Effects of Exergame Balance Training of Different Complexity on Cognitive Performance in Patients With MCI

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Abstract
Combining balance and cognitive training of different complexities through exergame balance training might train cognitive abilities in a better way in patients with mild cognitive impairment. The objective is to determine the effects of exergame balance training of different complexities on cognitive performance in patients with mild cognitive impairment (MCI). The methodology was a double-blinded, four-armed parallel design, Randomized Clinical Trial. Ninety-seven participants with mild cognitive impairments MoCA (18-24), between the ages of 50 and 75 years, participated in the planned physical and computer-based cognitive training and were randomly assigned to one of four exergame balance training groups (mild complexity, moderate complexity, high complexity, and control). Participants received three sessions per week for eight weeks. The assessment was conducted through Stroop A, B, C, and error at Stroop A, B, C at baseline, after the 4th and 8th week. The mixed model analysis of covariance while fixing the baseline values as a covariate was used to determine interaction effects between interventions and time. Post hoc analysis was performed to investigate between groups differences. A significant interaction effect of group and time was observed in Stroop C $p=0.032$, Errors at Stroop B $p=0.007$, and C $p=<0.001$. A significant difference between moderate and high complexity groups with the control group was observed ($p<0.05$). The results indicate that exergame balance training of moderate and high complexity influences cognition abilities to a greater extent.

Keywords: Balance, Cognition, Complexity, Exergame, Executive Function, MCI

1. Introduction

Mild cognitive impairment is an intermediate stage between dementia and normal aging (Mascitelli & Pezzetta, 2006) The prevalence of cognitive impairment is increasing globally with significant personal, social, and economic consequences (Larson, 2010). Literature suggests that early intervention of MCI can retain, delay, or enhance cognitive performance (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008). Physical exercises led to having promising effects on cognitive functions in healthy older adults in adults with dementia and MCI (Angevaren et al., 2008; Kramer & Colcombe, 2018; Yao, Fang, Leng, Li, & Chang, 2021). Accumulated evidence has shown that physical exercise is associated with several cognitive benefits (Christie et al., 2008; Voss et al., 2010) including improved executive function, attention, and processing speed (Kramer & Erickson, 2007). These skills are essential for preserving independence and delaying institutionalization but are frequently compromised by cognitive decline (Pesce, 2012).

Aerobic training affects neuroplasticity and cognition in a general manner by improving cardiovascular capacity and blood supply to the brain (Voelcker-Rehage, Godde, & Staudinger). Strength training, which includes repetitive movements of specific intensity, affects metabolic processes that alter neuroplasticity and cognition (Carey, Bhatt, & Nagpal, 2005). A specific level of muscular effort, frequency, and duration is required to initiate the neuroplasticity for aerobic and strength training (Kelly et al., 2014). There is a growing body of evidence that balance training significantly influences cognition (Ries, Hutson, Maralit, & Brown, 2015; Shubert, McCulloch, Hartman, & Giuliani, 2010) Balance training is considered to be task-specific and directly increases brain neuroplasticity and cognitive ability and stimulates informational processing to a greater extent as compared to other types of training (Rogge et al., 2017a). Balance exercise places a high demand on the vestibular system as there is a connection between vestibular nuclei, cerebellum and hippocampus, parietal cortices, and prefrontal cortex (Ide et al., 2022). For balance training, it is the neurocognitive demand and task complexity that increases the attentional demand and affects neuroplasticity and cognition (Rogge, Röder, Zech, & Hötting, 2018) (Netz, 2019). Balance training on a stable surface and an unstable surface can stimulate the vestibular system and neural pathway to a different extent. A stable surface is considered to be less challenging; it requires less attentional demand as compared to an unstable surface. If it is required to provide more challenging balance training then balance training on an unstable surface is superior to stable surface training concerning neurocognitive demand. However, the data regarding the effects of different types of balance training on memory, attention, Processing speed, and cognitive flexibility is rare so far.

