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The effect of self-regulation empowerment program training on neurocognitive and social skills in students with dyscalculia

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Summary

Aim: The current study aimed at determining the effect of self-regulation empowerment program training on neurocognitive and social skills in students with dyscalculia.

Method: The study was a semi-experimental with pretest/posttest design and a control group. The study sample was consisted of 26 students with dyscalculia in Guilan Province, Iran, 2018, selected by the convenience sampling method and assigned into two groups (one experimental and one control). To collect the data, Tower of Hanoi Task, Stroop Test, Dual N-Back Task, Wisconsin Card Sorting Test, and Social Skills Rating System were used before and after the intervention. A twelve-session self-regulation empowerment program training was implemented for the experimental group.

Results: Mann-Whitney U test, and Wilcoxon test were used for data analysis and Cohen's *d* test measured effect extent. The results of analysis showed that the self-regulation empowerment program training improved neurocognitive and social skills in students with dyscalculia.

Discussion: Students with dyscalculia are faced with various physical and psychological stressful factors, which leads to decreased quality of life. Considering the relationship between neurocognitive and social skills with self-regulation, one of the methods capable of assisting the rehabilitation of the students with dyscalculia is the self-regulation empowerment training.

Conclusions: According to the findings of the research, self-regulation empowerment training can improve the neurocognitive and social skills in students with dyscalculia.

self-regulation, neurocognitive function, social skills, dyscalculia

INTRODUCTION

Dyscalculia is a neurodevelopmental disorder diagnosed in childhood and one of the most important causes of poor academic performance [1]. Its prevalence among children is estimated to be between 5% and 9% [2]. In Iran, the prevalence of this disorder is 3.35% in boys, which is about 1% more than that in girls [3].

According to the Diagnostic and Statistical Manual of Mental Disorders, dyscalculia is a particular type of specific learning disorder. Students with this disorder have problems regarding learning and remembering mathemati-

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cal concepts, understanding numbers, difficulty in computing, and math reasoning [4]. The problem begins at an early age in some children, but often shows itself in preschool age and continues to the secondary and high school [5].

One of the problems of students with dyscalculia is their weakness in executive functions, including their ability to learn school lessons [6]. From the neurological point of view, this term relates to a wide network of frontal cortex functions and includes a large number of cognitive and meta-cognitive processes that develop during the course of the child's development [7].

Neurocognitive executive functions are associated with psychological processes responsible for controlling consciousness and thinking in action. These functions adjust and organize the outcomes of the behaviors [8]. Functions such as response inhibition, organization, strategic planning, cognitive flexibility, working memory, and problem solving can be considered as the most important neurocognitive executive functions helping humans in managing their lives and practice of learning and IQ activities. These functions are skills that help focus on important aspects of the assignment to accomplish it [9].

Dyscalculia is a neurological disorder. The organized visual/spatial skills used to do mathematics are controlled by the right hemisphere. The central frontal lobe is specialized for quick mental calculations, abstract conceptualization, problem solving, and writing. Parietal lobe has a wide range of cognitive functions and integrate and organize cortical sensation. The behaviors and movements involved in touch sensations can be involved in math operations and are associated with parietal lobe functions. Occipital lobe is the center of visual experiences. The visual control of mathematical symbols and geometric calculations are done there. The temporal lobe is involved in math skills, including auditory perception and long-term verbal memory. Disturbances in each area of the brain cause certain math problems, the most significant of which are difficulties in learning and remembering mathematical concepts, understanding numbers, difficulty in computing and math reasoning [10].

People with dyscalculia show socially unacceptable behavioral patterns. They have difficulty in adapting to new situations and often display maladaptive behaviors. Additionally, social relationships or emotional functions can also affect the disorder and cause problems in behavior, thinking, and misunderstanding of the others' behaviors. Hence, these students have a poor social understanding and lack of empathy in school [11].

