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THE DISCREPANCY OF THE ASYMMETRIES OF DIFFERENT ANALYZERS REDUCES MATHEMATICAL ABILITIES IN ADOLESCENCE

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SUMMARY

Background: One of the bases of the classification of individual differences in differential neuropsychology is that of interhemispheric asymmetry and interaction. There is conflicting evidence as to the role of the right and left hemisphere in providing mathematical abilities. Much of this discrepancy is due to different approaches to the measurement of interhemispheric asymmetry and the allocation of the various components of mathematical abilities. There is reason to believe that matching / mismatching the asymmetries of different analyzers affects mathematical ability.

Material/ Methods: The study involved 65 healthy subjects, aged 15 to 25 years (19 ± 2.3), including 4 men and 61 women. None of the subjects were engaged in mathematical activity professionally. To evaluate the manual asymmetry the following techniques were used: a standardized M. Annett questionnaire modification (Annett, 1970; Khokhlov, Burova, 2014) and the "Napoleon pose" (on the elbow). Visual asymmetry was assessed by means of the Rozenbakh test. Dichotic listening was used to assess audio-verbal asymmetry (Kimura, 1961) in the Russian-language adaptation (Kotik, 1974). Mathematical capacity was measured by a standardized test of mathematical (arithmetic, algebraic, geometric) abilities "MAAGA-2015" (Khokhlov, 2015).

Results: The discrepancy between the visual and the audio-verbal asymmetry is a negative predictor for arithmetic abilities (R^2 = 0.26), geometrical abilities (R^2 = 0.12), and mathematical abilities in general (R^2 = 0.23). The discrepancy between the manual and visual asymmetries significantly reduces the ability of geometric (R^2 = 0.09), and mathematical abilities in general (R^2 = 0.07). The positive impact of mismatched asymmetries was found only in relation to algebraic skills (R^2 = 0.07) when comparing the results of the Rozenbakh test and the "Napoleon pose", however, upon removing subjects, through the absence of the leading eye, from analysis the positive impact becomes insignificant.

Conclusions: Our study has shown that the discrepancy of asymmetries of different modalities creates a negative impact on the mathematical abilities of adolescence. The most significant negative predictor of mathematical ability is a mismatch of sensory (visual and audio-verbal) asymmetries. The findings confirm the need to take into account the combination of hemispheric asymmetries of different analyzers in neuropsychological studies.

Key words: inter-hemispheric asymmetry, lateral signs,
analyzers interaction, mathematical ability, differential neuropsychology

INTRODUCTION

The neuropsychology of individual differences is one of the modern branches of neuropsychological knowledge and neuroscience in general. When studying any psychological phenomena, the question of its structure and normal brain mechanisms are inevitably raised. Many classification types have been devised for studying healthy people, many of which take into account particular qualities of brain functions. One of the bases of such a typology of individual differences are the particularities of inter-hemispheric asymmetry and inter-hemispheric interaction.

Russian neuropsychology has suggested the term "profile of lateral organization" (PLO), which refers to the combination of lateral signs of sensory and motor asymmetries (Khomskaya, Efimova, 1989, 1991). The method of PLO determination is based on the following principles: the use of three types of asymmetries: manual, audio-verbal, visual; the assessment of not only the fact of asymmetry, but also its extent; the recognition of the varying significance of manual, visual and audio-verbal asymmetries. Information that was obtained within the framework of this approach shows the connection between PLO and the dynamic characteristics of mental activity, the operational structure of cognitive processes, the emotionally-personal sphere and other psychological characteristics (Khomskaya, Efimova, Budyka, Enikolopova, 2011; Moskvin, Moskvina, 2011). However, information about the drawbacks of this approach has surfaced over the last decade, and the techniques and tests used for assessing motor and sensory asymmetries do not always give consistent results (Nikolaeva, Borisenkova, 2008; Nikolaeva, Dobrin, Yavorovich, 2012, Khokhlov, Kovyazina, 2012; Khokhlov, Kovyazina, 2013b). Meanwhile, the idea that one should consider the asymmetry of multiple analyzers when comparing the inter-hemispheric relations with psychological characteristics remains highly relevant. A possible research technique is the use of different neuropsychological methods of hemispheric asymmetry assessment without a summation of their results within a single modality (different methods can measure the various components of the asymmetry of the analyzer).

