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# A POSSIBLE EXPLANATION OF BRAILLE LETTER CONFUSION. SPATIAL, MEMORY AND LANGUAGE FUNCTIONS

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*The present study is part of a major research project designed for investigating the background of Braille letter confusion. The research focuses on the spatial processing (e.g. mental rotation), language functions as well as on verbal memory functions of 7-11 year old children. 104 blind and sighted children matched for age, VQ were taking part in the investigation. Four experimental groups were created: 1) blind-low birth weight premature, 2) blind-full term, 3) sighted-low birth weight premature and 4) sighted-full term. Two different tasks were used for investigating the spatial processing; the Mosaic task (from ITVIC test) and a mental rotation task. This special mental rotation task (FDT as 'Flat Doll Task') usable both for blind and sighted children was designed and developed by us. For to Memory functions measured by using verbal working-memory and verbal long term memory tasks were investigated. Scores of three standardised tests (the Hungarian non-word repetition and listening span tests and the digit span test, RAVLT) were compared for the four experimental groups. The language functions were measured by using a verbal fluency and a phonological awareness test. Results of the psychological tests were compared to those of the letter confusion present in the Braille used by blind and in the traditional writing used by sighted children. The main purpose of our study was to shed light on the possible similarities and differences of letter confusion occurring in the two different writing systems based either on tactile or visual information, where three basic functions were assumed to contribute to a different extent to a letter confusion.*

**Keywords**: blindness, premature, language functions, verbal memory, spatial processing, letter confusion, Braille

In Braille letter reading a high rate of letter confusion is noticeable (Kovácsné, 2007) and the understanding of core functions behind is of theoretical and practical importance as well. A significant progress could be seen in this research area during the last several years, and we know more and more about on the different forms of letter confusion of neuropsychological background as well as about the possible differences in the average cognitive profile of sighted children (Csépe, 2005; Csépe, 2006; Csépe et al., 2006; Tóth & Csépe, 2008 etc.). Research on the neural background of Braille reading began at the end of the 1980s with the modern imaging techniques as PET and fMRI (Wanet & Defalque et al., 1988; Uhl et al., 1991; Pascual-Leone et al., 1992; Sadato & Hallett, 1999; Burton et al., 2002; Harada et al., 2004; Hannan, 2006; Duncan & Boynton, 2007). The first results showed, among others, that two classical areas of the occipital cortex taking part in processing visual information, the V1 and the V2 show a high activity during Braille reading.

In addition to the brain research data revealing similarities in the neural activity for script and Braille, a smaller number of studies were conducted for investigating the Braille letter, although these did not aim on exploring the cognitive background of this failure (Arter, 1998; Greaney & Reason, 2000; Veispak & Ghesquiere, 2010).

## The recognition of Braille characters

There are two models of the Braille character recognition. The traditional assumption is that the Braille patterns are perceived by touching them so that the tactile information processed is as global shape. Each Braille character consists of its own, global outline shape. Therefore, reading errors could be due to the lack of redundant features in the system (Nolan & Kederis, 1969). According to Heinze (1986) the location and place of the dots forming a Braille character is critical and not the numerosity for the recognition. In contrast to these models Millar (1997) suggests that those who are blind from birth on perceive and comprehend the Braille characters as structures and not as global forms. The most effective discriminative cues in the Braille system are rather the differences present in dot density or numerosity than the spatial features such as dot locations, outline shapes, or symmetry. Beginning readers often reverse characters of similar configuration and of those mirrored on the vertical or horizontal axes. As the Braille characters are structured along imaginary axes, beginning readers commit 'mirror-image letter' confusion type mistakes in judging single dots. This type of letter confusion can be seen in the following example.

d f h j

Since the reader decoding Braille detects one character at a time an processes both the spatial and temporal features of the character the word-reading in Braille means double 'successivity' associated with a higher working memory load.

## The cognitive functions of blind people

A proper review of the relevant literature reveals immediately that the majority of research aims mainly on investigating blind adults. Due to a frequent contradiction of results published it is difficult to find the appropriate items of the cognitive profile in order to form homogeneous groups. While the use of verbal tests is unproblematic, performance tasks may loose their validity during adaptation, and task-composition is of special importance when investigating blind subjects working under time constraints and with 3D objects may produce unreliable data (Cornoldi & Vecchi, 2000). The same is valid for failures of task design; measuring the same function with tasks adapted in different ways may lead to different outcomes.

Many studies show that blind people often outperform sighted ones cognitive functions (Hötting & Röder, 2009) such as short-term memory (Juurma, 1967; Smits & Mommers, 1976; Hull & Mason, 1995), long-term memory (Amedi et al., 2003; Röder & Rösler, 2003), auditory frequency discrimination (cit. Rokem & Ahissar, 2009) or speech perception (Hötting & Röder, 2009).

The short-term memory performance of blind children is, by a considerable measure, better than that of their sighted peers' (Smits & Mommers, 1976; Hull & Mason, 1995). In particular, they have a superior pitch memory as well as a memory recall advantage and remembrance to Braille and other tactile stimuli (Pring, 2008).