Moreover, these children have difficulty in interpersonal skills [12] and social adjustment [13] because of their weakness in doing classwork, lack of academic achievement, labeling by classmates and low self-confidence. Regarding the educational problems of these children, their school dropout rate is 1.5 times more than that at adolescence [14]. Therefore, children with specific learning disorder are more vulnerable to behavioral and social problems given their frequent and continuing academic failures. Compared with typically developing children, they have a high level of behavioral (internalized and externalized problems) and socioemotional (deficiencies in the processing of social data, high levels of social exclusion, loneliness and weak interpersonal skills) problems [15]. Moreover, about 38% to 78% of the children with dyscalculia have social and communicative deficiencies [16]. Therefore, attention to children with learning disabilities is important [12].

The families and schools of these children are considered as their first social environments, and evidence suggests that the exclusion of children with dyscalculia by peers would predict future problems, such as depression, drug abuse, school deportation, academic failure, delinquency in adolescence, and low occupational success in their lives [17].

So far, several techniques and methods have been used to educate students with dyscalculia, but studies show that each teaching method covers certain aspects of the problem and partly influences all the needs of these students [18]. Over the past few decades, an approach has evolved in the field of cognitive and social skills, i.e., the self-regulation approach; this approach is able to adjust and eliminate the gaps among cognitive-behavioral theories. This approach has managed to mitigate and eliminate the cognitive-behavioral theories [19]. The self-regulation empowerment plan has been designed and implemented in response to the lack of a comprehensive program for students who face problems in academic achievement due to failure in neurocognitive and social skills [20]. Self-regulation empowerment is an integrated and novel educational system based mainly on the development and extension of concepts and methods of traditional cognitive therapy that integrates the principles and foundations of cognitive schools, attachment, object relations, gestalt, and constructivism into one conceptual and educational model [21].

Self-regulation training strategies allow students to do homework and everyday activities by planning, organizing, and self-monitoring. Students can reconsider their multiple failures with self-regulation strategies and ultimately their active learning will improve. Thanks to self-regulation, these students can become aware of the usefulness of specific strategies for effective resolution and learning [22].

The results of the studies showed that self-regulation empowerment program affects the social cognitive development of elementary students with dyscalculia [23,24]. Khanjani et al. [25] showed that self-regulation training could affect the executive functions of students with learning disabilities.

Given the high prevalence of dyscalculia and its various associated cognitive complications, social, familial and educational areas [2], and owing to the scarcity of investigation in this regard, the present study aimed at determining the effect of self-regulation empowerment program training on neurocognitive and social skills in students with dyscalculia.

METHODS

Participants

The study was a semi-experimental with pretest/posttest design and a control group. The statistical population included all students with dyscalculia studying at the Dyscalculia Centres of Rasht, Guilan Province, Iran, in the academic year of 2018. Overall, based on inclusion criteria, 30 students were selected with convenience sampling and randomly assigned into the experimental and control groups, each of 15 subjects. The inclusion criteria were as follows: male gender, age 10–12, lacking any history of participation in any intervention plan, having dyscalculia for more than 2 years, not being involved in other interventions right now, and studying at the fourth to sixth grade at elementary school. The parents of the participants were asked to sign an informed consent form prior to the participation in the program; and the principles of the confidentiality protection and the ethical considerations were also considered in all stages of the study. During the intervention, four participants (two from the experimental group and two from the control group) withdrawn from the research process because of personal problems.

MEASURES

Tower of Hanoi (TOH)

The computerized version of TOH task was developed by Leòn-Carriòn et al. in 1991 to assess executive planning and problem-solving abilities. This test consists of three pegs attached to a flat base and three disks of different sizes. The validity of this test is correlated with the Tower of London test as 0.78, and its reliability has been found as 0.90 through calculating Cronbach α [26]. In Iranian population, its reliability was 0.72 obtained by the test-retest method and its validity has been reported as 0.57 with Meta-Cognitive Strategy Test [27]. The Cronbach α in the present study was 0.84–0.91.

