Effects of Daily Practice on Subitizing, Visual Counting, and Basic Arithmetic Skills in Dyscalculia

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Abstract
The ability of subitizing and counting undergoes a long lasting development lasting up to the age of 18 years. Large proportions of children with problems in acquiring basic arithmetic skills exhibit developmental deficits in the correctness and speed of this special visual capacity. The first study tests the possibility that subitizing and counting can be improved by daily practice. Altogether, 74 subjects (age 7 to 13 y) participated in the study. They were given a special task for daily practice during a period of 21 days. The difficulty of the task was manipulated by increasing the range of possible numbers of items (1-3 to 1-9) and decreasing the presentation time (300 to 100 msec).

The analysis of the pre-post training data revealed that subitizing and counting were significantly improved. About 85% of the subjects on average were able to improve both variables determining the quality of task performance: they reached the normal range of the control subjects (N=133) of the same age.

The second study shows, that basic arithmetic skills were significantly improved in a trained as compared to an untrained control group.

Introduction

Difficulties in acquiring basic skills in reading and spelling (dyslexia) are often accompanied by deficits in saccade control (Biscaldi et al., 2000) and/or in low level auditory discrimination (Fischer et al., 2004). Improving the perceptual deficits by daily practice leads to improvements of reading (Fischer and Hartnegg, 2004) spelling (Schäffler et al., 2004).

The previous paper has shown, that children with specific problems in acquiring basic arithmetic skills (children with dyscalculia) are impaired on a visual task requiring subitizing and counting of 1 to 8 items (*Fischer et al., 2005). The question remained open whether or not this visual capacity may be improved by daily practice and if so, does this improvement transfer to basic arithmetic skills. This questions was arised earlier on the basis of the fact, that dicrimination of quantities develops during the first years of life and constitutes the beginning of the delopment of the sense of number (Dehaene, 2005).

This paper describes 2 studies. The first refers to the effects of training of the visual task of subitizing and number counting. The second describes the effects of the training on basic arithmetic skills.

Methods of Study I

Subjects: Subjects were selected on the basis of their poor performance in basic arithmetic skills (Zareki, DEMAT) but reached normal reading and spelling levels. General intelligence (IQ) was measured by the Kaufmann ABC or the HAWIK test. Children with IQs below 85 were excluded from the study. Only those were included in the study, who could not perform the test task of visual subitizing and counting within the limits of the age matched controls. The test group contained 74 subjects in an age range of 7;0 to 13;11 years. They were divided into 3 different age groups as shown in Table 1. To compare the results of the post-training values with those of a control group we used the data of 133 subjects in the same age range (s. Table 1).

Visual stimuli, task, and procedure: The visual stimuli used for the training were small circles (items) and described in detail in the previous paper. Briefly, 1 to 9 items were presented in random order. The spatial locations of the items were selected randomly from an 4 by 4 raster. At each given number of items the spatial arrangement could be one of two types. The items were located in a loosely scattered way. The items were located in a compact grouped way such that was easily possible (for an adult subject) to group them together to subgroups as they occur at a die.

The visual display, the keyboard, and data collection were all implemented in a small hand held instrument. The children were given one instrument each to practice the tasks one session every day. A session lasted about 10 to 20 min.

The training tasks were essentially the same as used for the test with the following exceptions: because the children could not perform the test task according to their age control group the task was made very easy at the beginning of the training by selecting only item numbers up to 3 and by presenting them for 300 ms (level 1). As the child performed this task with increasing levels of difficulty from 1 to 11.The difficulty was increased by allowing more item numbers and by decreasing the presentation time. Each training session consisted of 140 trials.

At the beginning of the training period of 20 days each subject had to perform the test task in its original form to have the pretraining values. Similarly, the test session had to be repeated at the end of the training at day 21.

Data collection, variables, and analysis: The data were recorded by the test instrument and downloaded to a PC for later analysis. The response time r(N) and the percentage of correct responses p(N) was recorded for each item number N. For each subject we calculated the linear regression between the response times and the item number for N=4 to N =8. For N > 3 an almost linear relationship was obtained for most subjects. The slope of it measures the mean time per item, t. The basic reaction time T was calculated as the mean value of r(1). The mean percentage of the correct responses P was calculated for item numbers between 4 and 8. Note that T characterizes the performance for item number 1, while E describes the performance for item numbers between 4 and 8.