People with severe visual impairment perform better in auditory perception, language and memory tasks as compared to sighted people (Hötting & Röder, 2009). According to the research results of Röder et al. (2003) language processing and speech discrimination are more effective in blinds, probably due to a better tuned auditory perception. As it is broadly accepted in psychology, the language processing skills are strongly linked to working memory functions (Just & Carpenter, 1992), so that we may explain the better speech-perception of blinds by a higher working memory capacity. The experimental data of Hull and Mason (1995), Röder and Neville (2003) suggest that the working memory capacity of congenitally blind people is higher in the course of auditory word and number tasks than those of the sighted control.

In contrast to the above results some studies found that blind people complete the auditory tasks with lesser accuracy than their sighted controls. (Stankov & Spilsbury, 1978; Hollins, 1989; Miller, 1992). However, according to Röder, Rösler and Neville (2001) the performance shown by blind people in memory tasks is higher than that of to the sighted participants. As the authors argue, the reason for better memory is that the blind people's verbal information coding efficiency. is better that that of the sighted one.

As it is shown in a Hungarian investigation, primary school children with visual impairment reach the highest rates in practicing numbers and in vocabulary tests (Prónay, 2004). Moreover, X the tactile exploratory performance of blind people does not differ from that of the sighted people shown in visual modality when performing working memory tasks. However, the duration of visual impairment may act as a particular factor in influencing the individual performance. People with severe visual impairment show significant differences in their performance in cognitive tasks; congenitally blind persons as weakest most probably due to their incapability of using any visual experiences in building up a mental representation differing to a large extent the late-blind subjects. We may assume that in late blindness the spatial information of auditory and tactile modality is related to past visual experiences (Chen, Huang & Wang, 2010).

The early research data on congenitally blind, late blind and blindfolded sighted adults suggests that vision is not the obligate condition for a proper spatial construction required in mental rotation tasks. These tasks were designed for measuring the subjects' performance during similar-different judgment on pairs of forms to discriminate in the tactile modality forms. The two forms giving a pair could have the same orientation, or could be rotated in relation to each other 30 60, 120, or 150 degrees (Marmor & Zaback, 1976). Like the reaction times, The reaction times measured for the congenitally blind subjects, similarly to the sighted and the late-blind ones, increased as a linear function of angular discrepancy between stimuli, suggesting that the congenitally blind, like the sighted and adventitiously blind, could mentally rotate one form into congruence with the other in order to make judging easier. However, the congenitally blind participant's performance was characterized by a higher error rate than the late-blinds.

These results were confirmed by Carpenter and Eisenberg (1978) who used two letters of the (F and P) for tactile investigation. The letters presented in normal and mirror patterns were manipulated in order to examine the mental imagery performance of blind individuals. The two types of letters were collocated by six different rotational angles covering the entire arc of a circle (from 0° to 360°). The authors found a linear relation between the response-time and angular distance. The reaction time of the blind subjects was higher in the larger rotation angle as compared to that of the sighted control group. As a detailed analysis of the results revealed, while the congenitally blind subjects produced a 59° per second speed in the mental rotation task those who became blind later in life showed a 114° per second and the blindfolded sighted participants a 233° per second speed. The same pattern was found for the reaction time of the mental rotation; it increased between 0-180° and decreased between 180-360°.

However, significant group differences could not be shown in agreement with the results of Marmor and Zaback (1976). Moreover, the error rate did not differ in the three groups, and this was later confirmed by Dodds, Howarth, and Carter (1982).

According to some researchers the inconsistencies in the literature may be explained by such individual variables as age, educations well as age at the onset of blindness. To take these factors into account is especially important when the education of blind people is in focus the special task during education is how to contribute to the development of expertise important in mental rotation as well. Expert skills in Braille reading may have a common background with mental rotation. Therefore, we have to take account this skill, especially because we often encounter over-learned performance during comparative tests (Thinus-Blanc & Gaunet, 1997; Dulin & Hatwell, 2006).

From point view of the assumed importance of spatial functions in Braille reading is rather unfortunate the sporadic use and rare availability of mental rotation tests for blind children. We may assume the main reason is the above mentioned difficulty of creating homogeneous groups, as well as the low number of those visually impaired children who can be involved in an experiment. However, there are some studies which show, that children and youngsters (6-17 years) are less accurate in the mental rotation tasks then judgments are made on objects rotated with 90° and 270°, and the fewest mistakes are made at 180° (Koustriava, 2010).

## Aims of research, experimental questions

The goal of this research was to shed light on those basic cognitive functions that may contribute to errors occurring during Braille reading. For this performance produced in tasks measuring language functions, memory and spatial processing was investigated in 7-11 year old blind children. Our study aimed to look for similarities and differences between letter confusion occurring in the tactile and in the visual modality as "Braille-letter-confusion" and "sighted' letter-confusion". The performance shown by blind and sighted children forming four subgroups was investigated in tasks designed for measuring spatial functions, working memory and language functions and comparing them in the four groups.

Based on the results found in the relevant literature described above, we presumed that blind children achieved higher scores in language and memory tasks than their sighted controls. Furthermore, we assumed that children born premature with low birth weight will be outperformed by the full term groups, both blind and sighted.