Stroop Test

The stroop test was developed by MacLeod in 1991 to assess selective attention, inhibition, and set shifting. In the present study, we used the Persian version of the computerized stroop test. This test uses four different colors (red, blue, green, and yellow) and includes the following assignments: reading color word displayed in black font color (reading baseline), naming ink color of differently colored rectangles (naming baseline), naming ink color of colored words in incongruent format (Stroop effect) and denominating semantically expressed word displayed in incongruent color (Reverse Stroop effect). Participants react using a special keyboard which comprises four correspondingly colored buttons. Test-retest reliability of this test ranged between

0.84 and 0.91 [28], and its validity was reported by correlation with computerized Neurocognitive Test Battery (CNS Vital Signs) in the range of 0.55 to 0.86 [29]. In Iran, the reliability of this test was 0.82 by test-retest method and its validity has been reported as 0.80 through concurrent validity with Reaction Timer [30]. The Cronbach α in the present study was 0.78–0.85.

DUAL N-BACK TASK

The dual n-back task was developed by Jaeggi et al. in 2008 to assess working memory performance. In the dual n-back task, a series of blue squares are randomly flashed on the screen at one of the eight different locations and the letters are simultaneously presented via an audio output. The validity of this test is correlated with Turner and Engle's Working Memory Task (1989) as 0.60, and its reliability has been reported as 0.91 through calculating Cronbach α [31]. In Iranian population, the reliability of this test has been reported as 0.79 through calculating Cronbach α and its validity has been reported as 0.83 with Dichotic Digits Test [32]. The Cronbach α in the present study was 0.82–0.88.

Wisconsin Card Sorting Test (WCST)

The WCST was developed by Heaton et al. in 1993 to assess cognitive flexibility and executive dysfunction. This test consists of 64 non-similar cards with different shapes (triangle, star, cross, and circle) and different colors. In this study, the test is scored on the basis of the number of categories and sum of errors. The validity of this test was 0.86 and its reliability was 83% based on Kendal coefficient [33]. In Iran, the reliability of the test by a test-retest method was found as 0.85, and its validity was also correlated with Bender-Gestalt Test and reported to be 0.60 [34]. The Cronbach α in the present study was 0.72–0.83.

Social Skills Rating System (SSRS)

The SSRS which was developed by Gresham & Elliott in 1990 contains 36-item self-report questionnaire for the age range of 7 to 12 years that evaluates the aspects of social skills. The items are scored based on a 3-point Likert-type scale ranging from 0 (never) to 2 (very often). The SSRS has five subscales: cooperation, assertion, responsibility, self-control, and empathy. The validity of this test is correlated with the Piers-Harris Children's Self-Concept Scale (1984) and ranged between 0.45 and 0.67, also its reliability has been reported through the test-retest method as 0.87 [35]. In Iran, its reliability was between 0.72 and 0.83 through calculating Cronbach α, and its validity was correlated with the Child Behavior Checklist (CBCL) as 0.41 to 0.72 [36]. The Cronbach α in the present study was 0.86–0.89.

Intervention

The intervention used principles and methods of self-regulation empowerment program training [20]. The goal of the training was to improve overall student functioning. Training was provided in a group format in a total of twelve sessions, 1 day a week, each 60 min. The intervention was performed by the author in the experimental group. The instructional design of this program is directly linked with Zimmerman's three-phase cyclical dynamic feedback loop of self-regulation, whereby specific instructional modules target students' forethought, performance, and/or self-reflection phase processes (see Table 1). All educational features of the self-regulation empowerment program can be divided into two essential components: (a) sequence and content of instructional modules and (b) emphasis on strategic thinking [20]. Table 1 shows the self-regulation empowerment training techniques.

Table 1. Categories of self-regulation empowerment program training concepts and techniques

Instructional Modules	Purpose(s)
Introduction	To introduce students to the nature of self-regulation empowerment program and to examine students' beliefs about their academic struggles

Task Analysis	To help students analyze and identify components of successful studying and test performance
Goal-Setting	To teach students about setting short-term and long-term goals for biology tests
Strategic Planning	To teach students how to systematically develop strategic plans for attaining biology test grade goals
Strategy Training	To facilitate students' learning and recall of biology content for tests and or techniques for managing their behavior and environment when studying
Self-Reflection	To engage students in key reflective processes such as self-judgments (e.g., assessing goal progress and attributions about test performance) and self reactions (e.g., adaptive inferences)

Data Analysis

The existence of statistically significant differences between the mean scores of the control and experimental group in the components of neurocognitive and social skills in each stage of the study was proved by means of the non-parametric statistical test Mann–Whitney U for independent samples, since data did not adjust to the normal probability distribution.

