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TÍMEA TÁNCZOS

AGE-RELATED CHANGES IN VERBAL FLUENCY AND WORKING MEMORY AND THEIR ROLE IN SCHOOL ACHIEVEMENT

Summary of PhD Thesis

Supervisor:

Dr. Dezső Németh

Habil. Associate Professor

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The topic and the structure of the dissertation

With the advent of cognitive sciences, the approach with which we think about human abilities has changed fundamentally. The refined methodology of and theoretical advances in cognitive psychology, and the biological approach of cognitive neuroscience and neuropsychology have turned the attention to the fact that we cannot speak about "big" functions, such as thinking, memory or learning, in regard to human cognition. There is not a single memory or learning system, but numerous, there is not "one" thinking, but several approaches exist. These can be well distinguished from each other both at the psychological level and at the level of brain networks. We, therefore, must think in more focused functions (*Csépe*, 2005, 2011; *Racsmány*, 2007; *Kállai*, *Bende*, *Karádi* and *Racsmány*, 2008).

The purpose of this dissertation is to study the developmental aspects of specific cognitive functions – the working memory systems and the executive functions –, and to map their relationship to achievement in school. Four large empirical studies are presented in the dissertation. In the first, second and third study, the principles of the Hungarian version of the listening span test, letter fluency test and semantic fluency test are described. The tests allow us to study more focused cognitive functions, because they are quite well mapped also at the level of nervous system networks.

The results of the first study reveal that the performance measured with the listening span test steeply increases from childhood to the age of 17 years, and then in adulthood, after the age of 45 years, a gradual decrease can be observed. A further result is that the listening span showed the highest correlation with the digit span and the reading span test.

In the second study, where the letter fluency task was investigated across lifespan, children aged 5 to 6 years produced only a very small number of words and the performance reaches the level of adults at the age of 17 to 18 years. The best performance was measured in the age group of 35 to 49 years. The adulthood performance considerably decreased after the age of 50 to 69 years.

In the third study, the development of semantic fluency was investigated on a sample covering the entire age range. According to our results, the subjects aged 5 to 6 years could produce more words during each of the three semantic fluency tasks than during the letter fluency task, and then, after a gradual development, the performance reached the adult level at the age of 17 to 18 years. The best performance was shown by the age group of 35 to 49 years, and then the performance considerably decreased after the age of 50 to 69 years, which is in accordance with several earlier results. Semantic fluency performance, therefore, increases faster with age than the performance achieved during the letter fluency task.

The fourth study investigated how the working memory system and the executive functions predict the achievement in school. As a result of the study, a relationship could be demonstrated between certain subcomponents of the working memory and executive functions, and the achievement in school. Our analyses focused on three school subjects: Hungarian language and literature, mathematics, and science education. In the case of Hungarian language and literature, the Corsi block-tapping test and the backward digit span test were of predictive value. The mathematics achievement was predicted by the performance during the counting span test, the letter fluency cluster number measure and the Corsi block span. In the case of science class, the determining factors were the counting span, the letter fluency cluster number and the sharp switching measure of semantic fluency. In summary, therefore, the school achievement in fourth grade was determined by the spatial-visual working memory, the complex working memory and certain components of the fluency tasks that measure executive and language functions.

Our results may be important not only to pedagogy and school psychology, but also to the neuropsychological practice. This method of examination may also help in the detection of working memory, language and executive function impairments in children with learning difficulties. The results presented in this dissertation support that the study of the focused cognitive functions with an interdisciplinary approach may serve as a useful tool for the more accurate and more detailed understanding of the background and individual differences in school achievement.

Theoretical background and conceptions

In the past decades, numerous research studies on working memory and certain subcomponents of the executive functions have been published in the international literature. There are few studies in Hungarian, however, that would map in detail the age-related changes in working memory and executive functions on a sample covering the entire (or almost the entire) age range. The study of developmental aspects is important because not only does it help in understanding the development and operation of cognitive functions, but it may also allow us to understand atypical development and, for example, learning disabilities. The study of focused cognitive functions enables mapping the neurocognitive background of school achievement, which may help in the development of more effective improvement methods. In this dissertation, an attempt is made to fill in this gap with the presented studies.

Working memory capacity and executive functions have an essential role in learning, and thus may fundamentally determine achievement in school (*St. Clair Thompson* and *Gathercole*, 2006; *Engle, Carullo* and *Collins,* 1991; *Gathercole* and *Alloway,* 2008). Consequentially, poorer working memory and executive functions may be a main problem in children with learning difficulties as well (*Alloway, Gathercole, Kirkwood* and *Elliott,* 2009; *McLean* and *Hitch*, 1999).

