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The Effectiveness of Problem-Solving Training on Cognitive Fatigue and Executive Functions of Students with Math Disorders

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ABSTRACT

Mathematical disorders, which are rooted in genetic factors and central nervous system dysfunction, can cause cognitive and psychological processing disorders. This study aims to determine the effectiveness of problem-solving training on executive functions and mental fatigue in female students. This study is a quasi-experimental design with a pre-test and post-test with a control group. The statistical population includes female students in the first year of high school in Miandoab city in the academic year 2022-23, from which 40 people were selected as a sample based on the available method and randomly assigned to two control and experimental groups. The research tool includes Coolidge's executive functions, 2002 version, differential or diagnostic tasks (Sedak and Kafta), and a problem-solving training protocol. SPSS 25 software was used to analyze the data. Results were shown that problem-solving training significantly affects executive functions (F=16.35, P< 0.00) and reduces cognitive fatigue (F= F=21.75, P< 0.00) in students. Therefore, problem-solving training as a strong capacity can reduce fatigue and increase executive functions.

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Introduction

Learning disorders have a neurological basis and a developmental process and are characterized by difficulty learning and dysfunction in listening, speaking, reading, writing, and calculation (Dehghani et al., 2018). One type of learning disorder is a mathematical disorder. According to the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders of the American Psychiatric Association, to diagnose a mathematical disorder, a person has deficits in four groups of skills, including number comprehension, memorization, and recall of memorized material such as multiplication tables, correct and explicit mathematical calculations, and correct mathematical reasoning (American Psychiatric Association., 2022). Mathematical disorder is the degree to which a person's ability to calculate mathematics is much lower than that expected from their chronological age, IQ, and the amount of education provided. Research shows that mathematical disorder is seen in 6 per cent of students alone, and this rate has also been reported to be higher in girls. Some researchers believe that genetic factors, dysfunctions in the central nervous system, and psychological processing disorders are the most significant contributors to mathematical disorders.

Additionally, studies suggest that issues with the occipital lobe function may lead to difficulties with mathematics (Mrazik et al., 2019 & Hauser et al., 2013). Furthermore, research indicates that individuals with mathematical disorders may experience broader cognitive issues, including deficits in executive functions and cognitive fatigue (Wilkey., 2020).

Problem-solving and the ability to do so are complex human cognitive processes through which individuals identify, analyze, and solve challenges. It includes a set of cognitive operations such as identifying the problem, generating possible solutions, evaluating options, and implementing the chosen solution (Nurtamam et al., 2023). Problem-solving skills and their stages teach important points related to how to deal with a problem, including reflecting on the problem, defining the problem, recognizing the problem, considering different and multiple solutions, and choosing the best solution. Problem-solving learning is one of the active learning methods that various experts have spoken a lot about its importance. Active learning methods have a greater effect on learning than passive methods. Even though using problem-solving strategies is complex, it is very effective and motivating in learning and education. Problem-solving stems from scientific research methods used in acquiring knowledge. In this model, like the process of research, the learner is faced with a question in practice, collects information about it, organizes and classifies this information, and based on that, makes a hypothesis, tests his hypothesis, and finally draws conclusions and uses the results obtained to analyze similar information and data. Also, problem-solving skill training is the systematic provision of cognitive and behavioral skills training that helps an individual identify the most effective solution to a problem and effectively manage and solve problems that arise in the future without psychological distress (Losenno et al., 2020). Problem-solving is an important coping strategy that increases personal and social competence and development and reduces stress and psychological distress (Ozpınar & Arslan., 2023). Therefore, problem-solving requires purposeful strategies by which individuals define problems, decide on solutions, implement and monitor problem-solving strategies, and prevent cognitive burnout and fatigue. Sakka and Surmeli conducted an experimental study on the effectiveness of problem-solving skills training on self-efficacy (Saka & Surmeli., 2010). The results showed that problem-solving skills training positively affects students' self-efficacy. Alizadeh and Zahedipour examined the effectiveness of problem-solving and creative thinking training on students' executive functions and showed a significant difference between the experimental and control groups (Alizadeh & Zahedipour., 2004). Accordingly, training in problem-solving and creative thinking skills significantly increased perceptual reasoning, working memory, and planning and organization in the experimental group compared to the control group.