Although all these interventions are effective for cognitive enhancement, especially in older adults with cognitive decline, the challenge for these types of exercises is to motivate older adults to meet a minimal level of activity to bring about the required changes. Keep to the patient's engagement towards these exercises, Exergame training or video games training is considered to be effective cognitive training as it has better potential to gain cognitive benefits (Anguera et al., 2013). The level of motivation of patients by these Exergame training is proven to be effective for cognition (Lopes & Argimon, 2016) (Toril, Reales, & Ballesteros, 2014) Literature suggests that Exergame training can improve processing speed, attention, and reaction time to a greater extent, especially in individuals with the risk of cognitive decline (Toril et al., 2014).

This MCI population demonstrated a significant effect of combined training on neurophysiological parameters by increasing the mental challenge through combined intervention (Ballesteros, Voelcker-Rehage, & Bherer, 2018) (Rahe et al., 2015). Balance training was done in combination with other training eg, and resisted training also showed a beneficial effect on general cognition (Dorner et al., 2007) (Greblo Jurakic, Krizanic, Sarabon, & Markovic, 2017). Few studies have been conducted to compare the effects of conventional balance and Exergame training; these studies suggested that both trainings modulate the physical and cognitive outcomes differently. Exergame balance training is superior to conventional balance training in attaining physical and cognitive outcomes (Eggenberger, Wolf, Schumann, & De Bruin, 2016; Schättin, Arner, Gennaro, & de Bruin, 2016). Balance training in conjunction with virtual reality training has also been conducted in young and older adults (Anders, Bengtson, Grønvik, Skjæret-Maroni, & Vereijken, 2020). Despite existing knowledge that cognitive benefit with combined balance and Exergame training is superior to conventional balance training. The type and level of complexity of Exergame balance training that best promotes these adaptations remains to be elucidated. This study aims to explore the difference in cognitive improvement through different complexity levels.

2. Methods

2.1 Design and Setting

This randomized clinical trial (RCT) was conducted at Riphah Rehabilitation and Research Center of Pakistan Railway General Hospital, Rawalpindi, from September 2021 to December 2022. The RCT was registered with ClinicalTrials.gov clinical trial registry (NCT04959383). This study was approved by The Ethical Review Committee of Riphah International University, Islamabad, Pakistan.

2.2 Participants

Patients were recruited from Pakistan Railway General Hospital. Initial Screening was completed based on MoCA (Urdu Version), patients with MoCA range from 18-25 were recruited in the study. Patients of either gender, between the ages of 50 and 75 years, who were able to see and hear sufficiently to participate in planned physical and computer-based cognitive training were recruited in this study and were able to stand for 30 seconds with eyes open and eye close on a stable surface (50). Patients who were participating in any other cognitive training, participating in > 150 min/week of planned exercise of any kind, who were non-ambulatory or with major mobility disorder, history of dizziness patients with other neurological conditions, with any musculoskeletal impairment, virtual game phobia, and were excluded from this study.

2.3 Sample Size

The sample size was calculated by using G-power software, based on the effect size of MoCA from the previous study (Binns, Kerse, Peri, Cheung, & Taylor, 2020), the calculated sample size was 90 participants. To compensate for the loss of follow up total of 97 participants were recruited in this study.

2.4 Interventions

These trainings were provided 3 times per week for 8 weeks. The experimental group received the Exergame balance training on a wobble board. The experimental group was further categorized into three different groups according to the level of difficulty of the exercise with mild, moderate, and high levels of complexity respectively. The intervention was provided through a specially designed football mobile game with inbuilt different difficulty levels. The difficulty levels were selected by adjusting the size of the goal and the speed of the ball.

Each group received a 40-minute training session three times per week. Exergame balance training for 30 minutes, 5 min of stretching at the start and end of the session to warm up and cool down. The assessment was done at baseline, after 4th week, and 8th week.

2.4.1 Experimental Group Training and Setup

The experimental group received the Exergame Balance Training on a custom-made wobble board, able to rock in all directions with a mobile placed on the center of the balance board and connected to the Laptop, and from the laptop to the LED. The movement of the wobble board is incorporated with the movement of the ball in the game, movement of the wobble board moved the ball in the game. The complexity of the training is introduced by reducing the size of goal and increasing the speed of ball.

2.4.2 Control Group Training and Setup

Participants in the control group receive Exergame balance training on Wii Fit (stable surface). The first session was scheduled after the training session to develop an understanding of the treatment protocol. Electronic sensors, on the platform, detected position and were used to provide participants with real-time visual feedback. Each treatment session consisted of 40 minutes of training 3 times per week for 8 weeks. The participants performed three sets of balance games including soccer heading, table tilt, and penguin slide. Each 40-minute session included 5 minutes of stretching at the start and end of the session. The games used for intervention were soccer heading, penguin slide, and table tilt.

