Original article

The effect of basic neuropsychological interventions on performance of students with dyscalculia

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Abstract

Objective: There are many children who have dyscalculia. The aim of the current research was to investigate the effectiveness of basic neuropsychological interventions in improving mathematics performance of girl students (8-9 years old) with dyscalculia (mathematics learning disabilities) in Isfahan city of Iran.
Material and methods: The research method was experimental with pretest, posttest and a control group. To this end, the statistical population of this study comprised second grade girl students (8-9 years old) of elementary school during 2011-2012. Considering the entry requirements for the research, 30 girl students were selected by multi-stage sampling and were randomly assigned to two groups, experimental and control. To gather data, the Wechsler Intelligence Scale for children (WISC-III-R), Keymath test, math academic performance test and clinical interview were used. The obtained data were analyzed by covariance analysis and using SPSS18 statistical software.
Results: The results revealed a significant difference between the mathematics performance of the experimental and control groups, girl students with dyscalculia, in pretest and posttest stages with $p \leq 0.001$ significance level.
Conclusions: According to the results of the research, it is suggested that neuropsychological interventions can improve mathematics performance of students with dyscalculia and this method can be used for curing and assisting this group of students.

Key words: neuropsychological, mathematics learning disabilities, academic performance, dyscalculia.

Introduction

The term "learning disabilities" was first put forward by Kirk (1963). On the other hand, it is stated that learning disabilities are a set of heterogeneous disorders which manifest in serious difficulty with acquiring and applying listening, speaking, reading, writing and calculating, and these disorders have neurological origins which have a developmental process that begins at preschool and continues until adulthood (Gartland and Stronsnider 2007).

It has also been mentioned that learning disability is a type of neuropsychological disability which creates a serious problem for reading, calculating and writing, and if it is not assessed well, it has a potential influence on maladaptive performance of individuals and creates difficulties in life's dimensions and a neuropsychological assessment will be essential to determine the source of the problem (Emami 2010). On the other hand, some experts in the field of learning disabilities propose two views: 1) neuropsychological/developmental learning disabilities and 2) educational learning disabilities/achievement (Kirk *et al.* 2006).

Those who have chosen the neuropsychological/developmental view seek an internal cause for the students' problems in subjects. Based on this division, biological/genetic, perceptual-motor, visual processing, auditory processing, memory and attention disorders are classified into neuropsychological/developmental learning disabilities (Shaleve and Gross Tsure 2007).

The term neuropsychological and neurological dyscalculia is used when the defect and deficiency in doing mathematics skills is a sign of developmental or abnormal delay in understanding one or more mathematical operations (Mazzocco 2001). In addition, the American Psychiatric Association (APA) uses dyscalculia for children whose mathematics skills, given the child's age conditions and measured cognitive ability, are below the expectations. Thus, we assume that this problem, deviation or deferral in the process and expansion of mathematical concepts' growth and skills' achievements has happened in childhood. Regardless of this deviation or deferral, there is agreement that a neuropsychological origin exists in creating mathematical difficulties (Shaleve and Gross Tsure 2007).

The prevalence estimates of dyscalculia in students have been reported to be 5-8% (Rousselle and Noël 2007; Gersten *et al.* 2005) and nearly 5% in Tehran city (Ramezani 2001). It is supposed that there is a neuropsychological underpinning of dyscalculia which might be the result of genetic or non-genetic factors (Shaleve and Gross Tsure 2001).

One promising result of the conducted studies in the field of dyscalculia is the consistency of these findings in the association between neuropsychological characteristics and mathematical problems (Hale and Fiorello 2004). Three subtypes of dyscalculia have been suggested (Geary 1993). The first subtype is manifested by a deficit in verbal semantic memory (the memory related to the meaning of words) and leads to difficulties such as memorization and retrieval of arithmetic facts even after repetition and ample practice. This kind of disability seems to be associated with left hemisphere malfunction and is typically seen alongside a reading disorder.

