Calcularis: Evaluation of a computer-based learning program for enhancing numerical cognition for children with developmental dyscalculia

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Objective

This study aims to evaluate the computerized **adaptive training program Calcularis** that offers children with developmental dyscalculia (DD) or math difficulties at an early stage the possibility to train especially those aspects of numerical cognition, in which they still need support. Calcularis disposes over a user model allowing flexible adaptation on the basis of the internally mapped learning and knowledge profile of the individual child.

Methods

Study design and sample

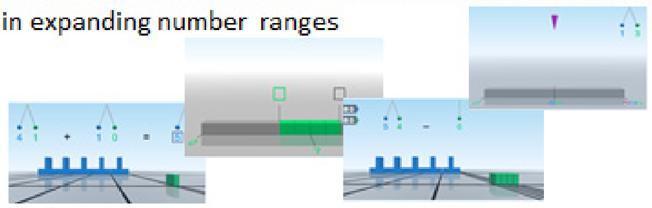
- 67 children with DD or severe math difficulties aged 7;0 to 10;11 years (M = 8.85, SD = 0.85)
- 47 girls, 20 boys (χ^2 (1) = 10.88, p < .001)
- Inclusion criteria: IQ-scores within normal range (16th to 84th percentile) and low arithmetic-scores (<15th percentile)
- Children were randomly assigned to one of three groups (Calcularis group, waiting control group (WCG), control training group (spelling))
- Training duration: 6 weeks (5 sessions à 20 minutes per week)

	t_1	6-8 weeks	t_2
Calcularis group	t_1	Calcularis training	t_2
waiting group	t_1	waiting	t_2
control training group	t_1	control training	t_2

Structure of Calcularis

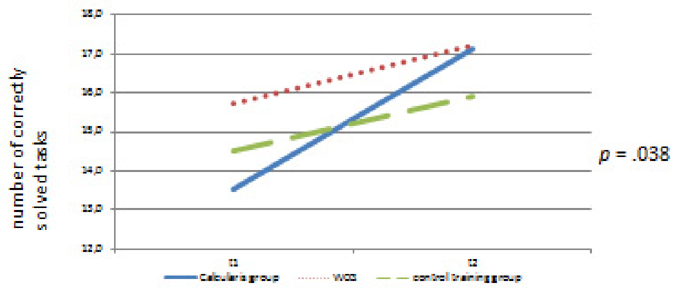
CALCULARIS

- Adaptive design
- Immediate response
- Training of **number representation**, formation and access to a **mental number line**, **arithmetic operations** in expanding number ranges

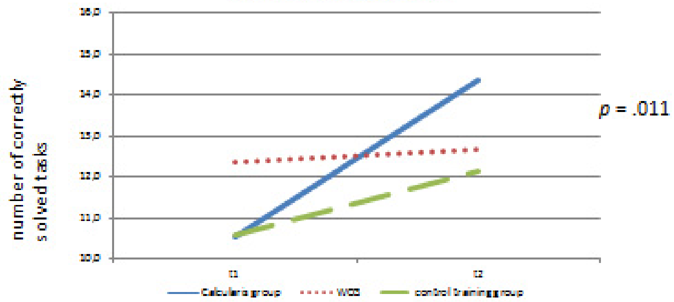


Results

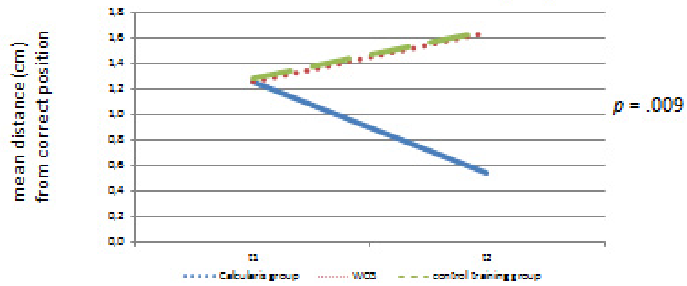
Addition (HRT)[1]



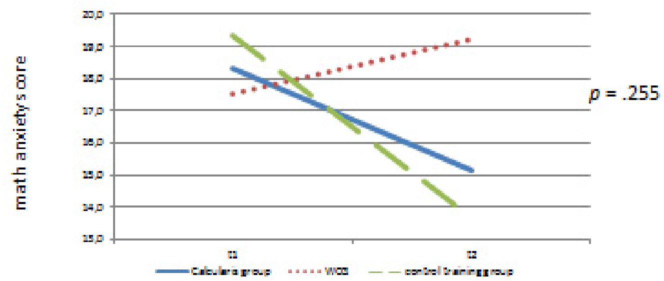
Subtraction (HRT)[1]