Based on the results of Koustriava (2010) we also assumed an inferior spatial function in blind children not only resulting in difficulties in spatial tasks but also in lesser success in detecting Braille letters in the space or in category-free Braille cells.

As Braille characters are read in successive processes organized in space and time due to tactility, we also hypothesized an increased of working memory in Braille reading. We question, however, that a strong connection between the verbal working memory, spatial functions recognition of the Braille characters existed?

The main question of our explorative work was to learn whether the same functions contributed to letter confusion in blind sighted children.

## Subject description, subgroup formation

One hundred and four sighted individuals of 7-11 years were investigated the inclusionary criteria was a VQ higher than 85 (MAWGYI-R). The study aimed to include the entire 7-11 year old population of the Hungarian 7-11 blind persons. The sample consisted of 4 subgroups selected according to the gestation weeks (and weight) at birth a and to visual impairment or intactness giving two subgroups as blind-low birth weight premature (BLBW) and blind-full term (BFT), and two further subgroups as control that is sighted-low birth weight premature (SLBW) and sighted-full term (SFT).. The four well selected subgroups could be described and characterized by age at investigation, VQ, gestation weeks at birth and birth weight.

Table 1. *Groups by gender*

| | | BLBW | BFT | SLBW | SFT | Total |
|---|---|---|---|---|---|---|
| Gender | male | 13 | 15 | 13 | 13 | 54 |
| | female | 14 | 9 | 13 | 14 | 50 |
| Total | | 27 | 24 | 26 | 27 | 104 |

Table 2. *Groups by age, VQ, gestation period, birth weight*

| | BLBW | BFT | SLWB | SFT |
|---|---|---|---|---|
| Age - month | | | | |
| Mean | 106.23 (13.624) | 113.50 (17.515) | 111.23 (14.589) | 108.22 (13.475) |
| Minimum | 88 | 84 | 88 | 88 |
| Maximum | 132 | 140 | 139 | 137 |
| VQ | | | | |
| Mean | 96.38 (6.652) | 99.17 (8.085) | 98.12 (8.548) | 99.78 (8.097) |
| Minimum | 86 | 85 | 85 | 85 |
| Maximum | 115 | 107 | 115 | 111 |
| Gestation period – weeks | | | | |
| Mean | 26.81 (2.079) | 39.75 (0.737) | 27.85 (2.222) | 39.56 (1.086) |
| Minimum | 24 | 38 | 23 | 37 |
| Maximum | 32 | 41 | 31 | 41 |
| Birth weight – gram | | | | |
| Mean | 931.92 (277.128) | 3286.67 (296.643) | 1048.54 (323.575) | 3273.89 (285.840) |
| Minimum | 570 | 2560 | 610 | 2550 |
| Maximum | 1780 | 3800 | 1900 | 3750 |

The most common cause of blindness in the BLBW group (N=26) was ROP (retinopathia prematurorum) (N=22). The other eye-diseases leading to blindness were of known origin asphthysis bulbi (N=1) and glaucoma (N=1), or unknown etiology (N=2). In the BFT group (N=24) blindness were caused by retinoblastoma (N=5), Leber's congenital amaurosis (N=4), chorioretinitis (N=3), tapetoretinalis degeneratio (N=2), glaucoma (N=2), buphthalmus (N=2), decoloratio papillae (N=1), anophthalmus (N=1), opticus glioma (N=1), microphthalmus+cataracta (N=1), PHPV ablatio retinae (N=1), or by unknown incidence (N=1).

The investigation on blind participants was carried out at the School for the Blind (Budapest) and that of blind children taught in integrative classes at their home. The sighted control group was investigated took place at their school or home and occasionally at the 1st Department of Obstetrics and Gynecology of the Semmelweis University. In order to keep the sample as homogeneous as possible the results of a 7 year blind-low birth weight premature boy of high VQ (VQ = 145) was excluded from the evaluation.

## Methods

### Cognitive functions

Special attention was paid to choosing the test tools test selection in the sense that only in order to apply easy to use tasks both for sighted and blind subjects. The language functions assumed to contribute to letter confusion were measured by using verbal fluency and phonological awareness tests.

Memory functions were investigated in verbal working-memory and verbal long term memory tasks as measured by the Hungarian non-word repetition test, the Hungarian listening span test (Racsmány et al., 2005), the digit span test, and the Rey Auditory Verbal Learning Test. Spatial processing was measured by using the Mosaic task from ITVIC and a mental rotation task called 'Flat Doll Task' (FDT). The FDT is a new test developed by us for investigating the egocentric mental rotation in a way that is convenient and easy to use both for blind and sighted children.

## Language function

The verbal fluency and phonological awareness tasks of the Hungarian version of NEPSY® were used. The developmental neuropsychological test battery (not standardized and not used in the diagnostic praxis in Hungary) was translated and adapted for Hungarian by permission of the publisher and used for research purposes exclusively in the research group of the second author.