Cognitive fatigue is an important concept in classifying psychology and cognitive science fields. It describes a state in which individuals face severe cognitive difficulties due to a lack of control over the situation and cannot implement appropriate strategies to achieve desired goals (Pitteri et al., 2023). In cognitive fatigue, external and out-of-control factors make people feel they have lost their effectiveness and ability (Dong et al, 2022). In these conditions, people use intense cognitive activities to search for solutions and strategies to achieve their goals (Shariatnejad & Zeydiasl., 2023); they try to search for and analyze appropriate information and resolve ambiguities and problems in the situation. Cognitive fatigue is a state of reduced cognitive capacity mainly attributed to prolonged mental activity. It usually manifests through symptoms such as difficulty concentrating, reduced endurance for cognitive tasks, and increased sensitivity to distractions (Linnhoff et al., 2023 & Bagheri et al., 2023). In general, when a person is experiencing cognitive fatigue, their cognitive resources and mental energy are reduced, which can lead to reduced efficiency in executive function and a tendency to exert less effort. Rafiei and Mikaeli examined the effect of cognitive fatigue on students' cognitive flexibility, with the mediating role of the need for cognition (Rafiee & Mikaili., 2015). The findings showed that cognitive fatigue hurts cognitive flexibility, and the mediating role of the need for cognition is significant. Ghanaei et al. examined the effect of cognitive fatigue and emotional intelligence on cognitive problem-solving (Ghanaei et al., 2004). The results showed that people with high emotional intelligence perform better in problem-solving, and there is no difference between girls and boys regarding emotional intelligence level. However, cognitive fatigue affected girls' problem-solving performance more than boys.

Another important factor that can be effective in problem-solving is executive functions. Executive function is a set of cognitive processes used to plan, manage, and control behavior in complex and changing situations. These processes include attention, working memory, motivational control, emotion regulation, and decision-making (Ansari et al., 2022). Executive function can link all these processes together and help individuals face challenging situations and choose appropriate strategies to achieve their goals. Executive functions may increase attention and focus, working memory accuracy, decision-making ability, and desirable motivational orientations.

On the other hand, excellent executive function requires appropriate energy and cognitive resources, which, if available, significantly increase problem-solving ability (Alizadeh & Zahedipour., 2004). Diamond and Lee believe that executive function plays a fundamental and vital role for individuals, which includes three main components: working memory or the ability to retain information, manipulating information in the mind, and finally, cognitive flexibility (Diamond & Lee., 2011). These components are important because of their relationship with progress in various functions and increased learning (Best et al., 2011). According to studies by Sepehri Bonab et al., quality of life, academic success, mental health, and career future depend on the role of executive functions; also concluded that goal-related cognitive processes and attention allocation differ in individuals with and without fatigue, and response selection is difficult in a state of cognitive distress (Sepehri Bonab et al., 2023). Despite the studies and research conducted on problem-solving, cognitive fatigue, and executive functions in different situations, there are still many gaps in their relationship, and its investigation in education, especially among students, is more important than ever. Therefore, the present study aims to investigate the role of problem-solving and its effects on students' cognitive fatigue and executive functions. This study's central question is: Does problem-solving ability and its effects affect cognitive fatigue and executive functions in female high school students in Miandoab?

Method

Sample and Sampling Method

The statistical population of this study included all first-year female high school students in Miandoab city during the academic year 2022-2023. The statistical sample consisted of 40 students who were selected using convenience sampling method. After determining the sample size, participants were randomly divided into two equal experimental and control groups (20 participants in each group).