This paper, in addition, reviews the neuropsychological, neurological and psychiatric connections of working memory and executive functions, that is, what type of working memory and executive function deficits the injury, developmental disorder or hypofunctioning of the different brain networks are associated with, and what cognitive symptoms they cause. We discuss the main objectives, hypothesis, subjects and results of the study in the Table 1.

Table 1. The outline of the four experiments

	Objectives	**Hypotheses**	**Participants**	**Methods**	**Results**
First study	- Investigation of age-related changes in complex working memory - Listening span test in a Hungarian sample covering the age range of 4 to 89 years - Comparison of the listening span test, the reading span test and the digit span test	1. There is a different between the development of the groups. 2. We expect an inverse U-shape curve. 3. We expect the best achievement until the age of 60. 4. There is a decrease in performance after the age of 60. 5. There is a strong relation between the listening span test and the reading span test.	N=671, from 4 to 89 years of age, in 9 age groups (277 female/394 male; 603 right-/68 left handed)	- Listening span test - Reading span test - Digit span test	An increase in capacity with development from 13 to 15 years of age, a slow-down in development rate between 19 and 30 years of age, and then gradual decrease in performance after the age of 31 to 49 years until old age
Second study	- Investigation of age-related changes in executive functions - Letter fluency task in a Hungarian sample covering the age range of 5 to 89 years - A more detailed analysis of the studied variables	1. There is a different between the development of the groups. 2. In regard to the number of words the children at the age of 5 to 6 say just a few words. 3. The performance reaches the adult level at the age of 17 to 18 years 4. There is a decrease in performance after the age of 50 to 59 years	N=562, from 5 to 89 years of age, in 11 age groups (281 female/281 male; 505 right-/48 left handed, 9 missing data)	Letter fluency test and its studied variables: number of words, errors, perseverations and clusters, cluster sizes, total number of switches and number of sharp switches	- Mapping the quality measures of letter fluency in different age groups - In regard to the number of words, the performance reaches the adult level at the age of 17 to 18 years, and then there is a decrease in performance after the age of 50 to 69 years
Third study	- Investigation of age-related changes in executive functions - Semantic fluency task in a Hungarian sample covering the age range of 5 to 89 years - A more detailed analysis of the studied variables	1. There is a different between the development of the groups. 2. Children say more words in the semantic fluency task. 3. In regard to the number of words, 4. The performance reaches the adult level at the age of 17 to 18 years. 5. There is a decrease in performance after the age of 50 to 69 years 6. More words on the semantic fluency task.	N=562, from 5 to 89 years of age, in 11 age groups (281 female/281 male; 505 right-/48 left handed, 9 missing data)	Semantic fluency test and its studied variables: number of words, errors, perseverations and clusters, cluster sizes, total number of switches and number of sharp switches	- Mapping the quality measures of semantic fluency in different age groups - In regard to the number of words, the performance reaches the adult level at the age of 17 to 18 years, and then there is a decrease in performance after the age of 50 to 69 years
Fourth study	- The relationship between school achievement and working memory and executive functions - Comparison of the developmental status of the cognitive functions at entering school and achievement in school four years later	1. The performance of the spatial-visual working memory tasks predicts the achievement of the Hungarian language and literature. 2. The performance of the spatial-visual and complex working memory tasks predict the achievement of the Mathematics. 3. The performance of the complex working memory tasks predicts the achievement of the Science education.	N=105 children of typical development (mean age = 6.79 years, standard deviation = 0.54) (59 female/46 male; 88 right-/17 left handed)	- Non-word repetition test - Digit span test - Reverse digit span test - Listening span test - Counting span test - Corsi block-tapping test - Letter fluency task - Semantic fluency task	- The performance of the spatial-visual working memory and short-term memory tasks predict the achievement of the Hungarian language and literature. - The performance of the spatial-visual and complex working memory and executive function tasks predict the achievement of the Mathematics. - The performance of the complex working memory and executive function tasks predict the achievement of the Science education.

Theoretical background and conceptions of the Experiment I.