- Verbal fluency

This task examines the child's ability of word generation and measures the semantic and phonological fluency. In the semantic fluency task subjects have to name animals, food and drinks. In the phonological part of the fluency words with two different consonants have to be generated. The task is to rehearse as many words per category as possible in 60 seconds. The words produced are recorded in 15 second intervals and the number of perseverations, various types of failure and nonsense words are registered as well.

- Phonological processing

This task measures phonological awareness in two classes of task; one for children under the age of 10 and one over. In children between the 7th and -th year of age both the phonological and phoneme levels are measured. The phonological level is investigated in tasks requiring spoken rhyme recognition, spoken rhyme categorization, spoken rhyme generation, syllable segmentation, syllable completion and syllable deletion. At the phonemic level phoneme deletion, phoneme isolation, phoneme matching, phoneme segmentation and phoneme manipulation are measured.

Between the 10th and 15th year of age the second set (B) of the NEPSY® phonological tasks estimating the phonological segmentation on syllabic and phonemic level is used. The subjects have to form new words via syllable or speech sound deletion, or via changing a phoneme in the given word.

## Memory function

- Hungarian Non-Word Repetition Test (HNWRT)

The skill of non-word repetition occurs in parallel with the developing reading skill, most probably as the result of a newly learned function that is the sound- by-sound segmentation of spoken utterances (Brady, Shankweiler & Mann, 1983). The Hungarian non-word repetition test consists of 36 meaningless words (1-9 syllables), four non-words corresponding both to the Hungarian phonology and phonotactic rules at each syllabic length used.

The examiner reads the non-words with flat prosody without expressed accentuation, and the subject's task is to repeat the non-word heard Digit Span Test (DST).

The Digit Span Test commonly used for measuring verbal working memory was developed and first described by Jacobs in 1887 for investigating the memory functions of schoolchildren. This test became a part of the Wechsler's tests (WPPSI-R; WISC III; WAIS-R), and the Hungarian IQ tests (MAWGYI; MAWI) used earlier included its translation as well.

The subject's task is the exact repetition of the number sequences read aloud by the examiner. The DST consists of seven pairs of random number sequences and each trial consists of four items (Racsmány et al., 2005). 'When a sequence is repeated correctly, the examiner reads the next longer number sequence, continuing until the subject fails a pair of sequences or repeats the highest sequences correctly' (Lezak et al., 2004:352). The number of digits in the longest sequence gives the capacity score of short term memory of the subject investigated (Racsmány et al., 2005).

- Hungarian Listening Span Test (HLSP)

This test is designed for measuring complex and higher level components of the verbal working memory. The items used in the LST are sequences read aloud by the examiner for task the subject whose task is to make right-wrong judgments and to memorize the sentence's last word for later recall. The subject's task is at the end of one block of sentences to repeat all the last words in the order of exposition. The HLSP (Janacsek et al., 2009) (consist of three series of sentences (blocks) and the test score is an average of the number of sentences of correctly repeated final word of the three blocks used.

- Rey Auditory – Verbal Learning Test (RAVLT)

This test was developed for investigating cognitive processes contributing to verbal learning (Rey, 1964). The test 'affords an analysis of learning and retention using a five-trial presentation of a 15-word list (list A), a single presentation of an interference list (list B), two post-interference recall trials – one immediate (VI), one delayed (VII) around 30 minutes – and recognition of target words presented with dis-tractors' (Lezak et al., 2004:422). Trial I measures immediate word span under overload conditions. List B measures proactive interference, trial VI. retroactive interference and trial VII. the delayed recall. The test is commonly used for detecting memory deficits and delineating dissociative lesions of retrieval and recognition processes.

## Spatial processing

- Mosaic task – tactile task of ITVIC (Intelligence Test for Visually Impaired Children)

The test consists of 14 block-design tasks. The subject's task is to reproduce a tactile pattern in two different frames. The test has two levels; the tasks 1-8 use a 2x2 square-size frame, the tasks 9-14 use a 3x3 square-size frame. The squares are used to construct replicas of the patterns made by the examiner. The squares have three variations: smooth, rough, and half smooth-half rough.

Blind subjects have to work under time constraints; in the first trial 6 minutes, in the second trial 10 minutes are given for finishing the pattern given. The test measures the subject's capacity to reproduce a spatial form based on a model. The rotation of the form may happen. Verbal mediation improves the performance, similarly to the visual task in sighted subjects so that subjects of good language function may use it for compensating. Low performance may be linked either to the lack of planning or to inadequate monitoring functions. It is worth to keep track on the time spent on exploration as well as on the number of returns. The Mosaik task is used in tactile form in the blind group and in visual mode in the sighted group.

- 'Flat Doll' mental rotation Task (FDT)

The FDT is our own design and developed for studying spatial rotation equally performable for blind and sighted children. This task is performed by using a doll figure made of thin wooden plate and a ball. The doll is easy to recognize and discriminate from the background both by tactile and visual means. The FDT consists of two trials and four 'subtasks'. During the first two trials the subject's task is to state whether the ball is on the figure's right or left side during rotation. During the second two trials the subject's task is to put the ball on the figure’s hand during rotation while the desired side is chosen by the subject. Each trial consists of two presentations. First the task is carried out in front of the subject’s body (non-mirror image task), the second is on the table (mirror-image task).