Next, non-parametric statistical test Wilcoxon for comparing related samples was used in order to prove the existence of statistically significant differences between the mean scores of the components of neurocognitive and social skills in each stage of the study, for both the control and experimental groups.

Finally, Cohen's *d* test in the pretest–posttest scores was used to determine the magnitude of the change experienced after the intervention program in the components of neurocognitive and social skills in the experimental group. All the statistical analyses were computed using the SPSS 24.0 package.

RESULTS

The age range of the participants was 10–12 years (mean = 11.24; SD = 0.16); the mean duration of the disorder in the experimental and control groups was 2.2 and 2.4 years, respectively. In the control group 24% of the students were in the 4th grade, 30% of the 5th grade and 46% of the 6th grade. In the experimental group, 26.7% were in the 4th grade, 33.3% in the 5th grade and 40% in the 6th grade.

Table 2. Status of neurocognitive and social skills pre-and post-intervention

Experimental group		Control group		Dependent variables	
Posttest mean (SD)	Pretest mean (SD)	Posttest mean (SD)	Pretest mean (SD)		
9.32 (2.13)	16.89 (2.89)	15.47 (3.75)	16.30 (3.12)	TOH_{Moves}	Neurocognitive skills
101.31 (4.02)	124.09 (3.47)	122.30 (3.89)	124.33 (4.45)	$TOH_{Time\ (S)}$	
47.33 (3.78)	58.89 (4.17)	59.79 (3.74)	58.32 (3.86)	ST reading $_{(S)}$	
49.18 (2.89)	60.48 (2.78)	59.12 (3.83)	60.74 (2.79)	ST naming $_{(S)}$	
75.36 (3.15)	84.21 (2.99)	84.11 (3.30)	84.79 (3.52)	ST effect $_{(S)}$	
98.17 (3.80)	110.10 (4.71)	110.89 (4.31)	109.30 (4.56)	Rev ST effect $_{(S)}$	
8.33 (2.39)	13.91 (1.89)	14.73 (2.02)	14.18 (1.68)	Dual n-back Auditory $_{(errors)}$	
7.17 (3.21)	12.71 (2.78)	11.89 (2.89)	12.49 (2.57)	Dual n-back Visual $_{(errors)}$	
4.51 (0.61)	1.67 (0.74)	1.39 (0.82)	1.70 (0.95)	WCST $_{(categories)}$	
4.85 (2.03)	10.56 (2.14)	10.89 (3.01)	11.28 (2.31)	WCST $_{(errors)}$	

12.36 (2.47)	7.98 (2.36)	8.88 (3.02)	8.28 (2.16)	Cooperation	Social skills
12.55 (2.09)	5.21 (2.14)	5.81 (2.34)	5.36 (2.40)	Assertion	
13.96 (1.98)	7.01 (3.12)	7.28 (2.30)	7.19 (2.96)	Responsibility	
10.01 (1.33)	4.85 (2.69)	4.14 (2.11)	4.18 (2.34)	Self-control	
12.28 (2.36)	6.01 (2.10)	6.44 (2.39)	6.11 (2.05)	Empathy	

TOH: Tower of Hanoi, ST: Stroop Test, WCST: Wisconsin Card Sorting Test, S: Second.

Firstly, the means and standard deviations (SD) for the dependent variables are presented in Table 2. We performed Mann-Whitney U test, and Wilcoxon test in all variables to assess differences between groups in pretest and posttest and to test for training as well as transfer effects.

