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The Impact of Cognitive Rehabilitation on Improving Executive Functions and Brain Flexibility in Diabetic Patien

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ABSTRACT

This quasi-experimental study examined the impact of computer-based cognitive rehabilitation on executive functions and brain flexibility in patients with diabetes. Thirty diabetic patients attending a diabetes clinic in Yazd were randomly assigned to intervention (n=15) and control (n=15) groups. The intervention group received 10 sessions of Attentive Rehabilitation of Attention and Memory (ARAM) over four weeks, while the control group received routine clinical care. Executive functions and brain flexibility were assessed at pre-test, post-test, and one-month follow-up using the Wisconsin Card Sorting Test. Mixed analysis of variance showed significant improvements in categories correctly sorted and reductions in perseverative errors in the intervention group compared to controls at post-test and follow-up. These findings indicate that structured cognitive rehabilitation can enhance executive functioning and brain flexibility in diabetic patients, potentially mitigating diabetes-related cognitive deficits.

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KEYWORDS:
Diabetes mellitus; Cognitive rehabilitation; Executive functions; Brain flexibility; Wisconsin Card Sorting Test; Computer-based training

INTRODUCTION

Diabetes is a chronic disease characterized by impaired insulin secretion and elevated blood glucose levels[1]. It is a modern epidemic and it has been shown to lead to a range of cognitive impairment such as dementia which has been declared a global challenge. It is therefore worthwhile to investigate the impact of diabetes on cognitive functions. [2] Although effective screening for various complications of diabetes is routinely performed, the impact on higher mental functions such executive ability is often overlooked.[3]

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Cognitive abilities and executive functions such as attention, working memory, and processing speed are severely influenced by diabetes [4]. Diabetes is also associated with reduced productivity; it also affects learning, efficiency, and psychomotor coordination speed [5]. Some studies have shown significant differences in the processing speed performance between diabetic and non-diabetic groups [6]. In line with this, several MRI techniques were utilized to determine the biochemistry and structure of the brain in diabetic patients and showed that a history of hyperglycemia was associated with increased diffusion in the frontal-parietal lobe and hippocampus [7] Evidence suggests that executive functions are correlated with short-term and long-term metabolic control [8]. Studies have shown that executive functions are being regarded as an umbrella term with a wide range of cognitive processes and behavioral competencies including verbal reasoning, problem solving, planning, sequencing, the ability to sustain attention, resistance to interference, utilization of feedback, multitasking, cognitive flexibility, and the ability to deal with novelty[2,3,7]. In addition, deficits in executive functions have been linked to many mental disorders, such as attention deficit hyperactivity disorder, schizophrenia, Alzheimer's disease, and autism [9,10]. Recent research suggests that psychological and cognitive interventions may help improve diabetes outcomes[11]. Cognitive interventions can be divided into two parts: one is cognitive enhancement, which increases a person's cognitive abilities above the level required for daily life activities, and the other is cognitive rehabilitation, which seeks to improve the emotional, social, and cognitive impairments caused by brain damage. Cognitive rehabilitation uses the following methods to achieve functional changes: consolidation, reinforcement, reconstruction of learned behavioral patterns, stabilization of new patterns of cognitive activity, and compensation of damaged nervous system functioning[12,13]. Restoration-based cognitive rehabilitation conventionally involves a set of tasks for specific cognitive. functions such as memory, attention, problem solving, etc. Tasks may include paper-and-pencil exercises, computer-based exercises, or similar daily activities, starting with simple levels and progressing to more complex ones. At the beginning of the task in a specific cognitive area (for example, attention), the exercise is done with constant practice and repetition; when a person succeeds in completing the task at all levels, from simple to complex, the higher level functions are strengthened [14]. The main purpose of cognitive rehabilitation can be defined as helping individuals with disabilities and brain disorders to achieve a desired level of health and reduce the effects of disorders on their lives [15]. This study aims at investigating the effect of cognitive rehabilitation using computer-based exercises on executive function and brain flexibility in patients with diabetes. It is anticipated that rehabilitation may be able to reduce deficiencies in some cognitive aspects of these patients.

MATERIALS AND METHODS

Study Design

A quasi-intervention method with a pretest-posttest control group design was used for this studyi in 2022 and applied permission from the Ethics Committee of Yazd University of Medical Sciences (IR.SSU. SPH.REC.1401.160).

