base of support, followed by extension of the body to an erect standing position while maintaining the centered COG position. The measured parameters are the weight transfer measured in seconds (sec), rising index measured in percentage, and COG sway velocity measured in degree per second. Tandem Walk (TW) test quantifies the characteristics of gait as the participant walks "heel to toe gait" from one end of the force plate to the other. The test measures the step width measured in centimeter (cm), speed measured in (cm/sec) and end sway measured in degrees per second.

For balance training, we used the Biodex balance training system (System, Balance SD, 230 VAC) of the faculty of Physical Therapy, Cairo University, Egypt. The system is a circular, multi-axial platform which tilt up to 20^{o} in every direction. The platform moves in response to changes in the subject's center of mass. It has six interactive game-like training modes, three of them were used to train subjects shared in this study which are postural stability, weight shift, and the random control. During the first 2 weeks of training, subjects were given a ten minute warm-up and accommodation consisting of tracing predictable patterns by moving the Biodex platform. Subjects then trained for 10 minutes that require less predictable movement patterns. After the second week, the warm- up and accommodation time was reduced to 5 minutes and the stability level of the platform progressively decreased. Subjects were closely guarded during the training and allowed to hold onto the attached handlebars as needed. By the end of the fourth week the accommodation time has been canceled.

The patients in the control group (G_2) were treated with a traditional physiotherapy program conducted by a neurophysiotherapist. This low-intensity exercise program consisted of: Passive prolonged stretch for the calf, hamstring, iliopsoase, pectoralis major and the anterior neck muscles; and concentric/eccentric resistance training to increase the muscle strength of the calf (especially soleus muscle), anterior tibial group, quadriceps, hip abductors, extensors and the back muscle.

Additionally, the functional training included: Standing up and sitting down; turning around using a large arc of movement, or using full body movements, the "clock turn strategy"; traditional gait training including instructions to walk with long steps, even stride length and swinging the arms. The patients were instructed to walk for two times a week for 30 min; focus on maintaining long strides and adequate ground clearance, maintain upright posture by consciously attending to standing upright, and reinforce physiotherapy strategies in the home and community. Participants in both groups attended 45-60 minutes session 3 times per week for 12 weeks for this traditional physiotherapy in addition to 20 minutes of training with Biodex balance system applied only for Participants in G_1.

Data analysis:

The Social Package for Social Sciences (SPSS) version 17.0 (SPSS Inc, Chicago, IL, USA) was used to analyze the data. Descriptive statistics such as means, standard deviations were used to describe the participants' demographic data. Statistical measures of the mean scores and standard deviation were calculated for the baseline and post-intervention for each participant. As there were two groups (balance training /conventional physiotherapy (G_1) and conventional physiotherapy (G_2) and two sets of measurements (pretreatment, post treatment) taken at different times for the rhythmic weight shift (RWS) , Sit to Stand (STS) test and Tandem Walk (TW), we used the paired t-test to show the statistical difference between the two groups in the selected measures at probability level of equal to or less than 0.005 ($p \leq 0.005$).

RESULTS

Twenty-six patients with idiopathic PD participated in the study, their demographic data is represented in table 1. All the 26 randomized participants completed the 12-week training protocols. The participants mean age is 53.84± 5.49 years of age in group one (G_1) and 54.53±5.62 in Group 2 (G_2) , the mean duration of illness in G_1 was 3.15±1.07 and 3.46±1.05 years in G_{-2}. The mean values of UPDRS motor and ADL scores during the "on" state in G_1 were 29.15±2.91 and 22.03±1.65, respectively, and 29.92 ± 3.36 and 21.23 ± 2.89, respectively, in G_2. According to the Modified Hoehn and Yahr staging the PD stage in G_1 is 2.84±0.66 and 2.61±0.42 in G_2. The assessment at baseline showed no significant differences between the participants in the 2 groups with respect to their demographic characteristics (P > 0.05).

Table 1: Participants' baseline characteristics.

Characteristics	Group 1	Group 2
Number	13	13
Age (year)	53.84± 5.49	54.53±5.62
Duration of illness	3.15±1.07	3.46±1.05
PD stage	2.84±0.66	2.61±0.42
ADL *UPDRS*	22.03±1.65	29.92 ± 3.36
Motor *UPDRS*	29.15±2.91	21.23 ± 2.89

The rhythmic weight shift reflects the patients' ability to follow the stimulus in the front/back and Right /left directions. The axis velocity measures the average speed in the intended direction. Training effects on the "on-axis velocity" in "front/back" directions and right/ left directions at different velocities (slow and medium) showed significant differences between the scores measured before and after treatment ($P \leq 0.001$), at the fast speed of the right/ left directions the p value is equal to 0.006. On the other hand a non-significant statistical effect of the conventional physiotherapy program was observed at the three speed of the test, slow (P=0.119), medium (P= 0.066) and fast (P=0.572) in the second group. Directional control measures the amount of extraneous movements present during reaching a target. Comparison of the mean values of directional control in G_1 measured before treatment with the corresponding values measured after treatment revealed a significant difference. The p value at slow and medium speeds of the front/ back and medium and fast speed of the right/ left directions d" 0.001. At the fast speed of the "front/back" directions the p values is 0.006 and at the slow speed of the right/ left directions, it is equal to 0.040. In contrast, there was no significant difference found for any of the speeds of testing the directional control in G_2 . At the slow, medium and fast speed the P= 0.247, 0.325 and 0.256 respectively (Tables 2 and 3).