The Listening Span Test (*Daneman and Blannerhasset*, 1984) presented in our paper is a widely used measurement tool of the working memory in the English-speaking world (*Weismer, Plante, Jones* and *Tomblin*, 2005; *Osaka, Osaka, Kondo, Morishita, Fukuyama* and *Shibasaki*, 2004; *Cornoldi, Marzocchi, Belotti, Caroli, Meo* and *Braga*, 2001; *Swanson* and *Sache-Lee,* 2001; *Chiappe, Hasher* and *Siegel*, 2000; *Gathercole* and *Pickering*, 2000; *Adams, Bourke* and *Willis*, 1999; *De Beni, Palladino, Pazzaglia* and *Cornoldi*, 1998; *Siegel*, 1994; *Stothard* and *Hulme*, 1992). This test is used not only in research but in neuropsychological diagnostics and for the investigation of different developmental and learning disorders as well.

Objectives and hypothesis of the Experiment I.

One of our objectives was to create the Hungarian version of the listening span test, and then to test it on a large sample, thus providing normative data for different age groups. Another objective was to map the correlation between the listening span test and other neuropsychological tests that measure cognitive functions. Our hypothesis were that there is an increase in capacity with development from 13 to 15 years of age, a slow-down in development rate between 19 and 30 years of age, and then gradual decrease in performance after the age of 31 to 49 years until old age.

Our work therefore fills a gap, because it completes the attention and memory test battery available in Hungarian with a working memory measurement tool that, unlike the reading span test, allows the examination of broader target groups (e.g., children and adults unable to read or having difficulty reading, and different pathological groups).

Participants and methods of the Experiment I.

A total of 647 subjects, aged 4 to 89 years, participated in the study (402 female/245 male; 588 right-handed/59 left-handed). Subjects were assigned to age groups, on one hand based on literature data, and on the other hand in order to obtain groups of appropriately large size for the analysis. The following tests were used in our research: non-word repetition test, digit span and reverse digit span tests, reading span test and listening span test. We discuss the measurements of the Experiment I. in the Table 2.

Table 2. The measurements of the Experiment I.

<table>
<tr><th>Measurement procedure</th><th>Studied function</th><th>Task</th><th colspan="2">Correct answer</th></tr>
<tr><td>Non-word repetition test</td><td>Verbal working memory</td><td>Repeat one by one
E.g., “szan”</td><td colspan="2">“szan”</td></tr>
<tr><td>Digit span test</td><td>Verbal working memory</td><td>Memorize and repeat in order
E.g., “7–2–9–1”</td><td colspan="2">“7–2–9–1”</td></tr>
<tr><td>Reverse digit span test</td><td>Complex working memory</td><td>Memorize and repeat in reverse order
E.g., “4–9–6–1”</td><td colspan="2">“1–6–9–4”</td></tr>
<tr><td>Listening span test</td><td>Complex working memory</td><td>True/False, memorize, repeat last words in order. E.g.,
“A tool that the seamstress often uses is a pair of scissors”
“In the beaks of birds, there is always a lot of coffee”</td><td>“true”
“false”</td><td>“scissors
coffee”</td></tr>
<tr><td>Reading span test</td><td>Complex working memory</td><td>Read, memorize, repeat in order. E.g.,
“John began to cry because his delicious peanut chocolate was eaten by the cheeky monkey that reached out from the cage.”
“Since it was always raining, I had to realize that I should finally buy a pair of waterproof shoes.”</td><td colspan="2">“cage”
“shoes”</td></tr>
</table>

Results of the Experiment I.

According to our results, the performance measured with the listening span test steeply increases from childhood to the age of 17years, and then in adulthood, after the age of 45years, a gradual decrease can be observed – this corresponds to the English-language literature data, according to which working memory reaches its maximum later than verbal memory during development, and it is more sensitive to age-related changes in old age. Therefore, the listening span test elaborated by us may serve as a useful tool for the more differentiated measurement of working memory in different age groups, especially in regard to the study of developmental psychological cognitive changes and cognitive changes associated with aging. A further result is that the listening span showed the highest correlation with the digit span and the reading span test.

Theoretical background and conceptions of the Experiment II.

Letter fluency tests are frequently used tools in the neuropsychological diagnostics of cognitive functions in neurological and psychiatric conditions, as well as in experimental psychological, cognitive neuropsychological and neuroscience studies (*Benton* and *Hamsher*, 1989; *Lezak*, 1995; *Spreen* and *Strauss*, 1991). The performance achieved during the test provides useful information about word retrieval strategies and the development of lexical-semantic networks (within the language functions) both in childhood and in adulthood.

