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PREDICTORS OF DEDUCTIVE REASONING IN PRIMARY SCHOOL CHILDREN

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Abstract
The relationship between reasoning and other cognitive skills is extensively discussed in the reference literature. At one pole, there are studies that consider memory a significant factor, and, at the other pole, there are studies that found no significant relationship between reasoning and memory. In this study, we propose to analyze the relationship between syllogistic reasoning, as form of deductive reasoning and other cognitive abilities (visual memory, respectively attention). We selected 215 primary school children to whom we applied the following instruments: a list of syllogistic problems, a scale for the evaluation of visual memory and a scale for the assessment of attention. The results show that visual memory explains in a better way syllogistic reasoning, while attention is intensely involved in solving counterfactual syllogistic reasoning tasks.

Keywords: deductive reasoning, syllogism, visual memory, attention, primary school

Introduction

The relationship between reasoning as cognitive ability and the other cognitive skills is extensively discussed in the reference literature. Some authors, supporters of factorial theories, argue that reasoning must be approached in close connection with intelligence. Thus, Spearman identifies two factors: factor g (a general ability) and factors s (specific skills). Thurstone includes reasoning in the category of six primary factors: the numerical factor,

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the verbal factor, the spatial factor, memory, verbal fluency and reasoning. For Cattell, intelligence is not a unitary construct; there are two types of intelligence: fluid intelligence (Gf) and crystallized intelligence (Gc). Fluid intelligence is involved in solving problems using inductive and deductive reasoning, concept formation and classification, whereas crystallized intelligence is involved in acquired declarative knowledge. The human intellect is a universe of processes organized into systems that perform tasks within problem solving (Demetriou, Spanoudis, & Mouyi, 2011).

The relationship between reasoning and memory should be discussed in terms of chronological age. In adults, working memory is linked to the successful activation of information - relevant framework when people reason with familiar causal conditionals. Thus, there is a certainty that cognitive skills do not have only a role in hypothetical, logical thinking, but they are necessary for reasoning in order to solve contextualized problems. During reasoning, memory structures that are associated with the content of the problem are automatically accessed and specific elements within the structure are activated. The less associated a given item is with the context of the task, the more we need greater effort and longer time in order to refresh it.

As regards the relationship between reasoning and other cognitive skills in early childhood, we shall present in the following pages Salthouse's theory, similar with Fry and Hale's theory (1996, *apud* Nettelbeck & Burns, 2010) known as "developmental cascade", which involves a sequence of stages within which the processing efficiency of a certain stage has a particular effect on the next stage. The child's cognitive development is described in terms of causal relations between chronological age, processing speed, working memory and fluid intelligence. After the statistical control of age, individual differences in processing speed influence memory; when we control age and processing speed, working memory influences fluid intelligence.

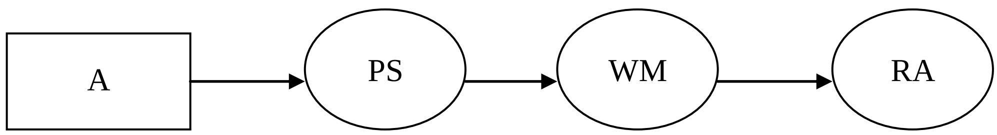

Figure 1. Developmental cascade (Nettelbeck & Burns, 2010)
(A - chronological age; PS - processing speed; WM - working memory; RA - reasoning ability)

Many studies have investigated the relationship between working memory and deductive reasoning. Gilhooly et al. (1993, *apud* Morrison, 2005) asked participants to solve syllogisms at different levels of complexity. In the first experiment, participants viewed or heard the premises, as these were read. Oral presentation should determine a higher demand of working memory, because the content of the premise had been preserved before they solved the problem. They found more errors in verbal condition than in visual condition. The author concludes that reasoning is dependent on visual working memory.