Task ‘A’ (non-mirror image task): The ball is put on the figure by the examiner. The subject’s task is to state whether the ball is on the figure’s right or left side during the rotation. The task is carried out in front of the subject’s body.

Task ‘B’ (mirror image task): The same as Task ‘A’ but the task is carried out on the table.

Task ‘C’ (non-mirror image task): The examiner chooses one hand of the figure and puts the ball on that side. The subject’s task is to put the ball on the figure’s same hand during rotation. The task is carried out in front of the subject’s body.

Task ‘D’ (mirror image task): The same as Task ‘A’ but the task is carried out on the table.

The task measures the performance speed and the number of correct answers. Every task consists of 9 ‘subtasks’ which are the rotated trials. The trials are performed in random order, so that the angle and the side of rotation are unpredictable.

## Statistical analysis

The results of the tests performed were compared in the four groups. The normative data were found very similar in the SFT group therefore the results of this group are not presented in the result section. A detailed analysis was performed in order to look for possible correlations between the three functions investigated by using different tasks and the letter confusion.

The Braille letter errors found in the blind group were classified in three categories following the results and suggestions of Pring (1994), Millar (1997) and Fellenius (1999). Letter errors of phonological nature not explicable by spatial character of the Braille cell formed the first category. Letter errors of spatial character, called ‘mirror-letters’ formed the second category. Letter errors not otherwise classified formed the third category or group of ‘other’ errors. The letter errors of spatial origin are easy to classify. This is due the fact that the Braille cell is touched in an angle of 30° by the index finger and therefore the discrimination is often very difficult as for example in case of the number 5 or 6 leading to a frequent error (Lorimer, 1996a, 1996b).

The letter errors produced by sighted’ readers we classified as phonological and spatial categories. The following errors were put into the last category: d-b-p-g or f-t.

For statistical analysis the SPSS 17 program was used, the type of analysis is given at the different tasks in the result section.

## Results

### Language function

The task performance measured in the verbal fluency and phonological awareness tasks were compared by using Repeated measures ANOVA for all four groups.

The mean scores of the verbal fluency task were found higher among the blind as compared to the sighted children and also among the full term as compared to the low birth weight premature born children. The difference was statistically significant between blind-low birth weight premature and the sighted-low birth weight premature groups (F(3)=4.483, p=0.003), as well as between the sighted-low birth weight premature and sighted-full term groups (F(3)=4.483, p=0.025).

Table 3. *Verbal fluency and phonological fluency performance in the four experimental groups*

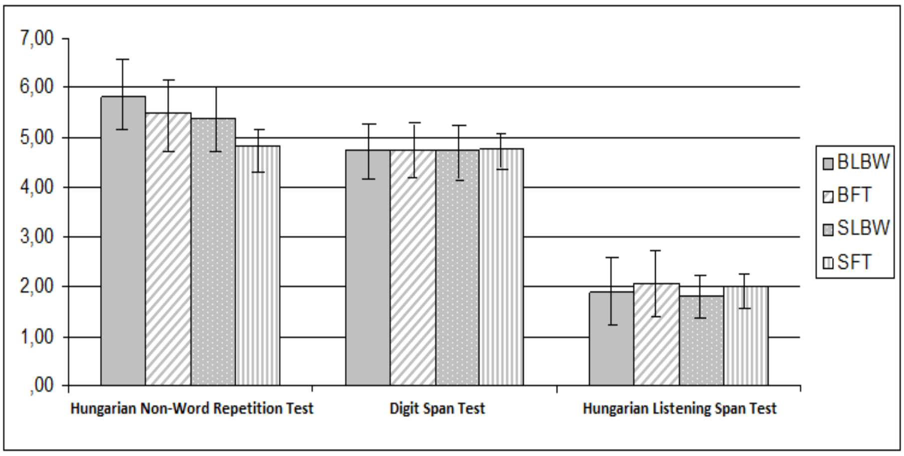
| | Group | Mean | SD | F-value | BFT | SLBW | SFT |
|---|---|---|---|---|---|---|---|
| Verbal fluency | BLBW | 47.44 | 22.889 | F(3)=4.483 | p=0.176 | p=0.982 | p=1 |
| | BFT | 60.32 | 16.983 | | | *p=0.003* | *p=0.025* |
| | SLBW | 41.39 | 9.519 | | | | |
| | SFT | 47.48 | 11.133 | | | | |
| Phonological processing | BLBW | 69.64 | 17.788 | F(3)=3.348 | p=0.984 | p=0.973 | p=0.192 |
| | BFT | 66.65 | 13.221 | | | p=0.491 | p=0.008 |
| | SLBW | 72.96 | 13.892 | | | | |
| | SFT | 78.78 | 11.732 | | | | |

The results of the blind group shown in the phonological awareness tasks were worse than those of the sighted groups and this contradicts to our expectations formed according to the relevant literature. The results confirmed the hypothesis only for the sighted group where the low birth weight premature children underperformed the full term groups. Furthermore, a significant difference was found between the blind-full term and the sighted-full term groups (F(3)=3.348, p=0.008).