Weight transfer evaluates the amount of time between the onset of the cue to move and the arrival of the COG over the feet while the rising index evaluates the amount of force exerted by the legs during the rising phase, additionally the center of gravity sway velocity evaluates the percentage of COG sway during the rising action. A significant effect of the balance training with visual feedback was observed in G_1 with a *P≤0.001* additionally in G_2 there is a significant improvement in the sit to stand test but the level of improvement is less than that observed with G_1 (table 4). The *P* values of weight transfer, rising index and center of gravity sway in G_2 are 0.019, 0.041 and 0.003 respectively.

The tandem walk test consists of three measures: the step width which measures the lateral distance between successive steps; speed that measures the velocity of forward progression in addition to the end sway which measures the average anteroposterior sway velocity. Table 5 details the comparison between the studied groups. There is a marked improvement among participants who received balance training with visual feedback P=0.000. on the other hand it is noticed that there is a non-significant improvement in Group 2 in the three subtests of the tandem gait (P= 0.454, 0.227 and 0.096).

Table 2: Rhythmic weight shift (RWS) test of the Back/Forward direction measured before/after treatments (mean ± standard deviation).

	Slow			Medium			Fast		
Group 1	Pre	Post	P	Pre	Post	P	Pre	Post	P
On-axis velocity	1.53±0.59	3.58±0.76	0.001	1.69±0.76	3.32±0.58	≤0.001	1.63±0.56	5.78±1.14	≤0.001
Directional control	44.77±8.66	59.25±8.39	0.001	32.91±6.47	40.86±5.48	≤0.001	38.42±6.92	48.28±8.16	≤0.005
Group 2									
On-axis velocity	1.67±0.49	1.93±0.43	0.119	1.53±0.27	1.67±0.11	0.066	1.44±0.58	1.85±0.34	0.572
Directional control	45.75±7.88	47.00±7.99	0.132	33.82±7.97	33.02±4.28	0.747	38.42±4.85	38.04±4.85	0.776

The on-axis rotation is represented in degree per second and Directional control is represented as percentage P is significant at P < 0.05.

Table 3: Rhythmic weight shift (RWS) test of the Right /left direction measured before/after treatments (mean ± standard deviation).

	Slow			Medium			Fast		
Group 1	Pre	Post	P	Pre	Post	P	Pre	Post	P
On-axis velocity	1.60±0.55	2.96±0.48	≤0.001	2.95±0.46	3.52±0.45	≤0.001	2.54±0.64	3.18±0.69	0.006
Directional control	45.56±5.01	47.87±1.9	0.04	50.55±2.92	57.28±2.54	≤0.001	48.98±4.43	55.59±3.19	≤0.001
Group 2									
On-axis velocity	1.68±0.44	1.95±0.56	0.085	2.78±0.81	3.05±0.39	0.146	2.55±0.69	2.74±0.56	0.472
Directional control	48.66±49.04	49.04±1.85	0.247	49.87±4.17	49.24±5.49	0.325	47.91±6.49	48.86±3.90	0.256

The on-axis rotation is represented in degree per second and Directional control is represented as percentage P is significant at P ≤ 0.05.

Table 4: Sit to stand test in both groups measured before/after treatments (mean ± standard deviation).

	Group 1			Group 2		
Test	Pre	Post	P	Pre	Post	P
Weight transfer	2.47±0.67	1.17±0.49	≤0.001	2.68±1.03	1.788±0.38	0.019
Rising index	5.88±1.47	15.17±3.43	≤0.001	6.08±1.64	7.69±1.27	0.041
Center of gravity sway	1.29±0.48	7.66±1.93	≤0.001	1.35±0.58	2.12±0.41	0.003

Weight transfer is represented in seconds, rising index is represented as percentage and Center of gravity sway is represented as degree per second. P is significant at P ≤ 0.05.

Table 5: Tandem gait in both groups measured before/after treatments (mean ± standard deviation).