Many theories argue that a significant restriction regarding the ability of reasoning refers to the limits of mental resources, in particular working memory. There are studies that demonstrate the link between working memory and performance in the case of deductive reasoning. The theory of mental models allows a more profound explanation of this idea. Reasoning involves the construction and manipulation of mental models, which are a form of analogous representations. Although the exact nature of these models and their relationship with mental images is not clear, it is assumed that spatial ability should influence reasoning. Studies in developmental psychology argue that deductive reasoning with abstract premises is more difficult (Markovits & Vachon, 1990, *apud* Markovits, Doyon, & Simoneau, 2002) and requires complex cognitive processes. Reasoning that has familiar content may involve the use of concrete representations (Barrouillet & Lecas, 1998; Markovits et al., 1996, *apud* Markovits, Doyon, & Simoneau, 2002).

Mental logic considers that participants, first of all, transform the premises in a propositional form. Then, they apply mental inference rules to extract the conclusion from the premises. According to this theory, some errors may appear. Those who solve syllogisms impress incorrectly the premises, they cannot have access to the corresponding inferential rule or the number of rules; the rule can be placed improperly in the working memory. The theory of mental model states that there are three stages in solving a syllogism. First, a model of possible states is built. Then, a conclusion is drawn relating the terms of premises. Finally, an alternative model is sought, which does not support the conclusion. But, there are syllogisms within which the representations of premises can be combined in a single way and syllogisms that may have two or three possibilities. If people are exploring all possible combinations of the premises, they will act correctly in solving them. Poor performance is explained by the difficulty to consider all the ways of combining the information from the premises because of the limitations of working memory.

The theory of logical rules for syllogistic reasoning and spatial reasoning emphasizes the role of language-based representations. Consequently, both spatial and syllogistic reasoning should seek resources of verbal memory. The theory of mental models proposes that reasoning depends on the manipulation of spatial representations, suggesting that spatial working memory is the best predictor for reasoning tasks. Although these two theories realize predictions on the role of verbal and spatial resources. These theories have in common the fact that the limits of working memory represent a key factor in determining the performance in the case of deductive reasoning tasks. The theories based on heuristic processes assign a minor role to working memory in reasoning tasks. Participants use strategies that require in a low extent explicit processing. Different people may adopt different strategies, some adopt verbal strategy based on rules, others adopt spatial strategy based on the theory of mental models.

The processing speed and the capacity of working memory for short term storing were considered key elements of intelligence. Working memory has a significant contribution in solving complex cognitive tasks. Studies on abstract syllogistic reasoning represent evidence that there is a strong link between working memory and reasoning performance. The better the working memory capacity is, the more normative responses we will have (Copeland & Radvansky, 2004; Gilhooly, Logie, & Wynn, 1999, *apud* Verschueren, Schaeken, & d'Ydewalle, 2005). The information stored in long-term memory and the coherent combination of the updated elements is a key of working memory. The relationship between working memory and reasoning is explained by the fact that reasoning presupposes a process of analytical thinking which captures the resources of working memory. Individuals with highly developed skills will use reasoning more intensively, in comparison to those who are in the opposite category. The role of working memory in deductive reasoning tasks is described by the following stages:

- *Representation and maintenance* (sentences that are brought together in the space of working memory represent the content of the problem and the probabilistic estimation. Regarding the representation of knowledge necessary in order to make a probabilistic estimation, it is assumed that the people involved in a process of reasoning are not aware of the situations facing them. Only the final product is available to conscience. Most models of working memory argue that there is a close relationship between the content of working memory, attention and consciousness. Such situations are not explicitly represented in working memory, but they are quickly accessed in order to produce automatic probabilistic estimates).

- *Retrieval* (there is no active control of the search process based on generating solutions. In its function of supervision, the central part of control should be involved in monitoring the updating processes).
- *Inhibition* (low levels of updating the situations required to infer probability appear in an automated, heuristic manner. Although the components of central control can control errors, there is a space for active blocking or inhibiting the automatically updated information).
- *Premise integration* (it is not necessary to integrate premises as the estimation of probability is based on all relevant situations. The final conclusion directly reflects the estimation of probability).