The second subtype of dyscalculia includes using developmentally immature methods for solving mathematical problems and frequent errors in solving simple problems (Geary 2010; Geary *et al.* 1999). The third subtype of dyscalculia, which has lower prevalence, apparently includes a visuo-spatial skills defect and leads to inappropriate columnar alignment or place value errors (placing decimal points inappropriately).

In etiology, and designing and preparing instructional interventions, attention to the characteristics and neuropsychological profiles of these children is pivotal. Potential cognitive factors of neuropsychology are involved in causing the three above problems. Hence, there have been a considerable number of investigations into neuropsychological features of children with mathematics learning disabilities during the last few years (Hale and Fiorello 2004).

One of these children's problems which has attracted the researchers' and experts' attention is the weakness of executive functions and attention that has been proved by a large number of studies (Semrud-Clikeman 2005; Fletcher *et al.* 2007; Meltz 2007; McCloskey *et al.* 2009; Geary 2010). Perception disorders (agnosia, discrimination and sense interpretation) have attracted the attention of experts in the field of learning disabilities. Some prevalent disorders in the field of perception are: visual reception disorder, visual discrimination, visual memory, auditory discrimination, auditory memory and sensory integration (Fletcher *et al.* 2007).

Other pieces of research have also demonstrated that students with dyscalculia have severe difficulties with language skills including phonological awareness, rapid automatic naming and speech production (Geary 1993; Bley and Thornton 2001; Geary 2004; Swanson and Jerman 2006). Moreover, research studies have shown that students with dyscalculia, in comparison to the normal group, have problems in visuo-spatial processing (Semrud-Clikeman 2005; Geary 2005).

Typically, students with dyscalculia have difficulty with memorizing auditory and visual stimulants. Swanson *et al.* (2009) concluded that memory scales can discriminate the students with learning disabilities from slow learners and average students. These researchers point out that the students with learning disabilities manifest dominant failures of active memory (short-term).

Numerous studies have demonstrated that these students have performance problems in memory functions such as active memory, memory for names, memory for faces, active visuo-spatial memory and long-term memory (Swanson and Jerman 2006; Jordan *et al.* 2007; Meyer *et al.* 2010).

Further, they are significantly weaker in acquiring and remembering mathematical concepts such as the facts and principles of mathematics, the concept of numbers, numeration, calculating and solving problems in comparison to normal students (Swanson *et al.* 2009; Jordan *et al.* 2010).

On the other hand, the studies conducted on brain hemispheres have suggested that mathematics is a reciprocal task and demands both right and left hemispheres' activities (Menon *et al.* 2002), which might relate to the nature of mathematics' assignments and reveal hemispherical differences, that is, patients with left hemisphere injuries encounter difficulty with calculation and patients with right hemisphere injuries face solely mathematics reasoning difficulties (Isaacs *et al.* 2001; Menon *et al.* 2002; Hale and Fiorello 2004; Geary 2010).

Additionally, the studies of Hale and Naglieri (2004) demonstrated that visual processing skills and processing speed anticipate mathematics achievement but the success variance in mathematics is associated with semantic and active memory. This view supports the belief that dyscalculia has a multiple neuropsychological origin. Also, the new imaging studies of neuropsychological processes in mathematics have illustrated that prefrontal and inferior parietal areas (which comprise angular and supramarginal gyri) are more involved in mathematics skills (Hale *et al.* 2003; Hale and Fiorello 2004; Varma and Schwartz 2007; Pennington 2009).

The research studies of Oreizi *et al.* (2005), Abedi *et al.* (2008), Mir Mehdi *et al.* (2009) and Abedi (2010) have shown that children with learning disabilities, particularly students with dyscalculia, have difficulties with neuropsychological aspects (executive functions, attention, language, visuo-spatial processing, memory and learning) and failure in neuropsychological skills can predict children's learning disabilities. Semrud-Clickeman (2005) also found in their promising investigations that a substantial number of students with learning disabilities have abnormal brain waves.