Setting and Participants

The study population was selected among the diabetic referring to the Clinic of diabetic in Yazd .The participants were voluntarily selected by a using a convenience sampling method by considering inclusion criteria consisting of age 65 years and Lower, ability to read and write, having a diagnostic record in the treatment center,not having a medical or psychiatric disorder, and not having a history of stroke or cognitive impairment .Exclusion criteria included unwillingness to resume the research, , absence of more than two sessions, using antidepressants and anticonvulsants, being hospitalized during the study, and death.

Sample Size

According to the research past and the mean±SD of varibles by considering the first error type of 0.05, the power of 0.80 the eventual number of participants in each group was determined to be 15. Thirty patients with diabetes were randomly divided into intervention (n = 15) and control (n = 15) groups. The intervention group consisted of 8 men and 7 women and the control group made up of 9 men and 6 women.

$$N = \frac{\left(Z_{1-\alpha/2} + Z_{1-\beta}\right)^2 (\sigma_1^2 + \sigma_2^2)}{(m_1 + m_2)^2}$$

Measurements

<u>1-data gathering form</u>

The first tool was the data gathering form which included the variables of age, sexuality, , level of education and diabetes.

<u>*2*- Wisconsin card sorting test (WCST)</u>

The Wisconsin Card Sorting Test (WCST) has been increasingly employed as a neuropsychological instrument test which measures planning, organization, abstract reasoning, concept formation, cognitive retention, the ability to change, inhibition, and actually all elements of brain flexibility except working memory. The original version of the WCST was developed by Berg et al. in 1948 [16]. It was designed to measure abstract reasoning and the ability to shift cognitive strategies in response to changing environmental contingencies. Thus, it is believed that WCST evaluates a complex range of executive actions, including planning, organization, abstract reasoning, concept formation, cognitive retention, ability to change, and inhibit impulsive responses [17]. This test was mainly based on the study of abstract reasoning, learning to search in the animals, sorting the colors, shapes, and sizes and was designed to measure human reasoning skills. RehaCom is a set of rehabilitation software that measures important cognitive functions, designed and developed from 2001 to 2012. This software includes exercises for attention, memory, executive functions, visual perception, visual motor abilities, etc. The executive functions section consists of 2 parts: planning for symbolic and daily shopping, logical reasoning, mental activities, and calculating numbers. In the section corresponding to visual and contextual skills, exercises focus on searching, reading, and perception of the shape in the context. One section also centers on perceptual and motor abilities. In some studies, the validity of this test is found to be 0.81 [18].

Outcome

In this study, two outcomes were considered that was Executive Functions and Brain Flexibility that assessed by WCST.

Intervention

After the criteria assessment by researchman , the research team selected software of Attentive rehabilitation of attention and memory (ARAM).Attentive rehabilitation of attention and memory (ARAM) is a software application that is a part of Neurocognitive Joyful Attentive Training Intervention as cognitive rehabilitation intervention[19]. In the ARAM, four joyful computer-based tasks were presented to participants. These tasks were graded and increased in level of difficulty based on responses. Grading was based on the number of flanker stimuli, velocity of presented stimuli, number of goal stimuli, and changing task rule. For example, in one task, a subject should arrange faces in different categories based on a given rule and three properties: emotional expression (sad, angry, and neutral), hair color (green, white, and black), and skin color (yellow, white, and black). Each face had one property from each category, and the subject should assign it to just one category based on the property specified by the given rule. Thus, in each set of tasks, the subject should inhibit two properties and act based on one property designated by the given rule. In other words, the cognitive demand of these tasks is inhibition of unrelated properties and selectively attending to related one[19] .the intervention group were trained by ARAM app in 10 sessions, 60 minutes 3 times per week. In contrast, the control group received periodic examinations , adherence to medication programs, and monthly blood sugar measurements. For data filling, The Wisconsin Card Sorting Test Before training , After 10 sessions.and one month after the intervention were completed. The statistical analyst analyzed the coded data after the study.