Position on mental number line (0-10)



Math anxiety (MAI)[2]



Conclusions

This study demonstrates that the adaptive training program Calcularis can be used effectively to support children with DD or math difficulties in their **numerical development** and to enhance **numerical cognition**. The results show that even after a rather short training period good effects with regard to **addition**, **subtraction** and **spatial number representation** were achieved. Furthermore, Calcularis led to a significant decrease of **math anxiety**, which may represent also an effect of increasing feelings of domain independent self efficacy, as the control training showed similar effects on math anxiety. Therefore we can strongly recommend implementing Calcularis into special need school programs and treatment procedures for children with developmental deficits in numerical cognition.

[1]Haffner, J., Baro, K., Parzer, P., & Resch, F. (2005). *Heidelberger Rechentest (HRT): Erfassung mathematischer Basiskompetenzen im Grundschulalter*. Göttingen: Hogrefe.
[2]Kohn, J., Richtmann, V., Rauscher, L., Kucian, K., Käser, T., Grond, U., Esser, G., & von Aster, M. (2013). Mathematikangstinterview (MAI) – erste psychometrische Gütekriterien. *Lernen und Lernstörungen*, 2(3), 177-189.

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ABSTRACT

ID:24657 - Calcularis - Evaluation of a Computer Based Learning Program for Enhancing Numerical Cognition for Children with Developmental Dyscalculia

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Abstract Text:

Background:

Developmental dyscalculia (DD) is a specific learning disorder of mathematical abilities. This study aims to evaluate an adaptive training program that offers children with DD or math difficulties the possibility to train especially those aspects of numerical cognition, in which they still need support. The program`s theoretical foundation of numerical cognition and development refers mainly on the triplecode model and the fourstep developmental model (Dehaene, 1992; von Aster & Shalev, 2007). The pilot version of Calcularis (“Rescue Calcularis”) has been evaluated on a neural level using fMRI and revealed significant neuroplastic changes accompanying increased math performance (Kucian et al., 2011). The program aims to automatize the different number representation, support the formation of and access to a mental number line and train arithmetic operations. Calcularis disposes over a user model allowing flexible adaptation on the basis of the internally mapped learning and knowledge profile of the individual child. For this purpose a dynamic Bayes net is used. Furthermore, repetitions are implemented to strengthen trained abilities. A bug library with typical error patterns allows for providing targeted games for the remediation of specific errors. A detailed description of the mathematical model can be found in Käser et al. (2012).

Objective:

The main objective of the present study is the evaluation of the efficacy of the training program Calcularis. To investigate its efficiency we combined two different approaches. First, we aimed to determine the efficacy by comparing the Calcularis training group with an untrained waiting group. The implementation of an untrained waiting group allows controlling for developmental and schooling effects as well as arithmetic development under regular conditions. Second, we compared the performance of the Calcularis training group with a group that received a computerized spelling training to examine the domain specificity of the training effects. Thus, the efficacy of the training can be determined by taking novelty and Hawthorne effects as well as unspecific training effects on domaingeneral functions into consideration. We hypothesized that the Calcularis group will demonstrate a higher benefit in the

analyzed measures for arithmetic performance and spatial number representation compared to both groups.

Methods:

Instruments

The Basic Diagnostics of Specific Developmental Disorders in Elementary School Age children (BUEGA) (Esser, Wyschkon & Ballaschk, 2007) serves for the assessment of verbal and nonverbal intelligence as well as the performance in reading, writing and arithmetic. The internal consistency coefficients determined for each school grade are sufficient to high ($\alpha = .81$ to $\alpha = .95$).

Additional aspects of intelligence were measured with two subtests (similarities, block design) of the Hamburg-Wechsler intelligence test for children (HAWIKIV; Petermann & Petermann, 2007). Both subtests show good psychometric properties for children aged 7 to 11 years with reliabilities of $r = .84$ to .89 for block design and $r = .95$ to .89 for similarities (splithalf coefficients, spearman-brown corrected).

On the basis of the two subscales “addition” and “subtraction” of the Heidelberger Rechentest (HRT 14; Haffner et al., 2005) arithmetic performance is assessed. Retest reliability was calculated over a twoweek period with high coefficients for addition ($r_{tt} = .82$) and subtraction ($r_{tt} = .86$).