To compare the performance at the beginning and the end of the training two characteristic variables were compared: the basic response time T and the effective recognition E = P/t. To see the efffects of training age curves were plotted for pre- and posttraining values of T and E. To characterize subitizing the mean response times tsim and percentages of correct responses psim were determined for item number 2,3, and 4. The corresponding effective recognition is calculated by psim/tsim.

ANOVAs were run to see whether or not significant training effects were obtained.

To estimate the success rate the data from a control group containing 133 subjects were used. They were divided into 3 age groups. Their mean values and standard deviations were used to count the number of test subjects who fall within the control range of 1 standard deviation from the mean valaue, i.e. above the 16 percentile.

Methods of Study II

The subjects of the second study recruited from a single German Grammar School. They were 7.5 to 9 years old. All received the same school lessons throughout the duration of the study. The total group of 21 children were divided into 2 groups, one received the training (N=10) the other had to wait (N=11). All of them received a standardized test of basic mathematical skills at the beginning of the study, after the training period of the test group, after the following training period of the former waiting group, and after another period, during which all participants went to school without further interventions.

The other details of the methods are described in the preceeding article.

Results

Count curves: Fig. 1 and Fig. 2 show count curves from age group 2. The percentage of correct respones and the response times are shown as a function of item number. By training the percentage of correct responses was increased for item numbers above 4 or 5. The response times were decreased. Note that the decrease was obtained also for item numbers of 1 to 3, while the percentage of correct responses was close to 100% before the training (in this age group) and therefore could hardly become higher. For age group 1 the percentage of correct responses for item numbers 1-3 were about 90% and could be improved to almost 100% by the training.

Age curves: Fig. 3 show the age curves of the effective recognition and the basic response time before and after the training. The increase of the effective recognition and the decrease of the resonse time can be seen in all age groups. ANOVA results confirm a significant effect of training (F=13.7, p=0.0004) and for the effective recognition (F=8.75, p=0.004).

Considering only small item numbers between 2 and 4 describing subitizing reveals that the training improves this variable significantly, also.

Success of the training: The percent number of children who reached the range of the normal control children (post-training values within the 16 percentile) in both variables was estimated as 85,1%. If one requires that only one of the two variables reached the normal range the percent number of successes were estimated as 87,3% for the effective recognition speed and 94,7% for the basic reaction time.

Another way of estimating the succes rate is to calculate the percent number of children who improved their pre-training value by a certain percentage. Both variables were improved by 5% in 74,3% of the cases. One or the other variable was improved by 5% by another 21,6% of the children.

These considerations show that the capacity of subitizing and number counting can be learned within 3 weeks of daily practice by almost all children.

Transfer to basic arithmetic: The most interesting question was asked by a second study. Is it possible that improvements of subitizing obtained by daily practice have positive effects on basic arithmetic skills. Evaluating the pre-post values of the standardized test (DEMAT) yields the results shown in Fig. 4. The test group (T-Gr 1) gained 3.2 points while the waiting group (W-Gr 2) lost 0.5 points. Using the two-tailed t-test this difference was significant with p=0.016. The ANOVA resulted in F=6.9, p=0.016. After the test and waiting period the waiting group was also given a 3 week training. Repeating the test showed that this group now gained 3.9 points (T-Gr 2). The t-test revealed p=0.002. In the same time the former training group gained another 2 points, eventhough the members received no further training but just visited school. After another 5 weeks of visiting school the former waiting group gained also another 2 points. At the very end of the study both groups had gained about 6 points.

Closer analysis shows, that among the 10 subdomains of the DMAT-test three were not improved by the test group. The first of them deals with the characteristics of numbers, the second with division, and the third with money. These three are only loosely related to subitizing and number counting. When these variables were excluded from the analysis, the differences between the test group and the waiting group became highly significant (p = 0.001) and similarly the transfer effect of the training of the waiting group reached a value of p = 0.002.

Discussion

The studies reported here have shown, that the basic visual capacity of subitizing and number counting can be improved within a period of daily practice of 3 weeks. The success rate of the training was about 85%. Moreover, the training transferred to basic arithmetic skills. A considerable transfer effect was seen directly after the training period, while a smaller additional effect was obtained during the post-training period, when the children continued to visit school.

Although a placebo group was not included in this study it is very unlikely, that general effects of the training have led to the improvements in arithmetic skills. First, not all domains of the DEMAT test were effected by the training. Furthermore, the visual capacities of subititzing and number counting are low level visual functions, probably not under control of psychological factors. Thus, what has been predicted by Dehaene (Dehaene, 2005) could be confirmed by this study.