Ethical Considerations

The study adhered to ethical standards, including obtaining the ethical code from the Yazd University of Medical Sciences, obtaining informed consent, maintaining confidentiality, and adhering to the Declaration of Helsinki

Statistical Analysis

This research used mean±SD to describe quantitative data. The Kolmogorov-Smironov test was used to analyze the normal distribution at 0.05,t- test, mixed analysis of variance and Mauchly's test.When the One Way mixed analysis of variance was significant, the post hoc (LSD) test was utilized for multiple/pairwise comparisons. All analyses were done by SPSS version 24 at a significance level of less than 0.05.

RESULTS

The Kolmogorov-Smirnov (K-S) test was used to determine variable normality in the intervention and control groups. The test findings showed .that all variables had a normal distribution. There were 30 participants in the study, 15 diabetic and 15 non-diabetic people. Among the study participants, 52.38% belonged to the 41–50 years age group and 47.62% belonged to the 51–60 years age group. Males and females representation was nearly equal (17 vs. 13). The mean (standard deviation) of the age of the participants was 65.6 (1.64) in the intervention group and 55.9 (1.94) in the control group. The Chi square test showed no significant demographic difference(Age, Sex, Level of education, Occupation) between the control and intervention groups (P>0.05). Descriptive statistics of the variables in the three phases, before, after, and on follow up, in both control and intervention groups are shown in Table 1.(mean and standard deviation of the results of Wisconsin card sorting test for the intervention and control group in three different stages). As shown in the table, follow-up(M=1.96) and Post-test (M=2.33) average Categories correctly sorted(Wisconsin Card Sorting Test)in intervention group Increase. follow-up(M=20.88) and Post-test (M=34) average perseverative errors in intervention group decreased. In Pre-test, The average of the Categories correctly sorted of the intervention group was higher and perseverative errors was lower than the control group .For data analysis, first the average of the intervention and control groups before the intervention was evaluated with t- test. The average of the categories correctly sorted of the intervention group(M=1.42) was higher than the control group(M=1.26).The average of the perseverative errors of the intervention group(M=36)was lower than the control group(M=39) .According to the results shown in Table 2, there is no significant difference in categories correctly sorted)T=0.56, Sig=0.76) and perseverative errors (T=0.49, Sig=0.66) between the control and intervention group before the start of the intervention (P< 0.05).In the following, the average of the groups after intervention and in the follow-up phase is Comparing. In order to evaluate the significance of the difference between the intervention and control group in the pre-test, post-test, and follow-up stages, mixed analysis of variance was carried out. This method was selected because of the fact that mixed models have more flexible structures than other methods of analysis of variance and that they do not have any limiting assumptions on the structure of the correlated data. Before using this analysis, Mauchly's test was used to evaluate the sphericity of the data. The result of Mauchly's test (P> 0.05) was significant for all the variables. Thus, mixed analysis of variance could be carried out. Table 3 shows the results of the mixed analysis of variance. As demonstrated in Table 3, the effect of each group on perseverative errors is significant. The results of within-group analysis show that the main effect of the assessment stage of perseverative error is significant. Table 3 also shows that the interactive effect of the groups and assessment stage on the selected perseverative error was significant (P> 0.05). The Least Significant Difference (LSD) test was used to show the difference between the main effects of the assessment (pre-test, post-test, and follow-up) stages. As shown in Table 4, there is a significant difference between the results of pre-test and follow-up stages regarding the perseverative error. The comparison of the mean scores shows that the perseverative error decreased in the follow-up stage (after the application of cognitive rehabilitation). Based on the obtained results, it can be inferred that cognitive rehabilitation has a positive effect on brain flexibility and executive function.

DISCUSSION

This research found a statistically significant difference in WCST mean scores following rehabilitation of attention and memory rehabilitation of attention and memory improved WCST in patients. The current study's results are consistent with Gholam Hossein Javanmard on the effects of Computer Aided Cognitive Rehabilitation on the Prefrontal Cortex on Executive Functions and Working Memory in Type Diabetic[20]. In Their investigation The executive functions and working memory of both experimental and control groups were assessed in the pretest and post-test stages through the Wisconsin Card Sorting Test software, and memory and attention improvement software. For intervention, the experimental group received cognitive rehabilitation for working memory in 10 half-hour sessions(one day in between),with memory and attention improvement software. The results of data analysis using covariance analysis showed improvement in cognitive flexibility and working memory and a decrease in overall perseveration in the experimental groupalso Renate M. van de Ven researched to track the behavioral and neural effects of computer-based cognitive flexibility training after stroke[21]. three groups, an experimental intervention group, an active control group who did a mock training, and a waiting list control group. Stroke patients (3months to5years post-stroke) with cognitive complaints were included. Training consisted of 58 half-hour sessions spread over 12 weeks. The primary study outcome was objective executive function. Secondary measures were improvement on training tasks, cognitive flexibility, objective cognitive functioning in other domains than the executive domain, subjective cognitive and everyday life functioning, and neural correlates assessed by both