Tools Used

Sedak and Kafta's (1999) Differential or Diagnostic Tasks

The diagnostic tasks used in this study are similar to those employed by Van Hecker and Sedak (1999) and Sedak and Kafta (1990) to investigate cognitive fatigue and learned helplessness. In these tasks, participants are presented with four problems and are allowed eight attempts to solve them. Each problem is represented through images that encompass five two-valued dimensions: a) shape (either a diagram or a circle), b) size (either large or small), c) letter size (either large or small), d) background (either plain or hatched), and e) line position (either above or below the shape). Line position (above or below the shape).

Coolidge's Executive Functions (2002 Edition)

Executive functions are assessed based on the Coolidge Neuropsychological and Personality Questionnaire, 2002 version. This questionnaire consists of 19 questions. The test is answered by parents (Mehmanpazir & Farokhi., 2021). This test identifies several neurological and behavioral disorders in children and adolescents aged 5 to 17. Each disorder has a specific and separate subscale, with two assessing executive functions and 19 items. These two subscales measure executive functions in the three areas of organization, decision-making-planning, and inhibition, and have a 4-point scale: never (0), sometimes (1), usually (2), and always (3). The highest and lowest scores that an individual obtains on this test are 57 and zero, and the higher the individual's score, the greater the problems in executive functions. Coolidge reported the reliability of the organization and decision-making-planning subscale as 0.85 and the inhibition subscale as 0.66 (Coolidge., 2002). The reliability of the questionnaire in the present study was 0.86.

Goldfried and Davidson Problem Solving Training Protocol

The problem-solving training protocol uses the original Goldfried and Davidson model to train problem-solving skills. This model includes: 1—Orientation to the problem 2—Description and formulation of the problem 3—Presentation of alternative solutions—Decision making 5—Implementation of solutions and its review. This protocol consists of 11 sessions, each lasting 45 minutes. The ultimate goal of this protocol is for the subject to go through the problem-solving stages step by step and achieve problem-solving skills.

Table 1. Treatment protocol

Meeting number	Meeting title	Meeting content
First session	Completing the demographic questionnaire and explaining the clients	Explaining problem-solving skills and measuring them in the experimental group.
Second session	Orientation (first step in problem solving)	Discuss problem-solving skills, encourage people to express themselves through story reading, and determine people's orientation towards problem-solving.
Third session	Strengthening the orientation step	Practice identifying ways to cope with problems, explaining negative automatic thoughts, explaining the principle of stopping thoughts, and identifying the negative and positive thoughts associated with the problem.
Fourth session	Problem definition	Given the direction set in previous meetings, efforts are made to focus the discussion on the issues, discuss them in more detail if necessary, break down the issues (if complex) into their components, set short-term goals, and avoid long-term and unattainable goals.

Fifth session	Strengthening the problem definition	Generating solutions to problems without judging whether they are right or wrong, explaining the brainstorming technique, fluidizing the mind, and writing down all possible solutions.
Sixth session	Generating alternative solutions	Teaching how to select appropriate solutions and compare them with other selection methods, the if...then..., overall screening, and discarding weak solutions.
Seventh session	Continue to produce alternative solutions	After reviewing the rules and principles, the subjects' problems are examined and solved. This session presents an incomplete story so that individuals can practice presenting different solutions.
Eighth session	Decision-making	Anticipating the possible consequences of each action and paying attention to the usefulness of its consequences.
Ninth session	Implement the selected solution	Implementing the chosen solution along with reinforcement and exercises in interpersonal relationships.
Tenth session	Emphasis on means-end thinking and review	Organizing and reviewing the steps, explaining the means-ends thinking method.
Eleventh session	Re view	Review all stages of problem-solving and conduct a problem-solving skills assessment.

Procedure

This study was conducted using a quasi-experimental design with pre-test and post-test. First, inclusion and exclusion criteria were established. The inclusion criteria for the study were: obtaining written consent from parents and students, and achieving satisfactory scores on intelligence tests and differential tasks. The exclusion criteria included absence from more than two training sessions and expressing unwillingness to continue participation in the training program.