A particular problem is the effect of matching / mismatching the asymmetries of different analyzers to psychological characteristics. This challenge is closely linked to the issue of intermodal interaction. A human's systematic mental activity is carried out by continuous inter-analyzer interactions that have their own laws, and which cannot be reduced to the sum of the regularities of the isolated functioning of the individual analyzers. In Russia, the interaction of the senses was actively investigated S.V. Kravkov (1948), but his results are almost never taken into account when conducting neuropsychological research. There is reason to believe that cross-modal interactions exist between all possible pairs of modalities, as they provide an effective adaptation of the organism to the outside world (Calvert, 2001; Spence, 2011). Interestingly, intermodal paths are characterized by pronounced lateral variations, which are different for different combinations of modalities (Catani, de Schotten, 2012). Our recent studies conducted with N.V. Morozova (Kovyazina, Khokhlov, Morozova, 2015, 2016) have shown that the cross-lateralization of manual and audio-verbal spheres negatively affects the productivity of audio-verbal perception. Although the discrepancy between asymmetries is a common phenomenon in the normal population, it is often seen as a deviation from the norm, indicating a delay in the formation of the lateralization process.

In this study an attempt is made to compare the matching / mismatching of lateral signs in the manual, audio-verbal and visual areas with the degree of manifestation of mathematical abilities in adolescent people. There is reason to believe that the discrepancy between the asymmetries of different analyzers reduces mathematical ability. The relevance of the topic relates to the need to identify patterns of brain provision for mathematical ability, an account of the typological features of hemispheric relations in the teaching of mathematics and the selection of mathematically gifted students.

To date, there is no consensus as to the success of individuals with a certain profile of lateral organization in mathematics. Much of this discrepancy is due to the different approaches to the measurement of inter-hemispheric asymmetry and mathematical abilities. In some studies (Annett, Kilshow, 1982; Matova, 1987; Lukianchikova, 2006; Knops, Willmes, 2014) evidence has been obtained that the right hemisphere plays the leading role, in others (Rickard et al, 2000; Arshavskii, 2001, Khokhlov, Kovyazina 2013a; Khokhlov, 2014) – the left hemisphere of the brain. Based on the theoretical foundation of Russian neuropsychology (Khomskaya, 2010), we have every reason to believe that the implementation of various components of mathematical abilities is associated with the leading role of different hemispheres, and for some components – with hemispheric interaction efficiency. There are also pieces of psychophysiological research in favor of this (Razumnikova, 2004; Aydarkin, Fomina, 2013). Meanwhile, there is no systematic published data showing the effects of matching/ mismatching asymmetries of various analyzers on mathematical ability.

In psychology, there is no single definition of mathematical abilities. Researchers emphasize the different aspects of mathematical activity, focus on different psychological characteristics that contribute to success in mathematics. In our work, we have relied on the concept of V.A. Krutetckii (1998), who proposed the division of the readiness to activity and ability. For the successful implementation of activity in addition to the ability needed are certain features of the will and the character, corresponding the relation to such activity (interests, aptitudes), etc. Abilities are only the features of the sensory, motor and mental spheres. Interest in a particular activity does not necessarily coincide with the ability to do so. This means that the success of the activities is not always possible to judge the abilities. The subject may want to do anything, but does not have the appropriate level of the sensory, mental or motor sphere (operational components of the activity), or possessing the requisite ability, have no desire to engage in the activity (Pąchalska et al 2015).

Since the activity of a professional mathematician differs from the activity of a man who studies to math, it is justifiable to speak about a minimum of two types of mathematical abilities. If the first type ensures activity in the study of mathematics, then the second is a collection of the individual features needed for professional mathematical activity. In this case studying professional mathematical abilities is far more complex, for in professional mathematicians it is practically not possible to separate ability from the other psychological characteristics which facilitate the success in the activity. Taking these circumstances into account, it would be better to compare mathematical abilities with the lateral signs in people who do not carry out professional mathematical activity and who are not trained in mathematical specialties. We understand that in this case we are talking about the first type of mathematical abilities. However, it is from such mathematical abilities as ones more related to the individual characteristics of analyzer systems, that we should expect a pronounced relation to the parameters of inter-hemispheric asymmetry.