Table I. Descriptive statistics of the variables

(Variable)	Group	Pre-test Mean(Standarddeviation)	Post-test Mean(Standarddeviation)	follow-up Mean(Standarddeviation)
Categories correctly sorted	intervention group	1.42±0.45	2.33±0.65	1.96±0.36
	Control group	1.26±0.56	1.80±0.38	2.18±0.38
perseverative errors	intervention group	36±1.56	34±1.33	20.88±1.88
	Control group	39±1.77	37±1.33	36.03±1.75

Table II. Comparing the mean level of primary variables before the intervention in the intervention and control groups

Test	Variable	Intervention group (Mean SD)	Control group (Mean SD)	T	Sig.
WCST	categories correctly sorted	1.42±0.45	1.26±0.56	0.56	0.76
	perseverative errors	36±1.56	39±1.77	0.49	0.66

Table III. The effects within and between groups of variance of the research variable

Source	Dependent-Size	SS	df	MS	F	Sig.
between-group	categories correctly sorted	2.58	1	2.85	3.63	0.06
	perseverative errors	24513.56	1	24513.56	5.68	0.03
error	categories correctly sorted	625.85	27	23.17		
	perseverative errors	4651.46	27	1722.72		
within-group	categories correctly sorted	725.45	2	270.69	4.22	0.05
	perseverative errors	56513.02	2	15568.32	8.12	0.03
time and group	categories correctly sorted	1263.69	2	471.52	2.29	0.06
	perseverative errors	65891.89	3.63	18152.03	2.56	0.02

Table IV. The Least Significant Difference (LSD) test results to investigate the difference between the mean of the intervention group in three distinct times

Test	Variable	Stage Comparison	SE	SD	Sig.
WCST	perseverative error	pre-test - post-test	1.74	0.26	0.33
		pre-test – follow-up	5.5	0.65	0.05
		post-test – follow-up	3.76	0.69	0.14

structural and resting-state functional Magnetic Resonance Imaging[22]. The three groups were compared at baseline, after six and twelve weeks of training, and four weeks after the end of the training. Furthermore, they were compared to healthy elderly who received the same training. This study provided insights into the field of Cognitive Rehabilitation as it not only looked at behavioral effects, but also at changes in the brain. In the current study, time lasted 4 weeks. used a software of ARAM was implemented in both genders, and WCST were filled out thrice.The results of this study indicate an increase in the scores of the participants in the follow-up stage due to taking computer-based cognitive exercises in diabetic patients. Numerous studies in the field of cognitive rehabilitation confirm the positive results of these techniques [23] . Evidence shows that computer cognitive rehabilitation improves performance in neuropsychological tests [24]. Computer cognitive rehabilitation program significantly increases the processing speed, brain flexibility, and visual memory and also plays a significant role in increasing the activity of the prefrontal cortex [24]. The exercises presented in this study involved a wide variety of areas such as prefrontal cortex, anterior cingulate cortex, and basal ganglia. Cognitive rehabilitation exercises help individuals become more aware of their cognitive abilities and find better ways to deal with such problems [8]. The results of a study conducted by McNally showed that executive function skills and brain flexibility are associated with adherence to treatment, which results in diabetes control [25]. It can be said that adherence to treatment in the patients who participated in this study led to an increase in the effectiveness of the test. In general, due to the importance of cognitive abilities and brain flexibility in daily human life, it is essential to conduct different studies on diabetic patients using various techniques. Further accurate studies are required to improve cognitive ability and executive function and to achieve more robust results.A small sample size limited the study's generalizability to society.

CONCLUSION

It can be inferred that computer-based cognitive rehabilitation can have a positive impact on brain flexibility and executive function in patients with diabetes. As a novel intervention, using software of rehabilitation enhances Executive Functions and Brain Flexibility

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Conflicts of Interest

The authors declare no competing interest.

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