After selecting the sample based on the aforementioned criteria and randomly dividing participants into experimental and control groups, the pre-test phase was administered to both groups to measure their levels of cognitive fatigue and executive functions before the intervention.

The educational intervention consisted of a problem-solving training program that was implemented for 11 one-hour sessions with a frequency of three sessions per week for the experimental group. This training program was completed over approximately 4 weeks. The control group received no specific intervention during this period and continued their regular activities.

After completion of the training period, the post-test phase was conducted for both groups to evaluate possible changes in the dependent variables (cognitive fatigue and executive functions). The collected data were analyzed using SPSS software version 25 and employing Analysis of Covariance (ANCOVA) method to examine the effectiveness of the educational intervention.

Results

In this study, 40 students (20 experimental group and 20 control group) were studied, and the effect of problem-solving training on cognitive fatigue and executive functions was examined. The table below presents the descriptive statistics for the research variables (Table 2).

Table 2. Descriptive indicators variables

variables	Groups	Pre-test		Post-test		Kolmogorov Smirnov	
		Mean	Standard deviation	Mean	Standard division	Statistic	sig
Cognitive Fatigue	Experimental	10.53	1.44	7.80	1.75	6.28	0.00
	Control	9.48	1.38	9.85	1.23	5.84	0.00
Executive Functions	Experimental	8.50	1.87	12.90	1.54	5.46	0.00
	Control	8.85	1.43	10.23	1.76	7.52	0.00

Table 2 shows the variables of cognitive fatigue and executive functions for the two experimental and control groups in the pretest and post-test. In the control groups, the mean of the variables in the pretest did not change much compared to the pretest. Still, in the experimental group, a significant decrease in cognitive fatigue and a significant increase in executive functions were observed in the post-test. The mean scores of the experimental groups in the post-test changed compared to the pretest. These differences may indicate the effect of the intervention. Also, the Kolmogorov-Smirnov test results on the data's normality show that the scores in the pretest and post-test were normal and significant at the 0.05 level.

To examine the homogeneity of regression slopes, the F value for the interaction of the group with the pretest for the cognitive fatigue variable (3.27) and executive functions (2.51), which are not significant at the $P < 0.05$ level. Therefore, the regression slopes for the research variables are homogeneous, so the assumption of homogeneity of regression slopes has been met. For the assumption of homogeneity of variances, the results of the Levine test for cognitive fatigue were (0.860) and executive functions (0.309), which are not significant at the $P < 0.05$ level. Therefore, the Pillai effect, Wilks' lambda, Holting effect, and largest root tests were used to validate the analysis of covariance, the results of which are presented in Table 3.

Table (3) Results of the analysis of covariance test for group membership effects

Variable	Test	Value	F	Effect size	Significant	Eta squared	Statistical power
Cognitive fatigue	Pillai effect	1.72	16.35**	0.75	0.001	0.72	1.00
	Wilks' lambda	0.04	16.35**	0.75	0.001	0.78	1.00
	Holting effect	7.75	16.35**	0.75	0.001	0.85	1.00
	largest root	2.46	16.35**	0.75	0.001	0.88	1.00
Executive functions	Pillai effect	1.32	21.75**	0.75	0.001	0.72	1.00
	Wilks' lambda	0.06	21.75**	0.75	0.001	0.78	1.00
	Holting effect	5.56	21.75**	0.75	0.001	0.85	1.00
	largest root	2.56	21.75**	0.75	0.001	0.88	1.00

p< 0/05*, p< 0/01**

Table (3) shows a significant difference between the experimental and control groups regarding dependent variables (cognitive fatigue and executive functions). As the results of this table show, the overall F of the Wilks' Lambda test is significant with a value of (0.04) (F=16.35 and P< 0.00). Therefore, a significant difference is observed between the experimental and control groups regarding dependent variables. Also, the statistical power = 1.00; in other words, there was no possibility of a type II error.