In a study conducted by Markovits, Doyon and Simon (2002) on conditional reasoning with concrete and abstract content, positive correlations were obtained between working memory and logical forms modus ponens, affirmation of consistent and negation of antecedent; however, there was no evidence regarding a relationship with working memory and modus tollens. This logical form is the most difficult and involves different processes than the other logical forms. Young children will respond more often correctly than the older ones to modus tollens. Although there are no statistically significant differences, there is a stronger association between short-term visual memory and concrete reasoning than abstract reasoning. These results support the idea that there are different ways of processing involved in reasoning with concrete and abstract premises, the concrete ones rely more on visual short-term memory and the abstract ones are dependent on verbal short-term memory. Positive correlations between working memory and reasoning with concrete premises are based on the theory of concrete models.

The results of this study converge with those of Copeland and Radvansky (2004, *apud* Verschueren, Schaeken, & d'Ydewalle, 2005) on syllogistic reasoning. The degree in which participants rely on analytical reasoning strategies is directly proportional to the size of control operations. The conclusion of this study is that memory does not have a decisive role in reasoning; however, it determines the processes that participants use in order to reach a conclusion.

Thus, the research findings concerning the relationship between deductive reasoning and memory, respectively attention have not reached a consensus; some of them support the important role of memory in solving reasoning tasks, others have not found a direct relationship between these skills. In this study we propose to analyze the relationship between syllogistic reasoning and visual memory, respectively attention at primary school age.

Objectives

The objective of this study is to analyze the relationship between the four forms of syllogistic reasoning and visual memory, respectively attention. The hypothesis that we are to test in this study is the following: we assume that visual memory, respectively attention represent predictors of performance in the case of syllogistic reasoning tasks.

Method

Participants

In this study, we included 215 primary school children, selected at No. 11 Middle School, Oradea. The average age is 9,647 and the standard deviation is 0,955. Out of the 215 school children, 85 pupils attend grade II, 74 pupils are in grade III and 56 are in grade IV. According to their gender, 100 pupils are female and 115 are male. The educational level of the parents determines the following sharing: 159 pupils have parents who are high school graduates and 56 have parents with higher education.

Instruments

In order to fulfill the objectives, we used a set of 16 syllogisms (Appendix 1). These syllogisms were grouped into four categories: universally affirmative, universally negative, particularly affirmative and particularly negative. Each category includes four syllogisms. Each syllogism consists of two premises and a conclusion. The conclusion is formulated as a question. Pupils must answer that question. In the case of each of these syllogisms, the children had the possibility to choose one option from the following: yes, no or unsure. If pupils chose the correct version, they were given one point. We calculated a total for each of the four categories and a total for all syllogisms. In addition to this list, we used a list of counterfactual syllogisms, two in each category (Appendix 1).

We also applied instruments for measuring visual memory (Memory of Design - MD) and Numbers / Letters (NL) within battery WRAML2.

Procedure

These syllogisms were applied in the paper and pencil version. As a way of application, we used the collective application, after a briefing. MD and NL were applied individually.

Presentation and interpretation of the results

We obtained significant relationships between visual memory, respectively attention and universally negative, particularly affirmative, particularly negative syllogistic reasoning, and in the case of counterfactual syllogisms, significant correlations were obtained with particularly affirmative and particularly negative syllogisms (Table 1).

Table 1. Matrix of correlations for the included variables

Measured variable	Total score MD	Total score NL
Syllogism	0.405**	0.203**
UA	0.111	-0.030
UN	0.406**	0.184**
PA	0.204**	0.142*
PN	0.283**	0.184**
Counterfactual syllogism	0.269**	0.350**
UA	0.130	0.255**
UN	0.049	0.127
PA	0.352**	0.363**
PN	0.291**	0.346**

Note: $^{**}p<.01$; $^{*}p<.05$

In order to verify if the regression analysis is appropriate, we calculated multicollinearity indicators: indicators VIF (Variance Inflation Factor) and tolerance. If VIF values are over 10, and the tolerance values are below 0.10, the conditions of use of regression are broken, due to high multicollinearity (Sava, 2004). We have to specify that for all variables included in the model we obtained VIF values above 1.90 and the tolerance coefficient values are above 0.10.

The dependent variable (criterion) is represented by syllogistic reasoning and counterfactual syllogistic reasoning, i.e. the scores obtained in the case of the four forms of syllogistic reasoning (UA - universally affirmative; UN - universally negative PA - particularly affirmative PN - particularly negative). The independent variables (predictors) are visual memory, assessed by Memory Design scale and attention, evaluated by Numbers/letters scale.