2.5 Randomization and Blinding

Following the baseline assessment, the randomization was carried out by the lottery method into groups (A=mild complexity group, B= moderate complexity group, C= high complexity group, D= control group). The patient received the allocated intervention. All participants, and outcome assessors, were kept blinded about group allocation.

2.6 Measurement of Cognitive Functions

Montreal Cognitive Assessment (MoCA) was used as a screening tool, it is a valid and reliable tool to estimate the severity of different cognitive domains (Ciesielska et al., 2016). Individuals with MoCA scores of 18-25 out of a total of 30 scores were recruited in the study. The Stroop color test is a valid neuropsychological test, that was used to evaluate a person's capacity to inhibit automatic or prompt reactions as well as selective attention and processing (Lansbergen, Kenemans, & van Engeland, 2007). Each participant practiced a trial run to develop an understanding of the test. Colored squares (red, green, blue) were presented in rows first (Stroop A), followed by those color words typed in black ink (Stroop B), followed by incongruent color words (Stroop C; in which participants will be asked to name the color of the ink while ignoring the written word). The number of errors while performing Stroop A, B, and C were also recorded.

2.7 Statistical Analysis

In this study, 97 patients were enrolled. The null hypothesis for the analysis was that there was no difference in cognition measured with Stroop A, B, C Test, Errors at Stroop A, B, C between the wobble-based Exergame balance training of different complexity groups versus stable surface Exergame balance training group.

SPSS ver. 26 was used for analysis. Mixed models' analyses of covariance were used separately. To account for potential baseline differences for each model, the pre-randomization baseline score was fixed as a covariate (De Boer, Waterlander, Kuijper, Steenhuis, & Twisk, 2015; Twisk et al., 2018). The fixed effects consisting of group, time (a factor indicating 4 weeks and 8 weeks), their interaction, and a random intercept effect for participants were determined.

3. Results

One hundred and sixty-two participants were assessed for eligibility. twenty-eight didn't meet the inclusion criteria and sixteen were not willing to participate. Ninety-seven MCI adults agreed to participate in this trial. Ninety-two participants completed 4 weeks (mid-assessment) (n=23 in mild, n=22 in complexity, n=24 in high complexity, n= 23 in the control group) Eighty-seven participants completed 8 weeks (final assessment) (n=21 in mild, n=21 in moderate, n=23 in high complexity, n= 22 in the control group).

The analysis doesn't consider the intention to treat analysis because of a clear description of the reason for dropouts. The dropout reasons were not associated with the type of intervention. During the trial, there were no adverse events or harm was reported. There were 76 males and 21 females in this study.

3.1 Interaction Effects

Significant time x group interaction was observed for Stroop C and errors in Stroop B and C ($p < 0.05$). No significant interaction was found for Stroop A, B and errors in Stroop A($p > 0.05$).

Table 1: Interaction effects (time × intervention)