Several papers have been published about studies using a Hungarian fluency test (*Mészáros Kónya* and *Kas,* 2011; *Szendi, Kiss, Racsmány, Boda, Cimmer, Vörös, Kovács, Szekeres, Galsi, Pléh, Csernay* and *Janka,* 2006; *Klivényi, Németh, Sefcsik, Janacsek, Hoffmann, Haden, Londe* and *Vécsei,* 2012; *Sefcsik, Németh, Janacsek, Hoffmann, Sciabbala, Klivényi, Ambrus, Háden* and *Vécsei,*. 2009), but no studies on large samples that cover multiple age groups have been conducted. This, however, is indispensable for the clinical and research use of the tests.

Objectives and hypothesis of the Experiment II.

The objective of our second study were the **i**nvestigation of age-related changes in executive functions with the semantic fluency task in a Hungarian sample covering the age range of 5 to 89 years and a more detailed analysis of the studied variables. Our hypotheses were in regard to the number of words, the performance reaches the adult level at the age of 17 to 18 years, and then there is a decrease in performance after the age of 50 to 69 years.

Participants and methods of the Experiment II.

A total of 562 subjects, aged 5 to 89 years, participated in the study (281 female/281 male; 505 right-handed/48 left-handed/missing data in 9 cases). Because of the literature data and the appropriate group sizes, subjects were assigned to age groups. The letter fluency test was used in our research (*Benton* and *Hamsher*, 1989; *Lezak*, 1995; *Spreen* and *Strauss*, 1991). During the test, the study subject is asked to say as many words as they can based on a given criterion (e.g., words beginning with the sound "K") and within a given period (e.g., one minute). The following variables were investigated: number of words, number of perseverations, number of errors, number of clusters, size of clusters, total number of switches and number of cluster switches. When determining the variables, primarily the works of *Troyer, Moscovitch* and *Winocur (*1997), *Troyer, Moscovitch, Winocur, Alexander* and *Stuss* (1998), *Mészáros*, *Kónya* and *Kas* (2011) were taken as a basis, although certain variables were modified. We discuss the measurements of the Experiment II. in the Table 3.

Table 3. The measurements of the Experiment II

Measure	**Hungarian examples**	**Result**	**Evaluation method**
Number of words	“kefe, kalapács, kos”	3	total number of words said minus the number of errors and perseverations
Perseveration	“kutya, kér, kutya”	1	repetition of words that have already been given as answers
Error	“kutya, Kálmán, krumpli”	1	number of words that do not belong to the given category
Cluster number	“kapa, kar,”	1	successfully generated words that belong to the same subcategory
Cluster size	“kappa, kar, karmol”	2	number of words that form the cluster minus one (perseverations and errors do not count)
Cluster switch	“karom, karvaj | kefe, kert”	1	number of switches between adjacent clusters
Sharp switch	“korom, koszt, | kis” | kör	2	number of switches between a cluster and a word that does not belong to any cluster, or between two words that do not belong to any cluster

Results of the Experiment II.

In regard to the number of words, an age-related difference was found in each of the three letter fluency tasks. During the letter fluency task with the letter “K”, the performance reached the adult level at the age of 15 to 16 years, whereas during the tasks with the letters “T” and “A”, there was an improvement in performance also in the age groups of 19 to 34 years and 35 to 49 years. It was found in all three letter fluency tasks that children aged 5 to 6 years could produce only a very small number of words, which corresponds to the results of previous research (*Spreen* and *Strauss*, 1991). The performance reaches the adult level at the age of 17 to 18 years, in accordance with the results published by *Klenberg, Korkman* and *Lahti-Nuttila* (2001). The good performance in adulthood considerably decreased after the age of 50 to 69 years, which supports the results of *Van Der Elst, Van Boxtel, Van Braukelen* and *Jolles* (2006) and *Brickman, Paul, Cohen, Williams, Macgreggor, Jefferson, Tate, Gunstad* and *Gordon* (2005), who had also found a decrease in performance after the age of 50 years.

As to perseveration, there was a slow increase in its rate after the age of 17 years, and then a progressive increase could be observed in old age, which, according to numerous studies, may be related to a decrease in the functions of the frontostriatal network (*Daigneault, Braunk* and *Whitaker,* 1992; *Kozora* and *Cullum,* 1995). Contrarily, a reverse pattern can be seen in the case of errors, i.e., the error rate showed a decreasing trend until the age of 9 to 10 years, and then this pattern did not change until the age of 89 years. In summary, the healthy subjects participating in the study produced a relatively low number of errors and perseverations, which corresponds to the results of several previous studies (*Kozora* and *Cullum,* 1995; *Tröster, Salmon, McCullogh* and *Butters,* 1989).