Table 2. Results of regression analysis aimed at estimating syllogistic reasoning based on visual memory and attention (N = 215)

Involved variables	R^2	Adjust. R^2	Beta	B	SE b
Visual memory					
UA	0.012	0.008	0.111	0.010	0.006
UN	0.165	0.161	0.406	0.053	0.008
PA	0.042	0.037	0.204	0.021	0.007
PN	0.080	0.076	0.283	0.036	0.006
Attention					
UA	0.001	- 0.004	-0.030	-0.004	0.010
UN	0.034	0.029	0.184	0.039	0.014
PA	0.020	0.015	0.142	0.023	0.011
PN	0.034	0.029	0.184	0.038	0.014

The obtained results show that visual memory best explains universally negative reasoning, Adjust. R^2=.161. Thus, 16.1% of the variance of the level of universally negative reasoning is explained by visual memory. Particularly negative reasoning is explained in proportion of 7% by visual memory. The analysis of these data enables us to conclude that visual memory has a higher explanatory power than attention in the case of syllogisms (Table 2).

Table 3. Results of regression analysis aimed at estimating syllogistic contrafactual reasoning based on visual memory and attention (N = 123)

Involved variables	R^2	Adjust.R^2	Beta	B	SE b
Visual memory					

Table 3. Results of regression analysis aimed at estimating syllogistic contrafactual reasoning based on visual memory and attention (N = 123) - *continued*

Involved variables	R^2	Adjust.R^2	Beta	B	SE b
UA	0.017	0.009	0.130	0.013	0.009
UN	0.002	0.006	0.049	0.005	0.008
PA	0.124	0.117	0.352	0.037	0.009
PN	0.085	0.077	0.291	0.032	0.010
Attention					
UA	0.065	0.057	0.255	0.040	0.014
UN	0.016	0.008	0.127	0.018	0.013
PA	0.132	0.125	0.363	0.058	0.014
PN	0.119	0.112	0.346	0.058	0.015

As regards counterfactual syllogistic reasoning, particularly affirmative forms are explained in proportion of 11.7% by visual memory (Adjust. R^2=0.117). Particularly syllogistic reasoning, both positive and negative, is explained by attention (for affirmative forms, Adjust. R^2=0.125, and for negative forms, Adjust. R^2=0.112) (Table 3).

Table 4. Results of regression analysis regarding the estimation of syllogistic and counterfactual reasoning based on visual memory and attention

Involved variables	R^2	Adjust. R^2	Beta	B	SE b
Visual memory					
Syllogistic reasoning	0.164	0.160	0.405	0.119	0.018
Counterfactual syllogistic reasoning	0.072	0.065	0.269	0.087	0.028
Attention					
Syllogistic reasoning	0.041	0.037	0.203	0.095	0.032
Counterfactual syllogistic reasoning	0.123	0.115	0.350	0.174	0.043

The analysis of Adjust. R^2 values leads us to conclude that syllogistic reasoning is explained in proportion of 16% by visual memory. Thus, there is a direct relation between the predictor and the criterion. If we increase the level of visual memory with a standard deviation, the level of syllogisms will increase by 0.405 standard deviations. Visual memory has a higher explanatory power than attention, in the case of syllogisms. Things change in the case of counterfactual syllogisms, which are explained in percent of 11.5% by attention (Table 4).

Table 5. Results of regression analysis regarding the estimation of syllogistic and counterfactual reasoning based on visual memory and attention for pupils in grade IV

Involved variables	R^2	Adjust.R^2	Beta	B	SE b
Visual memory					
Syllogistic reasoning	0.127	0.111	0.356	0.124	0.044
Counterfactual syllogistic reasoning	0.093	0.069	0.305	0.104	0.052
Attention					
Syllogistic reasoning	0.025	0.007	-0.157	-0.086	0.074
Counterfactual syllogistic reasoning	0.007	-0.018	0.087	0.038	0.071

In the case of pupils in grade IV, 11.1% of the dispersion of syllogisms is explained by visual memory. We can notice an increase of 0.356 standard deviations of performance in the case of syllogisms when visual memory increases with one standard deviation. Attention explains 7% of the variance of performance in the case of syllogistic reasoning (Table 5).