Outcome	Level of Assessment	Groups				Interaction Effect	η^2 F(df)	Between group
		Mild	Moderate	High	Control	p-value		p-value
Stroop A	Pre	0.56±0.42	0.64±1.01	0.45±0.32	1.62±1.49	0.629	0.003 (1,3) =0.235	<0.001
	Mid	0.65±1.05	0.60±1.04	0.51±0.66	1.49±1.51			
	Post	0.59±1.03	0.37±0.24	0.39±0.43	1.57±1.59			
Stroop B	Pre	1.76±1.28	1.67±0.90	1.59±0.77	1.51±0.86	0.166	0.026 (1,3) =0.317	<0.001
	Mid	1.39±0.92	1.46±0.97	1.32±0.52	1.60±0.94			
	Post	1.30±0.74	1.15±0.67	1.12±0.41	1.51±1.26			
Stroop C	Pre	0.90±0.42	0.89±0.54	0.73±0.36	1.00±0.61	0.032*	0.062 (1,3) =4.788	<0.001*
	Mid	0.64±0.33	0.76±0.38	0.64±0.36	0.90±0.41			
	Post	0.64±0.37	0.64±0.32	0.53±0.27	0.89±0.51			
Stroop A Errors	Pre	0.45±0.91	1.04±2.32	0.55±1.76	2.26±3.28	0.001	0.149 (1,3) =12.585	<0.001*
	Mid	0.18±0.66	0.62±1.91	0.77±2.35	1.86±3.45			
	Post	0.14±0.65	0.35±1.57	0.57±2.21	1.79±3.07			
Stroop B Errors	Pre	2.96±3.30	2.09±3.40	4.50±4.04	2.48±2.78	0.007*	0.097 (1,3) =7.729	<0.001*
	Mid	1.58±2.74	1.45±2.54	2.72±2.51	1.64±2.04			
	Post	1.40±2.21	1.15±1.98	0.95±1.32	1.74±2.07			
Stroop C Errors	Pre	1.30±2.42	1.81±3.67	2.00±2.67	1.48±1.95	<0.001*	0.200 (1,3) =17.981	<0.001*
	Mid	0.77±1.77	0.85±1.98	1.18±1.76	1.59±2.04			
	Post	0.90±1.84	0.95±1.79	0.29±0.72	1.26±1.94			

Table 1 presents mean±SD at pre, mid, and post-levels. Mixed ANCOVA while fixing the baseline values as co-variate, was applied to determine Interaction effects (time × intervention). Significance level (*$p<0.05$).
Abbreviation: MoCA, Montreal Cognitive Assessment.

3.2 Group Complexity Level Differences

A significant difference in group complexity was found for Stroop B, and errors in stroop C ($p<0.05$) with more significant difference in improvement were observed for high complexity and control group.

Table 2: Post-hoc analysis for group complexity level differences

Outcomes	Parameters	GROUPS					
		Mild – Moderate	Moderate - High	Mild - High	Mild – Control	Moderate – Control	High – Control
Stroop A	Mean Difference± SE [95% CI]	0.14±0.14 [-0.14-0.41]	0.01±0.14 [-0.27-0.29]	0.15±0.14 [-0.12-0.41]	0.17±0.16 [-0.15-0.49]	0.31±0.15 [0.01-0.62]	0.16±0.16 [-0.16-0.49]
	P Value	0.316	0.961	0.286	0.295	0.049	0.313
Stroop B	Mean Difference± SE [95% CI]	-0.02±0.14 [-0.29-0.26]	0.05±0.14 [-0.23-0.32]	0.03±0.13 [-0.24-0.29]	-0.36±0.14 [-0.63-0-.08]	-0.34±0.14 [-0.62--0.06]	-0.38±0.14 [-0.65--0.12]
	P Value	0.892	0.736	0.838	0.011	0.018	0.006
Stroop C	Mean Difference± SE [95% CI]	-0.06±0.08 [-0.21-0.09]	0.02±0.08 [-0.14-0.17]	-0.04±0.08 [-0.19-0.11]	-0.10±0.08 [-0.26-0.05]	-0.16±0.08 [-0.32- - 0.01]	-0.12±0.08 [-0.28-0.04]
	P Value	0.452	0.851	0.563	0.194	0.040	0.135
Stroop A Errors	Mean Difference± SE [95% CI]	-0.11±0.26 [-0.62-0.41]	0.11±0.26 [-0.41-0.64]	0.01±0.25 [-0.50-0.51]	-0.27±0.27 [-0.81-0.27]	-0.17±0.28 [-0.72-0.39]	-0.28±0.28 [-0.83-0.27]
	P Value	0.679	0.667	0.979	0.315	0.553	0.311
Stroop B Errors	Mean Difference± SE [95% CI]	-0.12±0.45 [-1.00-0.78]	0.36±0.45 [-0.53-1.26]	0.25±0.43 [-0.62-1.11]	-0.34±0.45 [-1.23-0.55]	-0.22±0.63 [-1.13-0.69]	-0.58±0.45 [-1.48-0.31]
	P Value	0.796	0.422	0.572	0.451	0.63	0.197
Stroop C Errors	Mean Difference± SE [95% CI]	0.26±0.31 [-0.36-0.88]	0.14±0.31 [-0.48-0.75]	0.14±0.31 [-0.48-0.75]	-0.58±0.31 [-1.20-0.04]	-0.85±0.32 [-1.48-0-.21]	-0.98±0.31 [-1.59--0.37]
	P Value	0.404	0.660	0.660	0.064	0.010	0.002