In regard to the number of clusters, a slow-rate increase could be observed until the age of 15 to 16 years, and then the performance remained similar until 89 years of age. The cluster size showed a progressive increase after the age of 5 to 6 years until 7 to 8 years, and then a decrease was found until the age of 12 years, which was followed by a stagnant performance until the age of 89 years. In summary, therefore, the adult performance is reached at adolescence in the case of both measures, which is then resistant to age. As to the total number of switches, an increase can be seen after the age of 5 to 6 years until 9 to 10 years, and then the performance remained similar after the age of 11 to 12 years until 50 to 69 years, which was followed by another increase in the oldest age group. Contrarily, no age-related difference was found in cluster switches. Similar results were observed by *Troyer* (2000).

In summary, the performance during the letter fluency test reaches the adult level at the age of 15 to 16 years (in the case of the letter "K") and at the age of 17 to 18 years (in the case of the letters "T" and "A"), and a decrease in performance can be observed after the age of 50 to 69 years. This development curve may partly be caused by age-related changes in the prefrontal cortex.

Theoretical background and conceptions of the Experiment III.

Besides the letter fluency test, the semantic fluency test is also a widely used tool in the neuropsychological diagnostics of psychiatric and neurological conditions, as well as in experimental psychological, cognitive neuropsychological and neuroscience studies, and it is one of those tools of good usability over a broad age range (*Benton* and *Hamsher,* 1976; *Lezak,* 1995; *Spreen* and *Strauss,* 1991). These tasks belong to the classical measurement procedures of the executive functions, and the performance showed during the test may provide a more accurate picture of the development of word retrieval strategies and lexical-semantic networks (within the language functions) both in childhood and in adulthood. Semantic fluency tests may be useful measurement tools in the exploration of the cognitive impairments of children in different developmental and genetic disorders. The Hungarian semantic fluency test has been employed in several studies (*Klivényi* et al., 2012; *Sefcsik* et al., 2009; *Szendi* et al., 2006, *Mészáros, Kónya* and *Kas,* 2011), but no studies on large samples that cover multiple age groups have been conducted yet, which is important for clinical and cognitive neuropsychological professionals to be able to use these tests.

Objectives and hypothesis of the Experiment III.

The objective of our third study were the **i**nvestigation of age-related changes in executive functions with the semantic fluency task in a Hungarian sample covering the age range of 5 to 89 years and a more detailed analysis of the studied variables. Our hypothesis were in regard to the number of words, the performance reaches the adult level at the age of 17 to 18 years, and then there is a decrease in performance after the age of 50 to 69 years.

Participants and methods of the Experiment III.

A total of 562 subjects, aged 5 to 89 years, participated in the study (281 female/281 male; 505 right-handed/48 left-handed/missing data in 9 cases). Because of the literature data and the appropriate group sizes, subjects were assigned to age groups. The letter fluency test was used in our research (*Benton* and *Hamsher,* 1989; *Lezak,* 1995; *Spreen* and *Strauss*, 1991). During the task, the study subject are asked to say as many words as they can within a given category (e.g., animals) and within a given period (one minute). The following variables were investigated: number of words, number of perseverations, number of errors, number of clusters, size of clusters, total number of switches and number of cluster switches. When determining the variables, primarily the works of *Troyer* et al., (1997, 1998) and *Mészáros* et al., (2011) were taken as a basis, although certain variables were modified. We discuss the measurements of the Experiment III. in the Table 4.

Table 4. The measurements of the Experiment III.

Measure	Example	Result	Evaluation method
Number of words	"dog, cat, fox"	3	total number of words said minus the number of errors and perseverations
Perseveration	"lemon, orange, *lemon*, banana"	1	repetition of words that have already been given as answers
Error	"dog, cat, mouse, *rose*"	1	number of words that do not belong to the given category
Cluster number	"dog, cat, cow, chicken" →domestic animals	1	successfully generated words that belong to the same subcategory
Cluster size	"dog, cat, chicken"	2	number of words that form the cluster minus one (perseverations and errors do not count)
Cluster switch	"lion, tiger | eagle, owl"	1	number of switches between adjacent clusters
Sharp switch	"lion, tiger, | hamster" | anaconda	2	number of switches between a cluster and a word that does not belong to any cluster, or between two words that do not belong to any cluster

Results of the experiment III.