## Memory functions

The memory functions were investigated by measuring verbal and complex working memory tasks; the HNWRT, the DST and the HLST. The measured performance of the four groups, were compared by using ANOVA and to compare the four groups.

Figure 1. *Group means of the verbal working memory tasks*



We expected a general advantage of the blind children over the sighted ones, so that our choice of working memory tasks corresponded to that of Röder and Neville (2003), and Hötting and Röder (2009). As Brigitte Röder points out in all her studies the working memory capacity for words and numbers presented acoustically is ‘specifically’ higher in congenitally blind subjects than that of the sighted ones. However, we may also assume that children born premature with low or very low birth weight show a low performance in tasks designed for working memory capacity measures and this may have a negative in blind children.

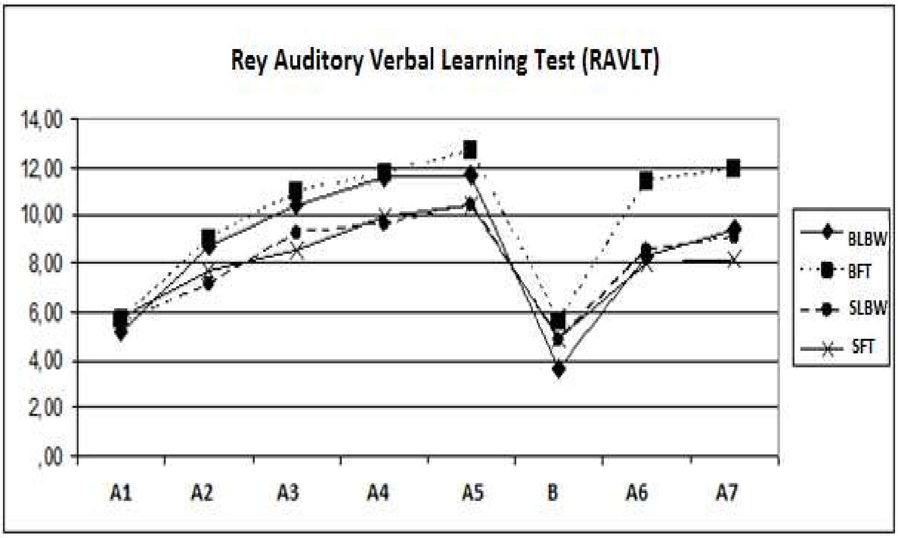
As we expected, only one of the two tests on verbal working memory produced significantly different results. Significant differences were found in the HNWRT between the blind-low birth weight premature and blind-full term children (F(3)=3.373 p=0.021A two-sample t-test used in a post-hoc analysis based on sub-grouping by age ( 7, 8, 9 and 10-11 yeas) revealed a higher performance in the 9 year old blind children who outperformed their matched sighted controls (t(21)=-2.578, p=0.018). Within blind groups the BFT children showed a strong tendency of better results. However, in the SLBW group the 7, 8, 9 year old subjects performed better than the full-term children loosing their advantage. This may be due to a large number and wide spectrum of developmental changes contributing to the effect of over-learned functions on our measurements.

The statistical analysis of the DST and HLST revealed a striking similarity of the four groups; the DST scores were the same for all four groups and no significant differences were found in the HLST. Although a tendency of better DST performance can be seen in blind children over the 9th year of age, a striking similarity is present in the performance of blind and sighted children under this age.

The post-hoc analysis made for subgroups broken down by age revealed an advantage of blind children over 9 as compared to sighted ones.

Results of the RAVLT were in agreement with our hypothesis; the blind group outperformed the sighted one and the full term groups performed better than prematures.

Figure 2. *Group results of the RAVLT*



As we can see on Figure 2. the blind groups outperform the sighted ones in the tasks catching direct and delayed recall.. It is important to note that while the blind groups showed no birth weight-/gestational age-related differences the performance of low birth weight premature slightly differed from that of the full term children. Significant differences were found in the A1-A5 trials between the blind and sighted groups, the blind groups differ significantly only in the A6 and A7 trials.

Table 4. *Summary table of statistically different trials of RAVLT in the four groups*