Table 2 presents the mean difference±SE and 95% confidence interval between mild, moderate, and high complexity groups and with the control group. Significance level (*$p<0.05$). Abbreviation: MoCA, Montreal Cognitive Assessment

4. Discussion

This study compared the effects of wobble board-based Exergame balance training (unstable surface) of mild, moderate, and high complexity on executive functions in patients with MCI. It was hypothesized that wobble board-based Exergame balance training affects executive functions differently as compared to stable surface Exergame balance training. While comparing the difference in improvement between wobble board-based Exergame balances training of different complexity, significant group × time interaction was found between Stroop C, Errors at Stroop B and C, while post hoc comparisons between different groups showed that a statistically significant difference with a higher effect size was found between the moderate and high complexity group with control group. This study affirms the hypothesis that Exergame balance training on unstable surface with increased complexity is effective in improving cognitive functions in patients with MCI.

The present study supports the findings of prior studies that balance training has a positive impact on cognition. Balance training improves cognition by engaging the vestibular system, which plays a vital role in cognitive processing and orientation by detecting linear acceleration during physical activity (de Oliveira Silva et al., 2019; Rogge et al., 2017b). The vestibular system exhibits diverse anatomical connections to the cortical centers that are involved in cognition including the vestibule-thalamo-cortical pathway dorsal tegmental nucleus pathway via lateral mammillary nucleus, the anterodorsal nucleus to the entorhinal cortex, a pathway through the nucleus reticularis pontis oralis to supra mammillary nucleus and medial septum to the hippocampus; and a potential pathway from the vestibular system via cerebellum and ventral nucleus of the thalamus to the parietal cortex (Hitier, Besnard, & Smith, 2014; Smith et al., 2010). The complexity of balance training is believed to induce plastic changes along the vestibular pathway ultimately enhancing cognition. It is already suggested that balance training with computerized cognitive training is effective in increasing cognitive performance in the elderly (Anders et al., 2020; Taheri & Irandoust, 2017).

To researcher knowledge Exergame balance training of different complexity is not compared previously in patients with MCI. In the current study, interactive Exergame balance training was provided on unstable surfaces and stable to assess improvement in executive functions. Participants were required to simultaneously maintain reactive postural control while playing the Exergame displayed on the frontal screen in a precise and coordinated manner. The multiple levels of difficulty further provided progressive challenges to cognitive abilities. The rationale behind this approach lies in the simultaneous stimulation of the cortical neural pathway through balance and Exergame training of varying complexity may stimulate the aforementioned pathway to a greater extent, and improve connectivity and cognition to a greater extent. Notably, previous research by Barcelos et al. and Ji Z et al. has shown that cognitive benefits derived from exergame training are directly related to the level of cognitive challenge or training intensity (Barcelos et al., 2015) (Ji, Feng, Mei, Li, & Zhang, 2019). The collective finding supports the notion that engaging in exercises with greater cognitive load likely results in enhanced brain connectivity and cognition. Exercise with greater cognitive load likely results in improved brain connectivity and cognition. Therefore, the present study expands the insight into the effects of Exergame balance training with varying cognitive complexities on individuals with MCI, potentially contributing valuable knowledge to the scientific community in this domain.

In the present study, the improvement was observed in various cognitive domains, specifically in Stroop C, and errors in Stroop B and C tests respectively. These findings are consistent with the findings of Ann Kathrin et al., who concluded that balance training can enhance spatial cognition. Additionally, Zhiguang Ji et al. observed improved performance in the Stroop task.

Future research should consider the complexity levels to be more distinct, using more sensitive cognitive assessment tools, and investigating longer intervention periods to further elucidate the effect of exergame training on cognitive function.

Future studies should consider modifying the complexity levels to be more distinct, employing more sensitive cognitive assessment tools, and exploring longer intervention periods to further elucidate the impact of exergame training on cognitive function.

5. Conclusion

The present study concluded that there is a positive effect of exergame balance training on selective attention and processing speed with more pronounced improvement with high complexity levels. Furthermore, the applicability of the results from the present study in patients with Alzheimer's disease should be explored.

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