Table 3. The results of non-parametric tests in experimental and control groups

Variable	Mann-Whitney U test				Wilcoxon test				Cohen's *d*
	Pre-test		Post-test		Control		Experimental		
	z	p	z	p	z	p	z	p	
Neurocognitive skills									
TOH $_{\text{Moves}}$	0.36	0.734	3.74	0.006*	0.91	0.148	-3.26	0.002**	0.89
TOH $_{\text{Time (S)}}$	0.86	0.645	4.36	0.004**	-0.87	0.254	-2.98	0.028*	0.84
ST reading $_{\text{(S)}}$	0.78	0.387	3.51	0.041*	-0.69	0.648	-3.58	0.021*	0.79
ST naming $_{\text{(S)}}$	0.86	0.741	3.36	0.008*	-0.48	0.387	-2.19	0.008*	0.76
ST effect $_{\text{(S)}}$	0.35	0.486	2.57	0.012*	-0.85	0.285	-2.39	0.003**	0.82
Rev ST effect $_{\text{(S)}}$	0.48	0.358	2.39	0.001**	0.69	0.632	-3.24	0.019*	0.84
Dual n-back Auditory $_{\text{(errors)}}$	0.36	0.741	3.18	0.007*	0.74	0.869	-2.17	0.002**	0.88
Dual n-back Visual $_{\text{(errors)}}$	0.74	0.322	2.84	0.023*	-0.63	0.587	-3.72	0.006*	0.91
WCST $_{\text{(categories)}}$	0.97	0.474	4.13	0.031*	-0.66	0.446	-4.21	0.018**	0.93
WCST $_{\text{(errors)}}$	0.89	0.235	3.89	0.004*	-0.71	0.323	-2.39	0.007**	0.83
Social skills									
Cooperation	0.74	0.365	2.76	0.004**	0.65	0.621	-3.75	0.002**	0.90
Assertion	0.49	0.258	3.48	0.019*	0.87	0.396	-2.98	0.007*	0.86
Responsibility	0.62	0.136	3.96	0.001**	-0.74	0.124	-3.69	0.017*	0.85
Self-control	0.58	0.741	2.87	0.003**	-0.65	0.338	-2.94	0.003*	0.80
Empathy	0.74	0.366	3.44	0.007*	-0.82	0.474	-3.11	0.018*	0.89

*p <0.05, **p <0.005, TOH: Tower of Hanoi, ST: Stroop Test, WCST: Wisconsin Card Sorting Test, S: Second.

Mann-Whitney U test for independent samples on the pretest scores revealed no statistically significant differences between the control and experimental pretest mean scores in the study variables. Contrarily, statistically significant differences did appear between the control and experimental groups at posttest in all the components of neurocognitive and social skills. After conducting Wilcoxon test for related samples on the experimental group scores, statistically significant differences were observed when comparing the pretest and posttest scores in all the components of neurocognitive and social skills. No significant differences were found in such variables after the pretest and post-test comparisons for the control group. Finally, By comparing pretest posttest scores of the experimental group, a Cohen's *d* test was accomplished to interpret the extent of the efficacy of 'self-regulation empowerment training'. The results showed Cohen's *d*, indicating that 'self-regulation empowerment training' had a remarkable effect on neurocognitive and social skills in the study participants (see Table 3).

DISCUSSION

The present study aimed at examining the effect of self-regulation empowerment program training on neurocognitive and social skills in students with dyscalculia. The results indicated that the self-regulation empowerment training was effective on neurocognitive skills in students with dyscalculia. This result is consistent with that of the authors' previous study [25].

To explain the study results, it can be said that the students should have command over a set of skills with neurocognitive aspects such as attention, executive functions, language, visual/spatial processing, and memory. These skills are the result of experience, training, and learning. Most students automatically do these skills, whereas students with dyscalculia encounter problems when using these skills in learning.

As the ability to plan and organize is a high-level function of the frontal cortex, it is believed that damage or disorder in the frontal lobe and some of the subcortical regions of the brain is significantly related with the child's ability to plan and organize [10]. Planning is an important part of purposeful behavior and involves setting up actions for organized progress and exposure with assignments. Students with learning difficulties often have difficulty in sorting out, organizing, prioritizing information, and focusing on details when trying to identify key issues. Thus, they may become confused with a lot of information, and cannot easily start new assignments or make a flexible shift in alternative strategies. These weaknesses are identified as problems in executive functions [22].