Furthermore, if one follows the evidence of parietal functions being involved in number processing (Dehaene et al., 2003) it follows from the present study, that neural connectivity in the parietal cortex is subjected to changes due to daily practice. These parietal functions can be altered even at ages well above school age. If the visual capacity of estimating quantities is developped early in life on a genetic basis one may argue, that this development was delayed in children with dyscalculia and that they expressed the phenomen as a consequence of the genetic defect. Yet, any other circumstances, which may have delayed the development of this special parietal function would also lead to signs of dyscalculia. In any case, it would be important to test a child's capacity of visual subitizing and number counting and to offer the opportunity of daily practice for improvements.

Deficits in subitizing are not selective for children with dyscalculia. Dyslexic children, for example, can also exhibit this kind of deficit but by different amounts and with lower percentages of affected subjects. Preliminary data show that these dyslexic children can also improve subitizing and visual counting by daily practice, but it is unknown at present, whether the training effects would transfer to reading and/or spelling.

The fact that improvements of subitizing and number counting transfer to basic arithmetic skills show that these elementary perceptual and/or cognitive capacities can constitute one reason for problems in learning to deal with numbers.
Similarly, dyslexic children can suffer from deficits in basic perceptual auditor, visual and/or optomotor skills. An improvement of the elementary functions transfers to spelling and reading (Schäffler et al., 2004); (Fischer and Hartnegg, 2004).

References

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Captions

Table 1 The number of subjects in each age group and their mean.

Fig. 1 Percentage of correct responses as a function of the number of items before and after the training. Data from age group 2.

Fig. 2 Responses time as a function of the number of items before and after the training. Data from age group 2. The linear regression line is drawn. Its slope defines the time per item.

Fig. 3 Age curves of the effective recognition speed (left side) and basic response time (right side) before and after the training.

Fig. 4 Age curves of the effective recognition speed for 2,3,and 4 items

Fig. 5 The transfer effects of the training to basic arithmetic skills are shown by the mean differences in points reached in a standard mathematical test. T-Gr 1 indicates the test group after the training. W-Gr 2 indicates the waiting group after the waiting. T-Gr 2 indicates the former waiting group (2) after the training.

Age Group (years)	7 - 8	9 - 10	11 - 13
Dyscalculia (N=74) Number (fem/male) mean age ± s.d. (years)	25 (10/15) 7,7 ± 0.5	30 (17/13) 9,4 ± 0.5	19 (5/14) 11,9 ± 0.9
Control (N=133) Number (fem/male) mean age ± s.d. (years)	35 (18/17) 7,5 ± 0,5	36 (20/16) 9,6 ± 0.5	62 (36/26) 11,9 ± 0.8

Table 1

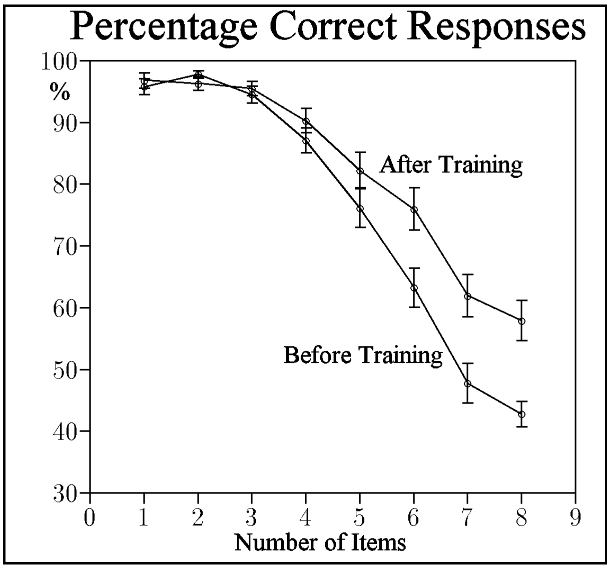
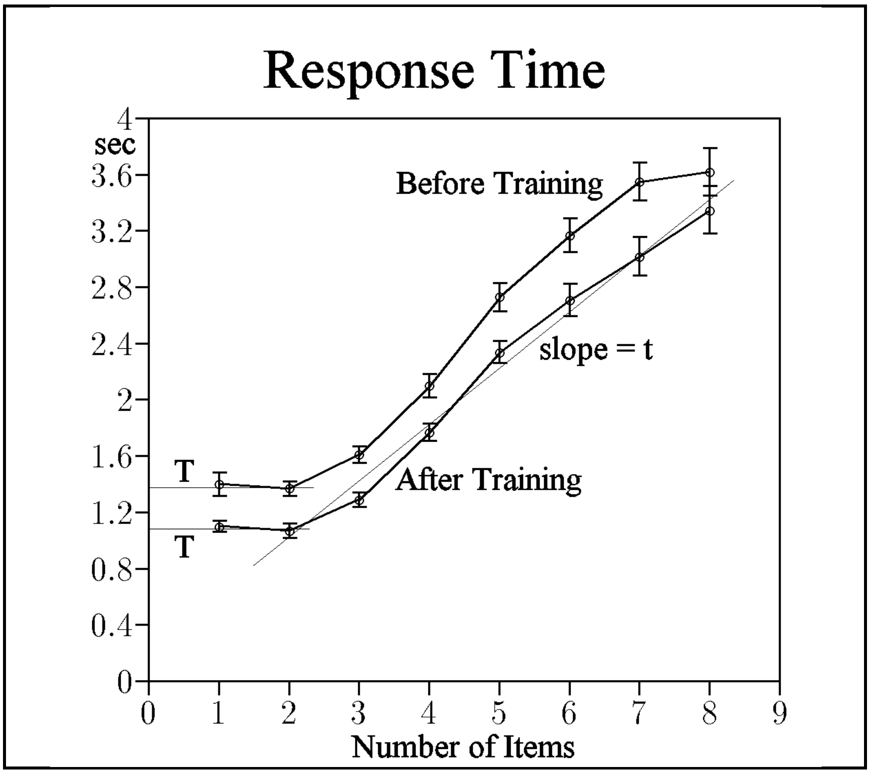