Discussions

The hypothesis that we formulated at the beginning of this study, according to which visual memory and attention represent predictors of syllogistic reasoning, was partially confirmed. Taking into account the obtained results, we tend to think that visual memory explains in a better way syllogistic reasoning, while attention explains in a better way counterfactual syllogistic reasoning. Of course, when you have to solve a counterfactual problem, attention is more intensely required, because the pupil has to operate with information that is contrary to reality. Negative forms of syllogisms are better explained by visual memory, because these require the activation of a larger amount of information in the process of solving them.

Memory is important for information processing, as the information retained for a short period of time affects reasoning and problem solving. This process is responsible for the maintenance/storage and handling of information during cognitive activity. Reading, analyzing and finding solutions appeal to working memory; therefore, the cognitive processes involved in a valid logical conclusion also include working memory. In the case of our study, we find that the visual memory and attention of pupils in the fourth grade does not explain very well syllogistic reasoning, as it happens at the level of the whole sample.

We conclude that the ability to successfully solve syllogistic reasoning is influenced by visual memory only at certain points of development.

One can highlight individual differences concerning reasoning skills because some people cannot conceptualize all possible models. Spatial memory facilitates solutions to deductive reasoning tasks according to mental models. Mental logic supports the role of verbal working memory. In order to solve correctly a problem of reasoning, a series of intermediary results must be kept in memory. Pupils retain the information from the premises, trying, based on these, to reach a correct solution. By means of memory, pupils are able to process informational units, facilitating the construction of complex concepts and relations.

Many theories of deductive reasoning claim that this ability is inherently related to memory. Both theories of reasoning, the theory of mental models and the theory based on rules, converge towards the idea that individual differences in the capacity of working memory should be correlated with the ability to provide appropriate logic responses to more or less complex inferential problems (Markovits & Quinn, 2002). Although working memory is clearly a plausible factor for the explanation of differences in solving problems of varying degrees of complexity and individual differences, there is variability in deductive reasoning tasks that cannot be explained in this way. This variation can be explained with difficulty only by the capacity of working memory to handle certain representations; certainly, other factors are also involved.

In the study conducted on the relationship between memory and conditional reasoning, which included pupils, Markovits and Quinn (2002) found that individual differences can be explained at least partly by the information stored in long-term memory. In order to provide an answer to two invalid forms, (consistent affirmation and antecedent denial) participants should be able to update the possible alternatives from memory. This is difficult since the particular nature of causal premises requests seeking alternatives in the semantic field. The results obtained by these authors show a strong correlation between the updating speed of alternative information within long-term memory and the performance on the case of the two invalid forms. However, the responses to modus ponens and modus tollens were not related to the updating speed of information. These results can reflect the basic limitations of working memory. Both theories (theory of mental models and theory of mental logic) consider that reasoning of modus tollens type involves deeper processing than other types of reasoning. In the case of our study, we could notice that negative universally syllogisms require deeper processing because visual memory is intensely involved. In solving these problems, the reference literature describes two stages. In the first stage, premises are analyzed and information on alternatives is updated. Thus, a multi-variable model set is generated. The second stage involves the application of decision-making algorithm to the model set. An individual is effective if he takes into consideration and updates the alternative antecedents, allowing the rejection of erroneous conclusions.

Attention has a facilitator role in maintaining mental representations in an active state in the presence of interference. It is the element that ensures efficiency in processing information. Attention favors efficient processing by providing cognitive resources. The information obtained from external sources becomes available in a short time because irrelevant information will be ignored.

Superior performance on tasks of reasoning is based on intense reasoning processes, while poor performance is explained by heuristic processes that require working memory in a lower extent. People with superior skills rely on information based on counterexamples, while people with poorly developed working memory will reason based on probabilistic information.

Taking into consideration the results of the study initiated by Capon, Handley and Dennis (2003) we notice that working memory represents a good predictor of syllogistic and spatial reasoning. Thus, people who have high scores on tests of working memory will draw logical inferences corresponding to syllogistic and spatial arguments. A less clear aspect from the presented correlations determines posing the question whether syllogistic and spatial reasoning depends on verbal or spatial representations. The theory of heuristics suggests that conclusions are selected based on simple related heuristics. Such heuristics require cognitive resources in a lesser extent and are applicable, usually, to those with a low educational level. Executive processes play a minor role in the implementation of such heuristic strategies in syllogistic reasoning (Chater & Oaskfoard, 1999, *apud* Copeland & Radvansky, 2004).