Some researchers (Gersten *et al.* 2005; Dowker 2005; Swanson and Jerman 2006; McCloskey *et al.* 2009; Penington 2009; Meyer *et al.* 2010; Jordan *et al.* 2010; Geary 2010; Abedi 2010; Mazzocco and Hanich 2010) have pointed out the influence of neuropsychological interventions (e.g., instructing and reinforcing executive functions, attention, language skills, visuo-spatial processing and active memory) on improving academic progress of children with dyscalculia. Moreover, these researchers emphasize that with respect to mathematics assignments which have multiple neuropsychological underpinnings, neuropsychological interventions must include all aspects.

It can be inferred from the studies mentioned above that the foundation of academic problems of students with dyscalculia is disorders and difficulties in neuropsychological processes, and provided that neuropsychological interventions occur the performance of mathematics students will be improved. Therefore, the chief question of this investigation is: do neuropsychological interventions have an effect on improving the performance of students with dyscalculia? The hypothesis of the current research is that basic neuropsychological interventions influence the mathematics performance of students with dyscalculia.

Material and methods

Research methodology

The current research employed a quasi-experimental design with pretest, posttest and a control group. The independent variable and dependent variable are respectively neuropsychological interventions and academic performance of girl students (8-9 years old) with dyscalculia in mathematics.

Statistical population and sample

The research population consists of all dyscalculia girls students (8-9 years old) in the second grade of elementary school during the 2010-2011 academic years in Isfahan city of Iran. Using multi-stage sampling, we chose two elementary schools randomly from all 6 educational districts in Isfahan. Subsequently, one class from each elementary school was randomly selected according to the entry requirements for the research: 1) serious problems in learning mathematics (arithmetic) by considering Keymath test scores, academic achievement test of mathematics and educational result paper of first and second grade girl students (8-9 age) of elementary schools; 2) having an average or upper IQ level determined using the Wechsler Intelligence Scale for children (WISC); 3) enjoying physical and psychological health affirmed by a physician, counselor and teacher; 4) having an appropriate social, economic and cultural status. Thirty students with dyscalculia were randomly selected from the above-mentioned schools and divided into two groups, experimental (15) and control (15). Furthermore, parents were satisfied with their children's participation and were informed about all the intervention stages. Eventually, neuropsychological interventions (independent variable) were conducted on the experimental group.

Research instruments

1. Wechsler Intelligence Scale for Children-III (WISC-III-R). This scale was designed by Wechsler in 1949; this scale was revised and named Wechsler Intelligence Scale for Children-III (WISC-III-R) after standardization. Shahim (1998) standardized it in Iran.
2. Keymath test. This test was made by Conolly (1988); in terms of topic and order it is made up of three sections – basic concepts, operations and applications – and each section is classified into three or four areas. Mohammad Esmaeil and Hooman (1999) standardized this test by making use of Cronbach's α for Iranian students of 6.6-8.11 years of age and the reliability was reported to be 0.57, 0.62, 0.67, 0.56, and 0.55. This test is considerably efficient at recognizing students with dyscalculia (Conolly 1988).

Procedures

After the pretest, in order to reinforce and instruct neuropsychological aspects (executive functions, attention, visuo-spatial processing, language, working memory), interventions were conducted in 10 sessions of 2 hours (2 sessions a week). Training the experimental group lasted for two months.

Neuropsychological interventions' underpinning is activities which cause the stimulation and reinforcement of neuropsychological connections. These activities include:

1. Reinforcing active memory: exercises related to reinforcing auditory and visual memory, enhancing recognition memory by hidden objects, practice with meaningless words, numbers and recalling them, following orders in story style, and showing a movie.
2. Reinforcing attention: reinforcing visual attention by pictures in which a particular feature or object is among other distractors, reinforcing auditory attention by audiotape, maintenance and auditory attention (hearing a favorable excerpt without attending to the noise).
3. Training executive functions such as planning and organizing: instructing planning for short-term goals, performing and following plans to achieve the goals, classifying cubes and bars based on length, color and thickness, constructing the structure according to the model, storing and recalling the details associated with a math problem.
4. Developing and reinforcing visuo-spatial perception: doing exercises associated with reinforcing eye-hand coordination, doing balancing exercises, finding ways through a labyrinth, identifying geometric shapes and volumes without using the eyes, moving according to perceptive and balancing mosaics, recognizing shapes from the background, copying models by using graph paper.
5. Reinforcing the skills related to speech and language: auditory discrimination reinforcement by using Belz, auditory sensitivity reinforcement by using dark cans, phonological awareness, fitting words into texts, listening comprehension, understanding words and mathematics concepts.

At the end of each training session, some assignments were given as exercise to the parents and a few sports in parallel with intervention programs such as bowling for reinforcing the child's attention, playing hula hoop and tire for reinforcing spatial perception, playing with dolls and attention to detail for reinforcing visual precision, preparing an audiotape for reinforcing auditory precision and storytelling were introduced.

Statistical data analysis

The research data were analyzed and interpreted by statistical criteria of average, variance, standard deviation and covariance analysis by making use of SPSS software.

Results

The principal research hypothesis was: neuropsychological interventions influence the academic performance of girl students (8-9 years old) with dyscalculia. To demonstrate the groups' differences, first the average and standard deviation of experimental and control groups and then covariance analysis are presented.

As Table 1 shows, the average of the whole experimental group in the pretest stage was 5.97, and this average for the control group was 6. In the posttest, the average of all scores of mathematics tests for the experimental group and control group was respectively 10 and 5.67. Eventually in the follow-up stage, the total average of the experimental group is 9.13 and 5.6 for control group. These results are shown in Table 1.

As can be seen in Table 2, considering the pretest scores as the auxiliary variable, neuropsychological interventions have led to a significant difference between the experimental and control group ($p < 0.001$); the effect size is 0.79. That is, 79% of the posttest variance (math academic performance) is caused by neuropsychological interventions. Statistical power of 100 also proves the sufficiency of sample size. Therefore, it can be concluded that neuropsychological interventions have had an effect on improving mathematics academic performance of girl students (aged 8-9) with dyscalculia.

Discussion and conclusion

As stated, the aim of the current research was to examine neuropsychological interventions' effectiveness on mathematics academic performance of students with mathematics learning disability. Covariance analysis showed that considering pretest scores as the auxiliary variable, neuropsychological interventions (reinforcing attention, executive functions in planning and organizing level, working memory, language skills and visuo-spatial processing)

Table 1. Average and standard deviation of math performance scores in two groups, experimental and control

Variables	Experimental group					Control group				
	n	pre-test		post-test		*n*	pre-test		post-test	
		SD	mean	SD	mean		SD	mean	SD	mean
basic concepts	15	3.33524	22.8667	1.63299	29.3333	15	3.02056	21.4667	1.11270	22.3333
operations	15	3.60951	31.2000	2.32584	44.5333	15	2.92770	30.0000	1.40408	28.6000
applications	15	3.45309	31.0667	2.76371	40.9333	15	2.50713	31.0000	1.57963	29.7333
total	15	9.31870	85.1333	6.13188	114.8000		6.96795	82.4667	3.55903	80.6667

Table 2. Summary of covariance analysis results related to the effect of neuropsychological interventions on math academic performance of students with mathematics learning disability