Of the three semantic fluency tasks, the "ANIMAL" semantic fluency task proved to be the easiest one, which is in accordance with the results of some previous research studies (*Baldo* and *Shimamura*, 1998; *Chan* and *Poon*, 1999; *Schwartz, Baldo, Graves* and *Brugger,* 2003). In the study, the subjects aged 5 to 6 years could produce more words during each of the three semantic fluency tasks than during the letter fluency task, and then, after a gradual development, the performance reached the adult level at the age of 17 to 18 years (*Chan* and *Poon*, 1999; *Klenberg*, *Korkman* and *Lahti-Nuutila*, 2001). The best performance was shown by the age group of 35 to 49 years, and then the performance considerably decreased after the age of 50 to 69 years, which is in accordance with several earlier results (*Troyer*, 2000; *Chan* and *Poon*, 1999; *Tombaugh, Kozak* and *Rees* 1999; *Loonstra*, *Tarlow* and *Sellers,* 2001; *Van der Elst* et al., 2001). Semantic fluency performance, therefore, increases faster with age than the performance achieved during the phonological fluency task (*Koren, Kofman* and *Berger,* 2005), that is, the age-related effects are significantly higher in the case of semantic fluency task than in the letter fluency test (*Gladsjo, Schuman, Evans, Peavy, Miller* and *Heaton*, 1999; *Troyer* et al., 1997). The number of perseverations was very low in each of the three semantic fluency tasks and in each age groups, but studies on patient groups consider it one of the best measures in brain damage (*Tröster* et al., 1989; *Kozora* and *Cullum*, 1995). Although an increase was found in the two oldest age groups, that is from 50 to 69 years and from 70 to 89 years, the number of perseverations was still very low.

The results show a similar trend for the number of errors, which increases in a U-shaped curve in the age groups of 5 to 10 years and 50 to 89 years. An exception for this is the "grocery shop" fluency task, where the lowest number of errors was seen in the oldest age group, and children aged 5 to 8 years produced considerably more errors. Overall, the error rate was very low in each of the age groups, similarly to the results of several previous research studies (*Kozora* and *Cullum*, 1995; *Tröster* et al., 1989).

As to the number of clusters, similarly to the number of words, a continuous development can be observed until the age of 35 to 49 years, and then the performances drops in the age groups of 50 to 69 years and 70 to 89 years. It is assumed that the development is caused by a more flexible cognitive control system until about 50 years of age.

Considering the total number of switches, there was an increase until the age of 15 to 16 years and 17 to 18 years during both the "ANIMAL" and the "FRUIT" semantic fluency tasks, and then the total number was stagnant until the age of 35 to 49 years, which was followed by a decrease in this measure in the age groups of 50 to 69 years and 70 to 89 years. A similar pattern can be seen also in the case of the "GROCERY SHOP" task, with the difference that the total number of switches was lower in the age group of 50 to 69 years than in the oldest age group.

The analysis of cluster switches also showed results of a similar pattern, i.e., the number of cluster switches increased until the age of 15 to 16 years and 17 to 18 years during the "ANIMAL" and "FRUIT" semantic fluency tasks, and then it remained constant until the age of 35 to 49 years, which was followed by a drop in this measure in the age groups of 50 to 89 years. Similar results were observed also in the case of the "GROCERY SHOP" task, except that the decrease in performance was not that considerable in the two oldest age groups, and the performance stayed at the level measured in the age group of 15 to 16 years.

When the results are considered from a gerontological point of view, it can be established that a decline in performance in regard to perseverations, errors, cluster number, total switches and cluster switches can be observed in the age groups of 50 to 69 and 70 to 89 years, i.e., the number of errors and perseverations increases, whereas the number of clusters and switches decreases at an older age. It can also be said, therefore, that older subjects switched less frequently during the semantic fluency task than younger ones, which may explain the decline in the number of words that can be observed at an older age. At the same time, cluster size is the only studied variable where the performance of old subjects remained intact, compared also with that of the younger subjects, which may indicate that the existing vocabulary is maintained at old age. The number of switches and clusters is therefore related to the frontal capacity, because cognitive flexibility is required for the strategic retrieval processes such as finding a new subcategory, switching and word finding within the new subcategory. Cluster size, on the contrary, which is rather a measure of the extension of the lexical-semantic knowledge network within a given subcategory, is related to the functions of the temporal lobe (*Troyer* et al., 1997, 1998; *Troyer,* 2000; *Abwender, Swan, Bowerman* and *Connoly,* 2001; *Robert* et al., 1997).