The development process in students with dyscalculia has been delayed or interrupted in achieving accuracy and attention. Although some students with dyscalculia are fully aware of mathematical operations, they are ignorant of symbols and values. Therefore, self-regulation empowerment program can be effective by enhancing visual memory as a perceptual skill, which is a key factor in math. It is effective in determining the exact location of numbers, addition, subtraction, deduction, decimal, and visual analysis skills [18].

Thus, self-regulation empowerment training enables the students to do homework assignments and daily activities by planning, organizing, self-monitoring, and reviewing their numerous failures. Finally, active learning in such students improves. This training teaches students how to evaluate and monitor their progress by using different learning strategies and trying to change their learning strategies, if necessary, to learn better. Through self-regulation, these students become aware of the usefulness of specific strategies for efficient and effective learning, and acquire the necessary capabilities in cognitive flexibility [21].

Moreover, the results showed that self-regulation empowerment training can improve the social skills of such students. This result is consistent with that of previous studies [21,24].

To explain this finding, it can be said that the students with dyscalculia show a different pattern of abilities and weaknesses compared to students with verbal learning disorder. Students with dyscalculia have problems in understanding nonverbal inputs in social situations and are socially isolated and less involved in the games. They may depend on their parents to evade social situations [24].

Learning disabilities and academic failure, being labeled, and receiving special education services will make the child feel different from the rest of his or her peers, which will increase the child's loneliness and lead to social problems and poor self-esteem. Because of visual-spatial problems in social communication, these children often make mistakes in interpreting the facial and body language of others, resulting in inability to make friend or maintain friendships and lack of social interaction. Social problems can increase their educational problems, as the relationship between students and teachers is poor, they lose group learning with their classmates [37].

Moreover, students with dyscalculia have disabilities in social functions, including answering nonverbal cues, understanding the feelings of others, and participating in social situations that need inhibition and participation [38]. Although dyscalculia becomes evident in early school years characterized with attention deficit, learning disability, academic problems, aggression, akathisia, and arousal [39], over time, they become chronic, persistent and a potent risk factor for emotional-behavioral problems in adolescence [40]. As a result, the development of mental problems in elementary school associate with poor academic results, academic failure, low level of self-esteem, and depression [41]. Thus, self-regulation empowerment strategies with the improvement of neurocognitive problems can greatly solve the educational problems of these students and improve their self-confidence in the relationships with teachers and other classmates. Self-regulation strategies for solving social problems also help students to control situations and issues more easily. Upon facing unpleasant events, they act more cautiously and are more aware of different solutions and evaluate them [23].

The existence of a group factor in the self-regulation empowerment program facilitates the activation of self-regulation techniques and has important effects on social judgments such as social exclusion, distrust, and emotional deprivation. In fact, due to the establishment of close links and relationships between members of the group, the possibility of experiencing learning techniques in a protective environment also increases. Moreover, by increasing the opportunities for strategic education, the feeling of self-efficacy and experiencing new behaviors are strengthened, so the members of the group learn to express their empathy and fulfill their emotional needs instead of abandoning their emotions [21].

LIMITATIONS AND FUTURE RESEARCH

This study had limitations such as a small sample size (26 students), the therapist and the researcher were the same person, and follow-up was not possible. To prevent the bias effect, it is suggested to use a larger sample size in each group and assign a single person as the therapist, and if possible, consider a 3-6-month follow-up course to evaluate the effects of training in a longer time in future studies. Based on the results of the current study, we suggest that specialists and therapists consider the self-regulation empowerment training approach and design training plans in working with the students with dyscalculia.

CONCLUSION

Learning self-regulation strategies improved neurocognitive skills and these skills affected the academic and family aspects of the students with dyscalculia. Additionally, by learning the self-regulation program, students managed to deal with their emotions and social interactions. This training has been more useful in terms of time, cost, efficiency and productivity compared to other existing trainings that focus on specific aspects.

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