Variables	Source	Type III sum of squares	Df	Mean square	F	Sig.	Partial Eta squared	Observed power
basic concepts	pre-test	0.330	1	0.330	0.164	0.689	0.006	0.068
	group	354.164	1	354.164	175.984	0.000	0.867	1.000
operations	pre-test	6.519	1	6.519	1.818	0.189	0.063	0.255
	group	1797.944	1	1797.944	501.419	0.000	0.949	1.000
applications	pre-test	0.670	1	0.670	0.128	0.723	0.005	0.064
	group	940.103	1	940.103	179.769	0.000	0.869	1.000
total	pre-test	13.293	1	13.293	0.520	0.477	0.019	0.107
	group	8388.149	1	8388.149	328.023	0.000	0.924	1.000

had an effect on augmentation and mathematics performance improvement of elementary students with mathematics learning disability. Consequently, the research findings prepare the ground to infer that mathematics is a bilateral task and needs the activity of both hemispheres (right and left) and strengthens the belief that students' disabilities in learning mathematics have multiple neuropsychological foundations and hence it needs multilateral examination of neuropsychological aspects and multidimensional neuropsychological interventions. The research results are in line with Gersten *et al.* (2005), Dowker (2005), Geary (2005), Swanson and Jerman (2006), McCloskey *et al.* (2009), Pennington (2009), Geary (2010) and Mazzocco and Hanich (2010). These researchers have shown the efficacy of neuropsychological interventions in mathematics academic performance of children with mathematics learning disabilities. They have reported that the performance of elementary school children with mathematics learning disabilities in neuropsychological tests (executive functions, attention, memory and visuo-spatial processing) is drastically weaker than normal children. To explain the research findings, it can be said that children have to be proficient in a set of skills which are neuropsychological aspects such as attention, executive functions, language, visuo-spatial processing and memory. Normal children will learn these skills automatically whereas children with learning disabilities encounter difficulty with applying these skills and are not able to master them automatically. On the other hand, identifying the weak points of a child with learning disability in neuropsychological dimensions can lead to an effective educational plan and understanding the problem.

Highlighting the effect of neuropsychological interventions on improving mathematics performance of students, the results of these studies support the view that during the process of mathematical calculations different areas of the brain and hemispheres are involved and children do not use one method for solving arithmetic problems. In this view it is concluded that mathematical errors of children also follow different patterns. Accordingly, multilateral neuropsychological examinations are needed to evaluate a child.

In examining the history pertaining to the topic it has been realized that behavioral neurology is the root of neuropsychology and behavioral neurology is a branch of neurology which concerns performance disorders of high cognitive levels (such as language, understanding, and visual perception) (Zillmer *et al.* 2008). On the other hand, the main purpose of neuropsychological evaluation is that the information obtained from children's behaviors is a reflection of the integration of the nervous system's performance (Stinnett *et al.* 2002).

Studies on neuropsychological characteristics of learning disability provide a firm logic for using neuropsychological cures for these learner populations, since this approach results in renewal and improvement of sensory-motor and perceptive systems of a child.

Neuropsychology involves the idea that the person's neuropsychological hardware determines the whole behaviors of a person and there are signs which indicate that stimulation or neuropsychological interventions cause changes in the brain's performance. There are also signs that stimulation or intervention can cause changes in the brain's performance (Zillmer *et al.* 2008).

The aim of early interventions' effect with augmenting the stimulations is to release the potential abilities of an individual. Likewise, numerous re-education efforts for people with stroke and traumatic brain injury (TBI) are the foundation of these hypotheses that the brain can improve to some degree.

Besides, the assumption of the neuropsychological approach is the mental ability to create a cause and effect relationship between the area of brain error and deviation in the student's mathematics ability. To classify special areas, the psychiatrist attempts to show which parts are responsible for mathematics performance of learners who have difficulties with mathematics. Afterwards, with the cooperation of learning disabilities and neuropsychology experts they design a set of neuropsychological interventions.

In conclusion, although this research has limitations including limitation of the kinds of instruments and sample selection, it is suggested that this investigation be practiced on various learning disabilities according to gender, age and also demographic features. It is also recommended that the managers and teachers of pre-elementary and elementary schools design rich educational environments along with instructive play so that the nervous prerequisites of the children for growth in executive functions, attention, visuo-spatial processing, language and memory are more reinforced and ameliorated. To this end, attention to neuropsychological interventions as fundamental mathematics learning skills can be an effective approach in curing and improving the performance of children with mathematics learning disabilities.

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