The aim of the study

The purpose of the study is to test the hypothesis that the discrepancy between the asymmetries in the manual, audio-verbal and visual spheres is negatively associated with mathematical abilities in adolescence, as well as determining the specificity and the extent of this connection.

MATERIAL AND METHODS

The study involved 65 healthy subjects, aged 15 to 25 years (19 ± 2.3), including 4 men and 61 women. 12 people had finished secondary or technical school, and at the time of the survey had an educational level not lower than the basic general (9 forms of completed schooling), 38 people were attending Moscow universities (non-mathematical specialties), 15 people had been awarded an academic degree in non-mathematical subjects.

For the study of sensory and motor asymmetries the following methods were used:

1. A standardized M. Annett (1970) questionnaire modification to assess the functional manual asymmetry (Khokhlov, Burova, 2014). The modification of the questionnaire consists of 12 questions (the first part of the Russian adaptation of the original questionnaire). The procedure of processing results assumes the use of weight coefficients for the different answers: “always right” (2) “more often right” (1) “any hand” (0), “more often left” (1) “always left” (-2). Percentile standardization was carried out on a sample of 232 respondents, which allows the conversion of raw scores into z-scores. The synchronous reliability of the questionnaire (Cronbach’s alpha) is 0.941.
2. The “Napoleon pose” test (crossing the hand on the elbow – R, L). When crossing arms on the chest the elbow of the leading hand will be on top. Here-

inafter, the abbreviation "R", "L" and "A" stand for the right-side, left-side asymmetry and ambidexterity (bilaterally), respectively.

3. The Rozenbakh test (R, A, L). the subject holds a pencil in his outstretched hand and fixes his eyes on a certain point or a vertical line (at a distance of 3-4 meters). A closing of the leading eye leads to a shift in the pencil's position.
4. Dichotic listening (Kimura, 1961) in its Russian adaptation (Kotik, 1974); conducted in two series. In the first series, the right earpiece is worn in the right ear, the left – in the left. 13 audio fragments of 4 words are presented in each ear simultaneously. After each fragment the subject needs to answer what words were heard. Then the headphones are reversed and the experiment is repeated. Data was obtained on 44 subjects The coefficient of the right ear was evaluated according to the results the dichotic listening (REC – right-ear coefficient). This coefficient was determined according to the formula: REC = $(\Sigma D - \Sigma S) / (\Sigma D + \Sigma S) * 100\%$, where ΣD is the total quantity of correctly reproduced words presented to the right ear and ΣS is the total of correctly reproduced words presented to the left ear.

Mathematical capacity was measured by a standardized test of mathematical (arithmetic, algebraic, geometric) abilities "MAAGA-2015" (Khokhlov, 2015). The test is a psychometric method designed to diagnose the level of mathematical abilities in adults and adolescents with an educational level not lower than the basic general (9 forms of completed schooling). This method can detect the level of development of the components of mathematical abilities (arithmetic, algebraic and geometric abilities), and determine the degree of development of mathematical abilities in general. The test included an additional attention scale, determining the efficiency of working with information and the current concentration on the task. Although attention in itself is not a mathematical ability, it should be considered in this study. The attention scale correlates with all the major scales of the test at the level of 0.2-0.3. There is a known connection between attention, other cognitive abilities and intelligence. In studies this scale can be used as the referent, allowing one to assess the specificity of the connection of other characteristics with mathematical abilities. The "Arithmetic" scale contains 7 test items (Cronbach's alpha – 0.612), the "Algebra" scale – 11 test items (Cronbach's alpha – 0.685), the "Geometry" scale – 7 test items (Cronbach's alpha – 0.606), the total of the "Mathematics" scale – 25 test items (Cronbach's alpha – 0.822), the "Attention" scale – 11 test items (Cronbach's alpha – 0.55). Test results correlate with academic performance in mathematical disciplines (0.4-0.5), the results of the unified state exam in mathematics (0.337), the results of the intelligence structure test by R. Amthauer (correlation with the math subtest – 0.692). The "Attention" scale correlates with the indicators of performance of the B. Bourdon Attention Test (0.3-0.4). The percentile standardization was carried out on a sample of 185 subjects, and allows the conversion of raw scores into z-scores.