A computer-based measure developed by Käser et al. (2013) was conducted to evaluate the quality of spatial representation of numbers. A number is presented verbally and visually on the screen and children were asked to indicate the position of the presented number on a number line by mouse-click. The mean distance (centimeter) between the correct location of the number and the indicated location on the number line was determined.

The Math Anxiety Interview (MAI; Kohn & Richtmann, 2013) assesses the intensity of math anxiety. The MAI demonstrates satisfying criterion validity and high coefficients of internal consistency ($\alpha = .90$).

Study design and sample

The study design comprised three groups. Children with DD or severe math difficulties were randomly assigned to one of three groups. Inclusion criteria comprised IQ-scores within the normal range (16th to 84th percentile; $T \geq 40$ to $T \leq 60$) and low arithmetic-scores (<15thpercentile; $T < 40$). The Calcularis group completed a 6-8 weeks training with 5 training sessions of 20 min per week (see Table 1). The spelling training group received a computer-based spelling training with the same duration and intensity.

Group differences were analyzed by means of Analyses of Variance (ANOVA) and chi-square tests. A series of repeated measures general linear model (GLM) analyses were conducted to evaluate training effects with assessment time point ($t_1 t_2$) as a within-subject factor and group (Calcularis / waiting / spelling training) as a between-subject factor.

Results:

The study sample consisted of 67 children aged 7;0 to 10;11 years (*M* = 8.85, *SD* = 0.85). The study population involved more girls (n = 47) than boys (n = 20), so the gender ratio deviated (χ^2 (1) = 10.88, $p < .001$) significantly from equal distribution.

There were no significant differences between the groups for gender, age or control variables (intelligence, spelling, reading) in the initial diagnostic procedure (t_1) (see Table 2). This was also the case for all arithmetic performance measures.

Table 3 summarizes the mean values and standard deviations of the mathematical performance as well as math and math anxiety measures for the three groups before (t_1) and after training or waiting period (t_2).

The group x time interaction was significant for HRT addition, HRT subtraction and the computer-test assessing spatial representation of numbers indicating that training progress differed between groups over time. Further analyses revealed that children of the Calcularis group demonstrated a higher increase in the performance regarding the outcome measures than the waiting group and the spelling training group with moderate to large effect sizes. The group x time interaction was also significant for math anxiety indicating the degrees of math anxiety differed between groups over time. Further analyses revealed that children of the Calcularis group demonstrated a higher decrease in math anxiety than the children of the waiting group with a large effect size.

Conclusions:

This study demonstrates that the adaptive training program Calcularis can be used effectively to support children with DD or math difficulties in their numerical development and to enhance numerical cognition. The results showed that even after a rather short training period good effects with regard to addition, subtraction and spatial number representation were achieved. Furthermore, training with Calcularis led to a significant decrease of math anxiety. Therefore we can strongly recommend implementing Calcularis into special need school programs and treatment procedures for children with developmental deficits in numerical cognition.

Tables:

Table 1: Training effects of the Calcularis group (CAL), waiting group (WG) and spelling training group (ST).

Outcome Parameter	Group	n	t1 *M (SD)*	t2 *M (SD)*		*F*	*p*	η2
HRT (addition)[a]	CAL	23	13.52 (4.14)	17.13 (4.45)	overall	3.19	.048	.091
	WG	22	15.73 (6.55)	17.23 (6.54)	CAL-WG	4.45	.041	.094
	ST	22	14.50 (5.41)	15.91 (4.39)	CAL-ST	4.56	.038	.096
HRT (subtraction)[a]	CAL	23	10.52 (3.25)	14.35 (3.47)	overall	6.36	.003	.166
	WG	22	12.36 (6.21)	12.68 (6.12)	CAL-WG	12.77	.001	.229
	ST	22	10.59 (4.56)	12.14 (4.14)	CAL-ST	7.01	.011	.140
computer-test	CAL	13	1.26 (0.97)	0.54 (0.19)	overall	5.68	.007	.245
(number line 0-10)[b]	WG	12	1.25 (0.81)	1.64 (1.21)	CAL-WG	8.19	.009	.263
	ST	13	1.28 (0.96)	1.66 (1.20)	CAL-ST	8.05	.009	.251
MAI (math anxiety)[a]	CAL	23	18.35 (9.09)	15.17 (9.09)	overall	5.85	.005	.155
	WG	22	17.55 (9.88)	19.23 (10.97)	CAL-WG	7.01	.011	.140
	ST	22	19.36 (10.73	13.64 (11.17)	CAL-ST	1.33	.255	.030

[a] raw value

[b] mean distance (cm) from correct position

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