Percentage Correct Responses
%
100
90
80
70
60
50
40
30
0
1
2
3
4
5
6
7
8
9
Number of Items
After Training
Before Training

Fig.1



Response Time
sec
4
3.6
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0
Before Training
slope = t
After Training
T
T
0
1
2
3
4
5
6
7
8
9
Number of Items

Fig.2

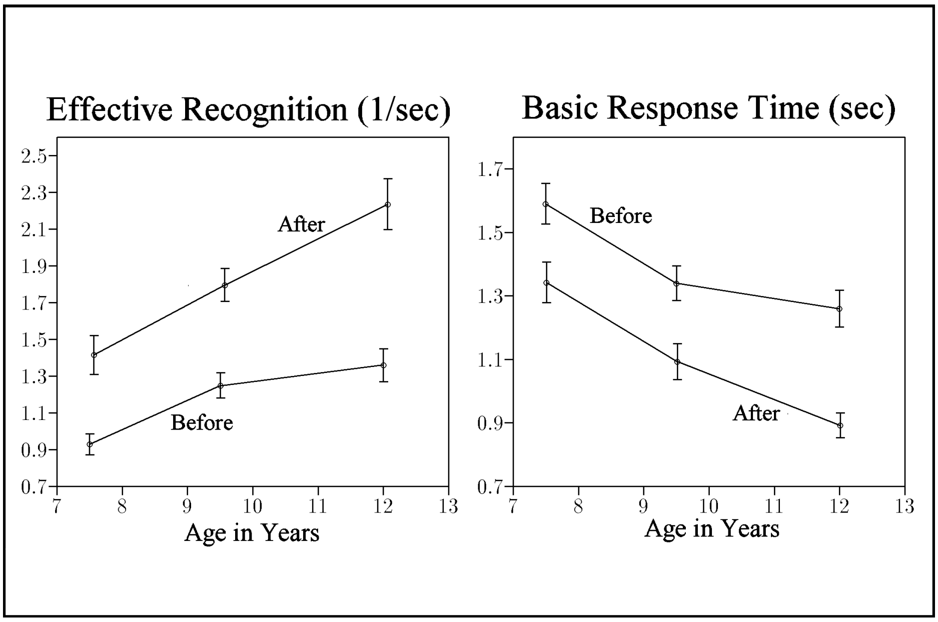
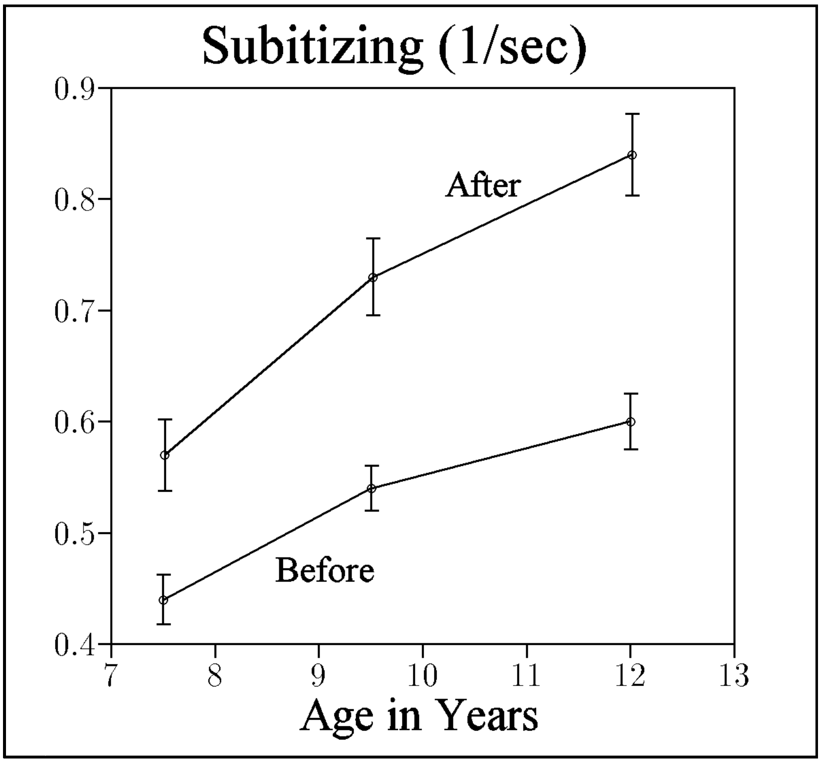