Table (4) Analysis of covariance test on post-test scores of variables with control of pre-test scores

Variables	Variables resource	Sum of squers	Degree of freedom	Means of squares	F	Significant	Effect size
cognitive fatigue	pretest	1257.44	1	1257.44	22.77	0.001	0.22
	group	382.86	1	382.86	27.52	0.001	0.32
	error	194.22	38	5.20	-	_	-
executive functions	pretest	1405.48	1	1405.48	40.55	0.001	0.57
	group	395.14	1	394.14	26.47	0.001	0.26
	error	168.55	38	4.43	-	_	-

Table (4) shows the covariance test results on the variables' post-test scores, controlling for the pre-test scores. As presented in this table, with the pre-test control, a statistically significant difference is observed between the variables cognitive fatigue (F = 11257.44, P < 0.00) and executive functions (F =405.48, P < 0.00) in the experimental groups and the control. In the present study, the squared parametric Effect size was reported to be 0.32 for the cognitive fatigue variable and 0.57 for executive functions. This indicates that problem-solving training explained 32% of the total variance of the cognitive fatigue variable and 57% of the variance of the executive functions variable.

Discussion & conclusion

The present study aimed to investigate the effectiveness of problem-solving training on cognitive fatigue and executive functions in female high school students. The results of the first hypothesis indicate that problem-solving training affects students' cognitive fatigue. Therefore, people who have developed cognitive abilities such as abstract reasoning, decision-making, and organization and have higher problem-solving abilities usually express cognitive fatigue less than people in the control group. People with problem-solving abilities usually choose effective coping strategies to reduce stress and mental distress and increase personal, social, and academic progress. The results of testing this hypothesis are consistent with the research of (Pitteri et al., 2023; Shariatnejad & Zeydiasl., 2023; Bagheri et al., 2023) and (Kupcewicz et al., 2022). These findings showed that the abilities obtained from problem-solving training lead to a reduction in cognitive fatigue Because subjects in a state of cognitive fatigue will face reduced motivation, increased time required for mental representations and a large number of cognitive failures (problems in regular hypothesis-testing, lack of complex strategies and inadequate cognitive organization) and perhaps cognitive helplessness, and these problems can directly hurt individual performance, including students' academic performance (Linnhoff et al., 2023). Therefore, achieving problem-solving skills can prevent a decrease in cognitive capacity, difficulties in concentration and attention, and a decrease in endurance for cognitive tasks (bagheri et al, 2023). Therefore, when a person is equipped with problem-solving strategies, his cognitive and mental resources increase, and he will be more successful in carrying out cognitive activities.

The results of the second hypothesis indicate that problem-solving training affects students' executive functions. This finding is consistent with the results of research (Ansari et al., 2022 & Sepehri Bonab et al., 2023) and (Ghasemi et al., 2022) which show that problem-solving training affects executive functions, with the explanation that executive functions, as a set of cognitive processes in challenging situations, use interconnected cognitive processes and appropriate strategies to achieve their goals and that thoughtful training in the problem-solving process will strengthen this issue (Yarmohamadi., 2022). In other words, cognitive activities resulting from problem-solving training lead to the formation of the process of problem identification, information search, formulation of appropriate hypotheses, and analysis and presentation of appropriate solutions, which usually increases the efficiency of executive functions and improves attention and concentration, working memory accuracy, and complex decision-making ability. On the other hand, high executive functions require an appropriate amount of energy and cognitive resources, which increase significantly if one can solve problems (Özpınar & Arslan., 2023). Also, problem-solving training as a cognitive activity can lead to the ability to retain and manipulate information, cognitive flexibility, and the ability to process complex problems, which usually results in increased deep learning and success in individual and social functions, quality of life, academic success, and mental health.

Accordingly, mechanisms should be provided to assess students' cognitive status, leading to assessing their problem-solving skills. Their problem-solving skills and abilities can be strengthened and improved by participating in appropriate courses if necessary. As a result, we can witness a reduction in cognitive fatigue and an increase in executive functions. Among the limitations of this research is the problem of coordinating the scheduling of educational classes with the school schedule, which was coordinated after a month.

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