	Group 1			Group 2		
Test	Pre	Post	P	Pre	Post	P
Step width (cm)	16.07±3.22	10.84±1.53	≤0.001	15.47±3.03	15.02±2.28	0.454
Speed (cm/sec)	13.67±1.78	19.16±1.56	≤0.001	14.13±2.35	14.96±2.07	0.227
End sway(°/sec)	7.05±1.77	4.55±0.84	≤0.001	6.88±1.64	5.92±0.49	0.096

P is significant at P ≤ 0.05.

DISCUSSION

The results of this study show the positive effect of manipulating sensory information under a condition of task related enhanced feed forward/ back on increasing postural stability in participants with PD. This can be attributed to the effect of the allocentric visual information or spatial working memory. The allocentric visual information refers to the ability to identify a target location relative to some other landmarks in the visual field, which in turn provides additional information about the location relative to the self, and improve the visual memory. As we used a long term training program (12 weeks), the PD subjects are able to remember and reproduce accurate motor performance in the functional tasks related to the postural control. This agrees with previous researches postulating that increased exposure to target sensory stimuli can improve the accuracy of matching performance [26,27,28] and that PD patients preserve the ability to learn new postural tasks. [29] Holschneider et al, stated that in cases of PD, functionally related external cues and long term exercise training increase the efficiency of neural processing (sensorimotor cortex, striatum, vermis) as well as the plastic changes of the brain.

The results of this study can be also attributed to the effect of the movable force platform on increasing the lower extremity proprioceptors and vestibular input. It rhythmically stimulates pressure load receptors of the feet, muscle spindles, and Golgi tendon organs of the leg muscles especially the soleus in addition to those of the neck muscle as well as the vestibular input monitoring the head position in space. [31, 32] These rhythmic inputs are transferred to neuronal circuits and increase the strength of inputs converging on pyramidal tract neurons[33] and stimulate the frontal-lobe cognitive strategies (working memory). This agrees with Campos-Sousa et al.[32] and Wegen et al. [33] These studies showed that frontal lobe areas can select a motor program in response to an external stimulus, and send it to the primary motor cortex, which is responsible for the execution of sequential movements. Additionally, Holschneider et al., [30] used brain imaging, to show that there are increases in perfusion in the prefrontal cortex, deep cerebellar nuclei, thalamus, and hippocampus, which compensate for a functionally disrupted BG, which support our findings.

The improvement in the PD postural control in the present study can also be ascribed to the effect of external cues on activating an alternate pathway involving the cerebellum, sensorimotor cortex, and lateral premotor cortex.[34,35] In this pathway, the cerebellum is responsible for movement timing, and the premotor cortex may be responsible for scaling the motor activity when facilitated by somatosensory cues related to the task. This means that the recruitment of these structures can compensate for an inefficient BG in PD.

Furthermore, the cerebellum has been shown to be an important neural module to integrate multiple sensory information from visual, vestibular, and somatosensory components in order to execute vestibular spinal reflex to assist postural control.[36] Therefore, the people with impaired BG might learn to integrate visual and vestibular information more efficiently through the cerebellum, which then would influence the brain stem and spinal cord to improve postural control.[37,38] It was also ascribed the improvement in PD patients' motor performance in response to external cues to the dominancy of the cerebellar-cortical pathways [39,40] which processes externally generated tasks with minimal recruitment of the BG-cortical circuitry.

A non-significant difference between base line measurement of the rhythmic weight shift and tandem gait was recorded. This can be attributed to the lack of the task oriented training in the traditional physical therapy program. Moreover, the postural muscle strengthening without functional training is not sufficient for improving postural responses. This is in close agreement with a previous study that claim that Cued task-specific training is better than exercise in improving motor performance in patients with Parkinson's disease.[41] On the other hand, this is not consistent with Dibble and colleagues who reported that Muscle force, bradykinesia, and quality of life were improved to a greater degree in those that performed high intensity eccentric resistance training compared to an active control group.

A significant difference was recorded in the second group between the baseline and follow up measures of the sit to stand test. This can be ascribed to the effect of the long term training of such task found as a functional training of the physiotherapeutic program on the PD patients to learn motor tasks based on external feedbacks. This is consistent with the results reported by Rochester et al.,[29] who stated that cued training would increase motor learning. Furthermore, it is demonstrated that externally cued practice over more extended periods (3–6 weeks) show significant benefits of training with a range of different external cues on gait, balance and transfers.[24]

Limitations

An important limitation of this study was the small sample size. Nevertheless, we were able to the show benefits of using external cues on the postural control of the participants of PD. Another limitation was the transportation between the faculty of physical therapy and the Kasr-Al-Aini hospital which consumed plenty of time and limited the number of participants.

CONCLUSION

Functionally related feed forward/ back improves parkinsonian directional control, weight transfer, rising index, center of gravity sway, step width, speed and end sway components of postural control. Further studies for PD patient's postural control within the modern virtual reality labs is one of the great projects for the future as they provide a simulation to the real life situations, real time analysis and biofeedback.

Conflicts of interest: None

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