

Theses

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**Mathematical intelligence and executive control functions
Attentional switching, attentional selectivity, memory updating**

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Theoretical background

The basic aim of the dissertation was to investigate the relationship between mathematical exceptionalism, and working memory as the central construct of the cognitive system, especially the effectiveness of attentional system.

It is expedient to interpret mathematical reasoning as mathematical intelligence, and mathematical exceptionalism as derivation of advanced factors of mathematical intelligence. Mathematical intelligence, like intelligence in general sense could be described in a hierarchical, factorial structure in which the factors represent abilities of different generality. Mathematical abilities appear as a congenital reasoning (inductive and deductive) potential, a system of knowledge acquired by learning, an ability to learn and remember, an ability to visualise and percept the spatial relations and less as speed of perceptual and cognitive processes. Accordingly, mathematical intelligence could be represented in the factors of fluid and crystallized intelligence, general memory and learning, broad visual perception, cognitive speediness and processing speed. Mathematical exceptionalism could be interpreted as the advanced level of mathematical abilities mediated by congenital and environmental factors.

Working memory could be considered as the functional hub of cognition. Working memory is a multicomponential, limited-capacity system for the temporary storage and manipulation of information. The (verbal and visual-spatial) subsystems specialised for the different aspects or modalities of information determine the processes and limitations of information-processing whereas the central executive is thought to be an attentional-supervisory system for the control, coordination and regulation of processes in working memory. The processes of control are carried out by some different but interrelated executive functions, such as attentional selection or inhibition, attentional switching, memory updating, and coordination.

Numbers of studies have shown that mathematical reasoning, especially mental arithmetic performance as manifestation of mathematical intelligence relies on resources of working memory. The involvement of components of working memory in mathematical reasoning may be different with respect to the development of mathematical abilities and different aspects of mental arithmetic. Besides the slave systems the central executive or the executive functions have a great impact on

arithmetical (simple and complex) performance and on individual differences in specific (mathematical abilities) and non-specific (math-anxiety) factors related to mathematical performance.

Aim of study and hypotheses

Our study looks for a possibility to interpret high-level mathematical performance on the basis of effectiveness of working memory, especially the supervisory-attentional system. Accordingly, our broadest hypothesis states that executive control processes of the central executive component of the working memory system have a crucial role in mathematical intelligence.

Contrasting the achievement of a group with excellent mathematical abilities and the achievement of another group with proper mathematical abilities both related to effectiveness of executive functions allows us to interpret the relation between mathematical intelligence and characteristics of basic – not definitely specific to mathematical reasoning – information processing. Accordingly, the above mentioned hypothesis could be specified as follows: the individual differences related to mathematical intelligence have their origin in individual differences related to effectiveness of executive control processes.

To test our hypotheses we have planned a series of experiments. In the first part of the study two different groups were selected. The goal of the selection was to form groups, which differ sharp from each other in respect of features of mathematical giftedness.

The goal of the laboratory experiments was to investigate the achievement of participants where the effectiveness of executive control functions is the exclusive determinative factor. In other words, we formed experimental situations in order to investigate the functions of central executive. The experimental paradigms were chosen on the basis of the methodology of attentional functions, accordingly computerised reaction time experiments were used to test attentional selectivity and attentional switching, whereas working memory (or memory updating) capacity was tested using a psychometric tool.

Our hypotheses about the possible results of the experiments are as follows: significant difference could be demonstrated between the gifted and proper groups' achievement in favour of the gifted group in effectiveness of attentional selectivity

and attentional switching as executive control functions, and in the working memory (or memory updating) capacity.

General intelligence, as well as general working memory capacity could be considered as primary determinative factors related to data from laboratory experiments and to the psychometric index. Consequently we investigated the relationship between the general intelligence and general working memory capacity indices and the relationship between the indices and the achievement in experiments related to attentional selectivity and attentional switching. Furthermore we re-examined the group differences after controlling the effects of working memory capacity and the level of general intelligence. In relation to these all, our hypothesis was that we will not find significant relationship between the efficiency of executive control functions and the general intelligence and general working memory capacity.