Effective Recognition (1/sec)
Basic Response Time (sec)
After
Before
Before
After
Age in Years
Age in Years
2.5
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
7
8
9
10
11
12
13

Fig.3



Subitizing (1/sec)
0.9
0.8
0.7
0.6
0.5
0.4
After
Before
7
8
9
10
11
12
13
Age in Years

Fig. 4

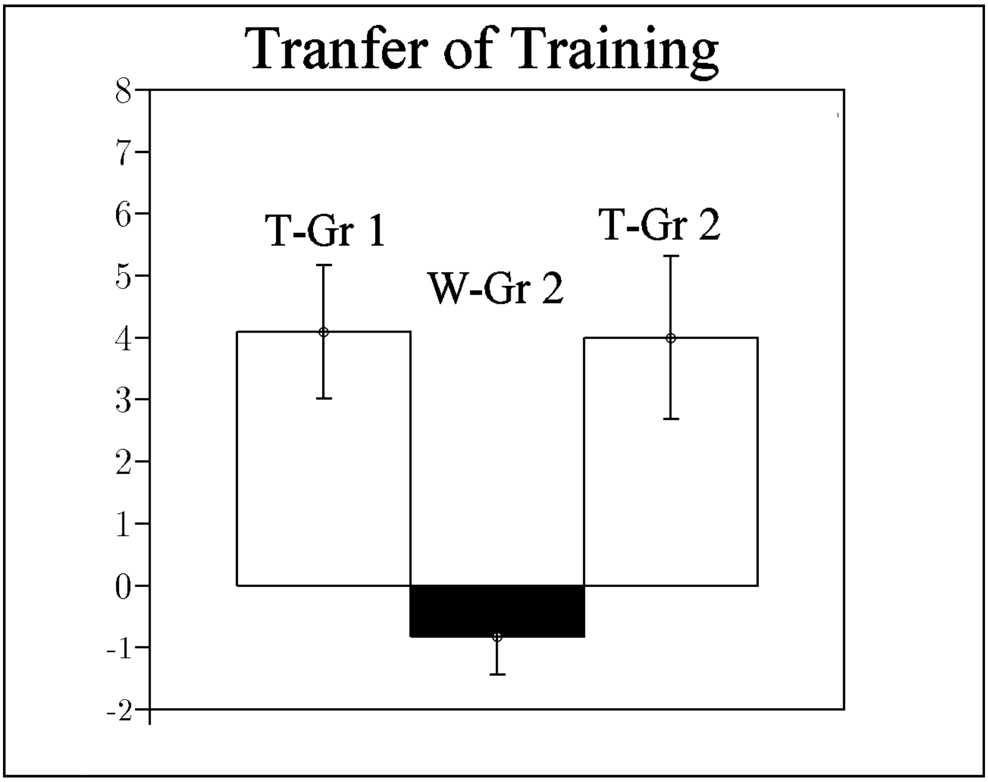


Fig.5