Detailed information about the development, psychometric characteristics and the test procedure of MAAGA-2015 is provided in the methodological guide

(Khokhlov 2015). The testing was conducted using an online version of the test which was based on a “Master-tests” platform of the integrated system of Internet services “HT-Line”, provided by the Innovation Centre “Humanitarian technologies”, Ltd.

Mathematical and statistical processing of the data was performed using RStudio 0.99.892 (packages RVAideMemoire, psych).

RESULTS

Descriptive statistics for the data listed below (Table 1).

First, the subjects were divided into two groups on the basis of the matching/ mismatching of visual and audioverbal asymmetry. One group consisted of those who had the matching of the indicators of lateralization based on the Rozenbakh test and on dichotic listening (quantitative values of REC were transferred into the categorical scale according to the rule: REC < -8 – “L”, -8 ≤ REC ≤ 8 – “A”, REC > 8 – “R”), the other those who had a mismatching. The results of the comparison of average values are given below (table 2).

Groups differ significantly on the arithmetic, geometric and mathematical abilities in general, at the level of the slight tendency toward significance on algebraic abilities. In all cases, there is an advantage for the coincidence of asymmetries.

A similar situation occurs when separating the subjects on the basis of the matching/ mismatching of visual and manual asymmetry. Manual asymmetry is determined by the transferring of raw scores from the modification of M. Annett questionnaire into the categorical scale, according to the rule: less than -8 – “L”, from -8 to 8 inclusive – “A”, greater than 8 – “R”. Results comparing the average values are shown below (Table 3).

Groups differ significantly with respect to geometric abilities and mathematical abilities in general. For all other variables the subjects with matching asymmetries also display higher values, although the difference is not statistically significance.

Table 1. Descriptive statistics of the measured variables

№	Variable	Variable type	Descriptive Statistics	N
1	M. Annett questionnaire (modification)	metric (standardized)	15.6 ± 10.9 (-0.2682 ± 0.8424)	61
2	Napoleon pose	categorical	R – 42.2%; L – 57.8%	64
3	Rozenbakh test	categorical	R – 55.4%; A – 24.6%; L – 20%	65
4	REC	metric	2.5 ± 19	44
5	MAAGA-2015 test “Arithmetic” scale	metric (standardized)	4.1 ± 1.6 (0.216 ± 0.9159)	65
6	MAAGA-2015 test “Algebra” scale	metric (standardized)	5.5 ± 2.1 (0.1141 ± 0.8354)	65
7	MAAGA-2015 test “Geometry” scale	metric (standardized)	3.7 ± 1.7 (-0.0343 ± 0.9752)	65
8	MAAGA-2015 test “Mathematics” scale	metric (standardized)	13.5 ± 4.3 (0.1397 ± 0.8098)	65
9	MAAGA-2015 test “Attention” scale	metric (standardized)	9.2 ± 1.1 (0.0647 ± 0.7540)	65

Table 2. Influence of matching/ mismatching of visual and audio-verbal asymmetry on the results of the MAAGA-2015 test

MAAGA-2015 scales	Matching of asymmetries (N = 18)	Mismatching of asymmetries (N = 26)	F (1, 42)	p	R^2
Attention	0.1638 ± 0.7534	0.0031 ± 0.8011	0.449	0.507	
Arithmetic	0.7178 ± 0.7739	-0.2213 ± 0.8273	14.436	0.0005	0.2558
Algebra	0.4166 ± 0.7832	-0.0625 ± 0.886	3.412	0.0717	0.0752
Geometry	0.3911 ± 0.7544	-0.2695 ± 1.0024	5.602	0.0226	0.1177
Mathematics	0.619 ± 0.6339	-0.177 ± 0.7924	12.562	0.001	0.2302

Table 3. Influence of the matching/ mismatching of visual and manual asymmetry in the results of the MAAGA-2015 test