In summary, the joint use of the letter fluency and semantic fluency tests helps the assessment of the frontotemporal functions, and therefore the clinical professional is provided with an easy-to-use neuropsychological diagnostic tool. Besides the classical measures, the more complex measures contribute to a more accurate and more detailed cognitive neuropsychological profiling. The aspects discussed in the studies may provide useful hand-holds not only during the neuropsychological diagnostics of classical neurological and psychiatric conditions, but also for the early diagnosis and improvement of different learning disabilities.

Theoretical background and conceptions of the Experiment IV. Cognitive functions and school achievement

The life and future of children are fundamentally determined by the achievement in primary school. Mapping the factors in the background of school achievement is of key importance not only from the viewpoint of the psychology of learning and school psychology, but also when considering improvement programs. In the past years, the factors affecting school achievement have been surrounded by a great deal of interest in the international literature. Primarily, the operation of working memory and the executive functions have been related to the achievement in school – the role of these, however, may be different for each school subject (*Krajewski* and *Schneider,* 2009; *Dahlin*, 2011; *Lu, Weber, Spinath* and *Shi,* 2011; *Bull, Espy* and *Wiebe,* 2008). In addition, the focused study of working memory and executive functions has an important role in understanding the learning difficulties of children.

Objectives and hypothesis of the Experiment IV.

The objective of our fourth, longitudinal study was to assess how the performance showed in the first grade during the tasks measuring the working memory and executive functions of children predicts the achievement in fourth grade. Our study may fill a gap from several aspects, because no research of this focus had been conducted in Hungary and, in addition, the more precise assessment of the working memory functions, as well as both the classical (number of words, errors, perseverations) and the newer variables (number of clusters, size of clusters, number of switches) of the fluency tests were included in our analyses. Our hypothesis were: the performance of the spatial-visual working memory and verbal short-term memory tasks predict the achievement of the hungarian language and literature, the performance of the complex working memory, spatial-visual working memory and executive functions tasks predict the achievement of the mathematics. In the case of science education the complex working memory and executive functions were predictable.

Participants and methods of the Experiment IV.

A total of 105 children of typical development (59 female/46 male; 88 right-handed/17 left-handed) participated in this longitudinal study. The mean age of the study subjects was 6.79 years (SD = 0.54). Data were collected in three schools in Csongrád county (Hungary). At the time of administration of the cognitive tests, the children were in the first grade of primary school, and their achievement results were obtained when they were in fourth grade. The school achievement was measured in terms of the final note received for each school subject.

The measurement procedures used during the study and the studied functions are summarized in the Table 5.

Table 5. The measurements of the Experiment IV.

Measurement procedure	Studied function	Task	Correct answer	
Non-word repetition test	Verbal working memory	Repeat one by one E.g., "szan"	"szan"	
Digit span test	Verbal working memory	Memorize and repeat in order E.g., "7 – 2 – 9 - 1"	"7 – 2 – 9 - 1"	
Reverse digit span test	Complex working memory	Memorize and repeat in reverse order E.g., "4 – 9 – 6 – 1"	"1 – 6 – 9 – 4"	
Listening span test	Complex working memory	T/F, memorize, repeat last words in order. E.g., "A tool that the seamstress often uses is a pair of scissors" "In the beaks of birds, there is always a lot of coffee"	"true" "false"	"scissor s coffee"
Counting span test	Complex working memory	Count dark blue circles on successive figures, and then recall the counting results in order.	the counting results	
Corsi block-tapping test	Spatial-visual working memory	Memorize and show in order E.g., "5 – 3 – 8 – 1" (where numbers indicate the blocks)	"5 – 3 – 8 – 1"	
Letter fluency	Language and executive functions[1]	E.g., Say as many words beginning with the letter "K" as possible within 1 minute.	"key…"	
Semantic fluency	Language and executive functions	E.g., Say "ANIMAL" category exemplars over 1 minute	"cat, dog, fish, camel…"	

Results of the experiment IV.