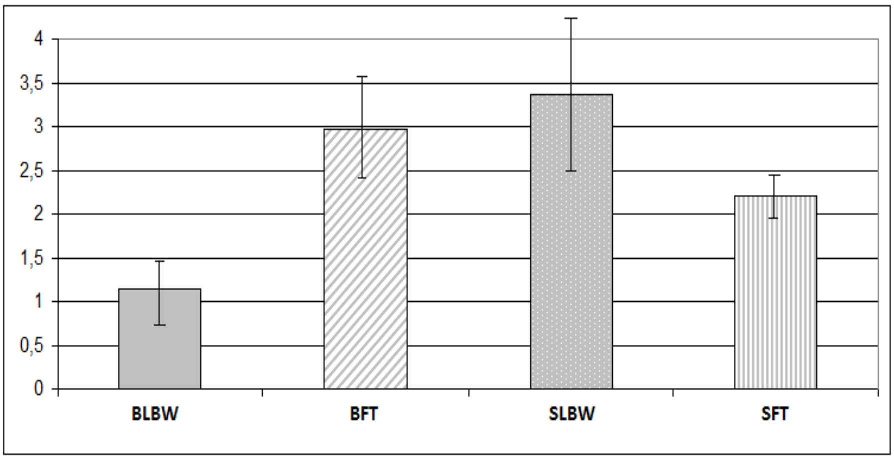
| | | BFT | SLBW | SFT |
|---|---|---|---|---|
| A3 | BLBW | | | |
| | BFT | | | F(3)=4.246 p=0.017 |
| A4 | BLBW | | | |
| | BFT | | F(3)=5.416 p=0.022 | F(3)=5.416 p=0.027 |
| A5 | BLBW | | | |
| | BFT | | F(3)=5.6735.673 p=0.002 | F(3)=5.673 p=0.002 |
| A6 | BLBW | F(3)=6.339 p=0020 | | |
| | BFT | | F(3)=6.339, p=0.018 | F(3)=6.339 p=0.001 |
| A7 | BLBW | F(3)=6.339 p=0.022 | | |
| | BFT | | F(3)=6.339 p=0.003 | F(3)=6.339 p=0.000 |

A closer look at the Figure 2. reveals a special turning point, that is the very low mean score of the BLBW group in trial B. We may explain the strong proactive interference as retrieval problem or cognitive fatigue. Moreover, the lower number of recalls in trial A6 as compared to trial A5 may sign a fast memory lapse during a slight recall delay or that of retroactive interference supported by memory or executive dysfunction as underlying functions (Lezak et al., 2004). Furthermore, as the group performance shown in the working memory tasks by did not differ from that of the other groups, the lower achievement can be explained by lower effectiveness of the executive functions. The lower scores shown in trial A7 could imply storage or recall problems. Interestingly, a mirrored pattern could be observed in the sighted-full term group; no significant differences occurred between the A5 and A6 trials, no low scores were found in trial A7.

## Spatial processing

The most unexpected result we found was the spatial performance of the SLBW group.

Figure 3. *Results of the Mosaic task in the four experimental groups*



We have found significant differences between BLBW and SLBW groups and BLBW and SFT groups (F(3)=54.675, p=0.000). We have also found p<0.001 significances between SFT and SLBW, and between BFT and SFT groups.

Blind groups showed significant deficiencies in spatial tasks such as mental rotation tests like the ‘Flat-doll task’. If the task is presented in a mirror-image arrangement, the difference between blind and sighted groups is larger. We have found significant differences in non mirror-image arrangements (Task ‘A’) between BLBW and SFT groups (F(3)=7.939, p=0.000) and (Task ’C’) between BFT and SFT groups (F(3)=5.246, p=0.000). In a mirror-image arrangement (Task ‘B’) were found significant difference between BLBW and BFT groups (F(3)=8.511, p=0.025) and (Task ’D’) between BLBW and SLBW groups (F(3)=6.253 p=0.016) also between BLBW and SFT groups (p=0.001).

We explain this as a result of extensive development. The low achievements of the blind group may come from the problem of comprehension and reproduction of spatial relation furthermore from inadequate monitory function.

## Relationship between letter confusion and the cognitive functions investigated

In the further analysis we aimed to discover reliable links between the language, memory and spatial functions in relation to the letter confusion. The letter confusion was investigated in a simple reading task, where all children read the same letters and syllables in the unimpaired modality: blind subjects read Braille, sighted subjects read written small letters of 12 font on white papers. The letter reading errors were divided into two groups: phonological type and spatial type.

The correlation analysis was performed by using the same SPSS program as for the other statistical analyses.

In the blind groups the phonological type errors in Braille letter reading showed a negative correlation with VQ (r(48 )=-0,394, p=0.005), RAVLT (r(48)=-0.316, p=0.025), h phonological awareness (r(48)=-0.343, p=0.015), verbal fluency (r(48)=-0.298, p=0.036) and DST (r(48)=-0.306, p=0.031). Moreover, a negative correlation of the phonological type errors in Braille was found with the Mosaic task scores (r(48)=-0.348, p=0.013) and the mirror-imaged mental rotation tasks: ’B’ task (r(48)=-0.367, p=0.009), ’D’ (r(48)=-0.392, p=0.005). In sighted groups a negative correlation of the phonological type letter confusion and the VQ (r(50)=-0.369, p=0.007), phonological awareness (r(50)=-0.317, p=0.022) and HNWRT (r(40)=-0.375, p=0.006) was found

The spatial type Braille errors showed a negative correlation with scores of the Mosaic task (r(48)=-0.348, p=0.013) and those of the non-mirror-imaged mental rotation tasks: ‘A’ task (r(48)=-0.352, p=0.012), ‘C’ task (r(48)=-0.337, p=0.017), as well as of the mirror-imaged mental rotation tasks: ‘B’ task (r(48)=-0.341, p=0.015), ‘D’ task (r(48)=-0.452, p=0.001). In the sighted group no correlation was found between the test scores and spatial type letter errors. The results are summarized in Table 5.