The exploration of the interrelationship between the different contributing factors provides an opportunity for us to adopt a position on the question of the unity or diversity of executive control functions. Our hypothesis states that the control and regulation of working memory are carried out by some, different executive functions.

Subjects and methods

13-14-year old students (N=112) from a secondary school with a program for gifted students participated in the selecting part of the study. On the basis of Renzulli's Three-Ring-Concept of Giftedness general intelligence (Raven Advanced Progressive Matrices), specific, mathematical abilities (mathematical test), creativity (Torrance test of Creative Thinking), school motivation (Kozéki-Entvistle's School-Motivation Test) and school achievement (teachers' evaluation questionnaire, scores in mathematics and physics) were tested using a number of paper-and-pencil psychological tests and questionnaires. The classification of students into two, gifted (N=16) and capable (N=22) groups by a sorting schema based on the normalised general performance scores was generated from the weighted scores of tests and questionnaires. The age-group and the field of the study together with the materials and the sorting procedure ensured the sharpest contrast between groups in terms of mathematical abilities. In addition we can say that the most gifted students were selected for the laboratory experiments.

The first experiment examined the attentional switching using the value-amount version of task-switch paradigm. The second experiment tested some questions remained open after the first experiment by a modified version of the amount-value task-switch procedure. In both of the experiments using the *switch cost* (in terms of both reaction time and error rate), as an index of switching ability measured/characterised the efficiency of attentional flexibility (switching) or efficiency of executive control.

The third experiment tested the attentional selectivity using the Eriksen's noise/compatibility (flanker) paradigm, a version of Stroop task and partly the data from task-switch experiments. To characterise the attentional selectivity or inhibiting, an aspect of executive control *compatibility cost* (in terms of both reaction time and error rate), as an index of efficiency of processing were used for data from both of the experiments.

Finally the reading span task was used, which by loading the double function (storage and processing) of working memory tests the capacity of working memory or capacity to update memory.

In all of experiments and analyses we tried to partial out the effect of IQ as well as the effect of working memory capacity on attentional selectivity and flexibility and on group differences using Raven and reading span data as covariates.

Results

The obtained results of the analyses of reaction time data show robust basic effects (switch effects and compatibility effects). The switch costs from both experiments, as well as the compatibility cost from first task-switch experiment and from noise/compatibility experiment could not be explained by either the level of intelligence or general working memory capacity. However, the compatibility cost from the second and more memory-demanding task-switch experiment shows a significant negative relationship with working memory capacity.

The group comparisons show the superiority of the gifted group in switch costs resulting from both of the experiments and in compatibility cost from the task-change tasks, but not in the compatibility cost from the noise/compatibility task. The group differences remained sharp after controlling the effects of IQ and working

memory capacity. The analyses of the error rate data show that the speed-accuracy trade off effect could not eliminate the group differences.

The obtained group differences in the working memory capacity, which was in a strong linear relationship with IQ, could be interpreted only as a tendency.

In summary, based on the results we can state that the selective attentional and the flexible attentional aspect of the executive control seem to be independent but related control processes. Furthermore, the phenomena of attentional selection and attentional switching cannot be entirely accounted for on the basis of general working memory capacity hypothesis. Our findings are in accordance with the hypothesis that attentional selection or inhibition, attentional switching or switching and the working memory capacity or (memory) updating reflect independent mechanisms of executive control functioning, which could be interpreted in the framework of a multiple (fractionated) central executive.

Second, we can state that the general intelligence was found to be in close relationship only with the capacity of working memory or capacity to updating which is in accordance (indirectly) with the notion of the fractionated central executive and with the general intelligence (*g*)-general WM capacity hypothesis, too.

Third, we can state that the mathematical intelligence seems to bear a relation mostly the efficiency of attentional switching and attentional selection or inhibiting functions of central executive, but the working memory capacity (or updating function) only indirectly, mediated by the level of intelligence.

Consequently, mathematical intelligence could not be reduced to the high level of general intelligence, rather it seems to be a special pattern of the intellectual abilities, which abilities, first of all the fluid abilities seem to be a special pattern of elementary information processes, particularly that of the control, supervisory regulatory processes.