The achievement in each school subject was predicted best by the tests measuring the following cognitive functions: in the case of Hungarian language and literature, the Corsi block-tapping test and the backward digit span test were of predictive value. These results are in accordance with several previous research studies that demonstrated that good spatial-visual abilities are indispensable e.g. for reading and reading comprehension *(Lovegrove, Martina* and *Slaghuisa,* 1986; *Goulandrisa,* 1991*; Von Károly, Winner, Gray* and *Sherman,* 2003).

As to the achievement in mathematics, the capacity of complex working memory was the strongest determining factor, in accordance with some previous research studies (*Bull* and *Scerif,* 2001; *Espy,* 2004; *Lu, Weber, Spinath* and *Shi,* 2011). According to *Van Den Bos, Van Der Ven, Kroesbergen* and *Van Luit* (2013), every component of the working memory is related to the achievement in mathematics. In our study, the performance during the counting span test, the letter fluency cluster number measure and the Corsi block span were the strongest determining factors of achievement in mathematics. Creating more clusters during the letter fluency task may be related to better switching abilities, which also proved to be a determining factor of the achievement in mathematics. Other authors, however, interpret this variable as a measure of the access to the lexicon (*Hurks, Hendriksen, Vles, Kalff, Feron, Kroes, Van Zeben, Steyaert* and *Jolles,* 2004; *Hurks, Schrans, Meijs, Wassenberg, Feron* and *Jolles,* 2010; *Takács, Kóbor, Tárnok* and *Csépe,* 2013; *Tucha, Mecklinger, Laufkotter, Kauzinger, Paul, Klein* and *Lange,* 2005). In addition, the capacity of the spatial-visual working memory measured with the Corsi block-tapping test also played an important role in the achievement in mathematics, which corresponds to the results of *Meyer, Salimpoor, Wu, Geary* and *Menon* (2010). This task simultaneously requires a good short-term storage capacity and a more complex, spatial-visual information processing capacity, and thus its involvement in the mathematical achievement also corresponds to the results of *Holmes* and *Adams* (2006), according to which the performance showed during the measurement procedures of the central executive and spatial-visual working memory is what best determines the mathematical achievement in children of typical development aged 8 to 9 years. Spatial-visual functions help the development of the concept of numbers, counting and arithmetics (*McLean* and *Hitch,* 1999). In summary, therefore, the good spatial-visual abilities, complex working memory, as well as switch and flexibility may help for example in solving written mathematical tasks and calculating in the head.

In our study, a better achievement in science class was explained best by a greater complex working memory capacity measured with the counting span test, since the manipulation and storage of information is best reflected by this test. Besides, similarly to the case of mathematics, a higher number of clusters, which indicates more flexible, better switching abilities, was also seen here. In the case of semantic fluency, a lower number of sharp switches was associated to the better achievement in school. A possible interpretation of this is if children are able to recall the words produced during the fluency task in groups (clusters) and to switch between clusters (as opposed to sharp switching), this synthesizing thinking may help in a better school achievement.

In the case of science class, the counting span, the letter fluency cluster number and the sharp switching measure of semantic fluency were included in the model. In our study, in summary, the school achievement in fourth grade was determined by the spatial-visual working memory, the complex working memory and certain components of the fluency tasks that measure executive and language functions.

Overall, our results show that the achievement in Hungarian language and literature was predicted by the spatial-visual and complex working memory. The mathematical achievement was predicted by the same cognitive functions, completed by the switching and strategic retrieval component of the executive functions. In the case of science education, the complex working memory and the clustering and switching components of the executive functions proved to be of predictive value. Our results have pointed out that a detailed cognitive profile may help in understanding the background of learning processes and predicting the future school achievement of children.

Conclusions

This dissertation has made an attempt at bringing the theoretical and methodological aspects of cognitive psychology, cognitive neuroscience, neuropsychology and educational studies closer together: 1) it has studied more focused cognitive functions from a developmental aspect, and 2) has studied the relationship of these to the achievement in school.

The main results of the dissertation:

1) Creation of the Hungarian version of the listening span test

2) Mapping of the age-related changes in working memory with the help of the listening span test. The developmental curve has a reversed U-shape.

3) Creation and testing of the Hungarian version and evaluation of the letter fluency test.

4) Creation and testing of the Hungarian version and evaluation of the semantic fluency test.

5) Mapping (with detailed measures) of the age-related changes in the executive functions measured with the letter fluency and semantic fluency tests. The developmental curves of the main quantitative measures have a reversed U-shape.

6) The developmental status of the cognitive functions measured at the time of entering school partly predicts future school achievement.

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