Individual differences in working memory reflect the differences in controlled processing. Consequently, they will be reflected only in situations which either encourage or require controlled attention (Engle, Kane & Tuholski, 1999, *apud* Capon, Handley, & Dennis, 2003). Working memory and the attention system are not entirely separate or unitary within specific systems. They can be organized similarly to intelligence as hierarchical structures with a factor that overloads more specific subordinate factors.

Memory is an important component of active processing of information. It is the aspect of cognition where information is actively maintained, handled and elaborated. When there are a high number of mental models that need to be examined in order to reach a logical conclusion, more logic errors occur. The difficulty of answering correctly proposed syllogisms involves other explanations than those proposed by Johnson-Laird (high number of mental models). The inability of people to draw a valid, plausible inference is due to failure in understanding any valid model (Gilinsky & Judd, 1994).

The correlation between working memory and syllogistic reasoning is insignificant in the study conducted by Johnson-Laird, Oakhill and Bull (1986, *apud* Barrouillet & Lecas, 1999). The explanation of these authors is that syllogistic reasoning of children is based on other processes than the construction and manipulation of mental models.

In a previous study on the relationship between syllogistic reasoning and cognitive development (Boroş, 2011), we found that between „modus tollens" reasoning type and intellectual development there is a highly significant relationship, Adjust. R^2 coefficient being 0.52. Another line of research argues that abstract reasoning and cognitive abilities are not good predictors of reasoning and decision in real everyday situations. Social, motivational and affective influences, as well as previous thoughts affect the way in which individuals reason on various issues.

Some authors argue that heuristic responses decrease along with age due to the development of cognitive skills, while others argue that heuristics are independent of cognitive abilities. Therefore, all theories argue that analytical reasoning requires de-contextualization of problems.

The information on premises is updated during reasoning. It is unclear whether reasoning is influenced by the access to knowledge connected to premises; it is true that some people can find the logic solution even to counterfactual problems if they receive instructions. In some circumstances, this is difficult (Markovits & Potvin, 2001, *apud* Simoneau & Markovits, 2003). The inhibition of activated information is a complementary process that can explain this aspect. One difficulty in solving reasoning with counterfactual premises is represented by preventing access to empirical data, allowing access to potential antecedents. People solve reasoning problems in two ways: either they rely on fast access to stored information (based on automatic update mechanisms) or they base on rules and conscious processes (based on explicit evaluation forms). There is an antagonism between the two systems because the first system generates answers automatically, answers that are often incompatible with the normative responses generated by the explicit system.

Conclusions

The results of our study do not allow us to have a clear position on the relationship between syllogistic reasoning and visual memory, respectively attention. It is certain that visual memory is a more powerful explanatory factor for syllogistic reasoning, and attention for counterfactual syllogistic reasoning. We support the idea of researchers Heit, Rotello and Hayes (2012) that reasoning and memory represent elements of a whole and benefit from the same mechanisms. In addition, we would state that the two skills function within the same human cognitive system. What are the other variables that need to be considered in discussing this relationship? What is the relationship between inductive reasoning and visual memory, respectively attention at primary school age? These are questions that we shall attempt to answer in future studies.

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Appendix 1

Examples of syllogisms

Universally affirmative
1. All houses have windows.
All windows are made of glass.
Do all houses have glass windows?

Universally negative
1. All bears are animals that live in the forest.
No animal in the forest is fed with food.
Are bears animals that eat food?

Particularly affirmative
1. All houses have windows.
Andrew has a house.
Does Andrew's house have windows?

Particularly negative
1. In spring, no migratory bird leaves to hot countries.
The swallow is a migratory bird.
Do swallows leave to hot countries, in spring?

Examples of counterfactual syllogistic

Reasoning tasks
1. All frogs feed with honey.
A frog lives in the lake
Does this frog feed with honey?

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