Table 5. *Correlations between task scores and letter errors*

| | Blind groups | | Sighted groups |
|---|---|---|---|
| Braille spatial letter confusion | Mosaic task (r(48)=-0.348, p=0.013)<br>Mental rotation test<br>’A’ task (r(48)=-0.352, p=0.012)<br>’B’ task (r(48)=-0.341, p=0.015)<br>’C’ task (r(48)=-0.337, p=0.017)<br>’D’ task (r(48)=-0.452, p=0.001) | ’Sighted’ spatial letter confusion | |
| Braille phonological letter confusion | VQ (r(48)=-0.394, p=0.005)<br>Phonological awareness (r(48)=-0.343, p=0.015)<br>Digit span test (r(48)=-0.306, p=0.031)<br>Rey (r(48)=-0.316, p=0.025)<br>Verbal fluency (r(48)=-0.298, p=0.036)<br>Mosaic task (r(48)=-0.348, p=0.013)<br>Mental rotation test<br>’B’ task (r(48)=-0.367, p=0.009)<br>’D’ task (r(48)=-0.452, p=0.001) | ’Sighted’ phonological letter confusion | VQ (r(50)=-0.369, p=0.007)<br>Phonological awareness (r(50)=-0.317, p=0.022)<br>Hungarian non-word repetition test (r(40)=- 0.375, p=0.006) |

The above results strengthen the suggestion that successful Braille reading requires well developed spatial functions. A successful orientation in mirror-imaged locations ensures the correct recognition of Braille characters, and this skill relies on egocentric rotations during reading; blind children encounter the Braille character as mirror patterns where the reference is their own body axis. The correlations found between the ‘B’ and ‘D’ task scores of the ‘Flat-Doll’ Test with letter recognition is in agreement with this assumption.

It seems that la successful recognition of letters coded in the two modalities (tactile and visual) correlates with VQ, the level of phonological processing and the capacity and span of the verbal working memory. In blind groups this skill is supported as shown by the high correlation values by the capacity of long-term memory (Rey) and executive functions, in addition to the spatial abilities.

## Discussion

In a research study performed in group of 104 sighted and blind children we examined some basic cognitive functions assumed to contribute to letter recognition and letter confusion type errors. Three main cognitive domains, language memory and spatial processing were investigating by using a special set of tasks Our results do not support the cited data of the relevant literature on a higher impact of phonological awareness on Braille reading in blind children as these children of 7-11 years of age did not outperform their sighted matched control. Irrespectively of the modality of letters to read the test scores achieved in the phonological processing tests correlated with letter recognition in both groups. However, blind children showed better results in many tasks and tests requiring well developed linguistic and executive performance correlated well with the successful Braille letter decoding. The performances of children born premature were in the lower range both for blind and sighted.

The working memory tests revealed significant differences between the blind and sighted groups as well as between the full term and the low birth weight group of children born premature. The Hungarian non-word repetition test showed a high correlation with the letter reading performance. The level of development of the verbal working memory seems to be crucial both modalities in achieving a successful letter decoding. The impact of verbal working memory on letter decoding of blind children improves at the age of 9 as compared to sighted subjects. (This tendency was notable using Digit span test.) The working memory task scores in the SLBW group were astonishingly high. As our SLBW group belongs to a special sample, we may explain this result with the efficiency of early intervention and development used in formal education and this is in agreement with the conclusion drawn by Dulin & Hatwell (2006).

The complex working memory tests did not provide any further ground for differentiating between the blind groups or the sighted groups. However, the Rey (RAVLT) test showed significant differences between the blind and sighted groups this is in agreement with the conclusion drawn by Hull and Mason (1995), Röder and Rösler (2003) etc. The retrieval difficulty found in the BLBW group can explained by weaker executive functions, and a strong connection between the recognition of Braille characters and the success of delayed memory retention can also seen.

All the tests chosen for investigating the spatial processes assumed to correlate with letter decoding gave significant results. However, while the Mosaic task showed significant differences between the blind and sighted groups, no difference was found in reference to the gestational age. In this task an extremely high performance could be seen in the SLBW that can only be explained in further research. Results of the Mosaic task - the success of spatial processing – could be well linked to the success of Braille letter recognition in the blind groups. Moreover, the mental rotation task performance revealed significant differences between the blind and sighted groups and between the full term and low birth weight premature groups. In blind children the mental rotation performance, especially the results of mirror-image tasks highly correlated with the success of the of the Braille letter recognition. Now we presume that the Braille cell with axis' referenced to the human body can be divided into two parts (1, 2, 3 dots – right side; 4, 5, 6 dots – left side), so that the development of the egocentric spatial functions (especially mental rotation) may influence the success of Braille reading as it is a mirror-image compared to the blind child's body axis. Based on our result we suggest that the Braille letter confusion is due to weaker functions both in the phonological and spatial function where both underdeveloped phonological processing and erroneous mental rotation may lead to Braille letter confusion.

A deeper understanding of the developmental aspects of these function need an expansion of the age range with participants up to the 16th year of age. Our investigation shed light on the importance of task choice as well as on that of the cognitive domains investigated. Therefore, our further studies will focus on different task touching upon the crucial factors of the verbal spatial attention and executive functions as well as those of the memory system both in blind and sighted groups.

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