MAAGA-2015 scales	Matching of asymmetries (N = 31)	Mismatching of asymmetries (N = 30)	F (1, 59)	p	R^2
Attention	0.2312 ± 0.699	-0.0965 ± 0.8305	2.788	0.1	
Arithmetic	0.2538 ± 0.8344	0.047 ± 0.9599	0.808	0.372	
Algebra	0.2801 ± 0.7337	-0.0769 ± 0.957	2.684	0.107	
Geometry	0.222 ± 0.8636	-0.3406 ± 0.9655	5.761	0.0196	0.089
Mathematics	0.3243 ± 0.7225	-0.113 ± 0.8715	4.564	0.0368	0.0718

Matching/ mismatching results from the Rozenbakh test and the “Napoleon pose” significantly affect only algebraic abilities, moreover the smaller standardized value is observed with the matching of lateral signs (N = 27, -0.1483 ± 0.8573), than with a mismatching (N = 37, 0.306 ± 0.7989); F (1, 62) = 4.746, p = 0.0332, R^2 = 0.0711. This pattern refutes the assumption about the negative impact of any cross lateralization. In addition, it is confirmed that the M. Annett questionnaire and the “Napoleon pose” test measure different components of manual asymmetry which relate to mathematical abilities in different ways. However, it should be taken into account that the Rozenbakh test results have three gradations, while the “Napoleon pose” test – two. Accordingly, all subjects with the lack of a dominant eye are in the group with a mismatched lateralization when comparing the asymmetries. We have previously shown that a visual bilaterality is a positive predictor of algebraic abilities, so matching/ mismatching asymmetries might not matter. To verify the result of the analysis, we excluded subjects with an absence of visual asymmetry. The differences were no longer statistically significant, however in the group with the mismatched lateral signs the standardized value of algebraic skills (N = 22, 0.1917 ± 0.8389) remained higher than in the group with a match (N = 27, -0.1483 ± 0.8573).

The matching/ mismatching of audio-verbal and manual asymmetries were not significantly associated with the components of mathematical abilities.

DISCUSSION

The discrepancy of asymmetries of different modalities negatively impact on mathematical abilities in adolescence. The most important feature is the matching/ mismatching of visual and audio-verbal asymmetries, which is significantly associated with arithmetic (R^2 = 0.26), geometric (R^2 = 0.12), and mathematical abilities in general (R^2 = 0.23). Less important is the matching/ mismatching of manual and visual asymmetries which are significantly associated with geometric (R^2 = 0.09) and mathematical abilities in general (R^2 = 0.07). The positive impact of the discrepancy between the asymmetries is found only in relation to algebraic abilities (R^2 = 0.07) when comparing the results of the Rozenbakh test and the "Napoleon pose" test, but it becomes insignificant when one removes the subjects with the absence of the leading eye.

Thus, the most significant negative predictor of mathematical ability is a mismatch of sensory asymmetries. There are different interpretations of the results. Firstly, a general principle of reciprocal activity of the cerebral hemispheres may be behind the negative impact of the mismatching of the sensory asymmetries. Activation of one hemisphere is accompanied by the inhibition of the other, so if asymmetries are mismatched the effectiveness of both analyzer systems is reduced. Secondly, the discrepancy of asymmetries could hinder intermodal collaboration and an integral perception of the world. The effectiveness of intermodal interaction, in turn, is a positive predictor of mathematical abilities. Thirdly, the existence of certain intermodal complexes which process perceived information and play a role in the process of thinking is possible. The configuration of these complexes depends on the characteristics of the inter-hemispheric relationships (see also Oszwa 2007). Differences in the organization of these complexes specify the manifestation of various abilities.

The results of this study confirm the necessity of taking into account the combination of asymmetries of different modalities in neuropsychological studies. In the long term the available neuropsychological typology of individual differences can be supplemented with the lateralization of intermodal interactions. We believe that for some mental processes and psychological characteristics this typology will have a much greater predictive ability.

CONCLUSIONS

Our study has shown that the discrepancy of asymmetries of different modalities creates a negative impact on the mathematical abilities of adolescence. The most significant negative predictor of mathematical ability is a mismatch of sensory (visual and audio-verbal) asymmetries. The findings confirm the need to take into account the combination of hemispheric asymmetries of different analyzers in neuropsychological studies.

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