ORIGINAL ARTICLE

The Efficacy of Cognitive Training Programs in Children and Adolescents

A Meta-analysis

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SUMMARY

Background: Cognitive therapies are intended to improve basic cognitive functions, whatever the cause of the deficiency may be. Children and adolescents with various cognitive deficits are treated with behavioral therapeutic and computer-supported training programs. We here report the first meta-analysis of the efficacy of such programs.

Methods: We systematically searched the Medline, Embase, PsycINFO, PSYDEX, and ERIC databases to find pertinent publications for a meta-analysis of cognitive training programs that are used in children and adolescents to improve attention, memory, and executive performance (primary goals) as well as behavior/psychopathology, intelligence, and school performance (secondary goals). The mean differences between the treatment and control groups are given here as standard deviation (SD) scores.

Results: 1661 potentially relevant publications were found, including 22 studies that were considered in the meta-analysis, 17 of which were randomized controlled trials. The target variables were measured with more than 90 different testing techniques. The overall effects of cognitive training on attention (SD 0.18, 95% CI -0.11–0.47) and executive function (SD 0.17, 95% CI -0.12–0.46) were consistently small. A relatively strong effect was found on memory performance (0.65 SD, 95% [-0.12–1.42], albeit with marked heterogeneity ($I^2 = 82\%$) owing to two studies. The largest effect was found in the area of behavior and psychopathology (SD 0.58, 95% CI 0.31–0.85), but this last figure is derived mainly from studies that lacked an active control group.

Conclusion: Cognitive therapies for children and adolescents have generally favorable, but probably nonspecific effects on behavior. On the other hand, the specific effects, however, were weak overall. Therapeutic benefit has been demonstrated only for certain individual types of therapy for specific indications.

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Cognitive therapy and training programs focus on basic functions that underpin cognition, particularly attention, retentiveness and memory, visuospatial perception, and executive functions. Courses for children utilize cognitive behavioral therapy (CBT) (according to Meichenbaum et al. [1], modified from Lauth and Schlottke [2]) and computer-aided training programs (CTPs), e.g., Captain's Log, Cogmed, or Rehacom (*eTable 1*). The aim is to ameliorate the impairment of basic functions and thus improve competence. Such training programs are used in children with the following disorders:

- Disturbances in mental development
- Severe attention disorders
- Acquired cerebral function disorders or brain injury, also status post mild craniocerebral trauma (e1, e2)

Cognitive therapy and training programs are most frequently indicated in children with attention deficit disorders or attention deficit hyperactivity disorders (ADD/ADHD), where the efficacy of solely medicinal treatment has been questioned (3). The best results in children with ADD/ADHD have been achieved by medicinal treatment in combination with intensive behavioral therapy training of the child together with the parents/guardians (4, 5). Whether such extensive, long-term programs are practicable (outside the context of studies) in normal family and school conditions is uncertain (6).

Systematic reviews of the literature on evaluation of CBT in adults with acquired brain injury (7–9) show that it is only sometimes effective, because the studies do not completely satisfy scientific criteria.

Although favorable results have been found for individual interventions, the effects remain unconfirmed because not all studies are of sufficiently high methodological quality (10, 11). Assessment of the effects of CBT in children with ADD/ADHD varies (12–14). One point of criticism is that transfer of, for example, acquired learning techniques and improved basic functions to school performance or the family situation has not been demonstrated convincingly (13).

The common feature of all treatment approaches in cognitive training is that they aim for favorable effects in at least one of the basic functions or their components, e.g., selective or divided attention or

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working memory. It thus seems desirable to achieve a synopsis of the efficacy studies to date—both CBT-based and computer-aided—in the form of a meta-analysis. Do cognitive therapies lead to improvement in functions promoting cognition, and do they enhance behavior, intelligence, and school performance?

Methods

Patient collective/indications

In searching the literature for relevant publications, no limitations were imposed on the indication for cognitive training. The interventions were carried out in pediatric patients with acquired brain injury, ADD/ADHD, or specific learning disorders and for improvement of cognitive performance in healthy children and adolescents.

Interventions and goals

Child-centered treatment approaches were analyzed: CBT or CTP. In Germany, physicians can prescribe these treatments as ergotherapeutic interventions (§ 38 of the Regulations Governing the Prescription of Remedies [*Heilmittelrichtlinien*]: Cognitive performance training/neuropsychologically oriented therapy). The interventions are not disease-specific, but focus on various functional disturbances: disorders of attention, memory, executive functions (e.g., capacity for self-regulation of behavior and reflective problem-solving), and visuospatial perception. These were the primary outcome measures of the meta-analysis. Furthermore, secondary effects on behavior, intelligence, and school performance were investigated.

Controls

The control group was recruited from comparable patients who had received either no treatment (passive control group) or treatment with a different postulated mechanism of effect (active control group).

Outcome assessment

The treatment effects were determined immediately after conclusion of treatment. No limitations were placed on the tests used, but defined criteria with regard to construct relevance and construct representativeness had to be fulfilled. In order to be able to summarize the effect sizes, we compared the Z-score differences between intervention group and control group.

Search strategy

A systematic literature survey was conducted in the Medline, Embase, PsycINFO, PSYNDEX, and ERIC databases (up to 5 March 2012); publications in German or English, no restrictions on type of study or year of appearance. The abstracts of 1661 initially identified publications were inspected. Thirty-seven potentially suitable studies and 28 further publications cited therein were examined in full using the CONSORTS checklists for nonpharmacological treatment studies (38). Twenty-two studies were subjected to analysis (*eFigure*).

A more detailed account of the methods is available in the online supplement (*eSupplement*).

Results

Twenty-two studies published between 1986 and 2012 were included in our meta-analysis (*Table 1*); overall, they provided data on 905 children and adolescents over the age of 5 years from nine different countries. The discontinuation rate was low in all studies, with an average of 5.6%. The cause and grade of the heterogeneous disorders was usually described clearly. The criteria for the diagnoses ADD and ADHD were based on the edition of the ICD or the Diagnostic and Statistical Manual of Mental Disorders (DSM) valid at the time. Acquired brain injuries were caused by craniocerebral trauma, HIV infection, cerebral malaria, or brain tumors.

The CTPs varied both with regard to both their methods and their goals. Details can be found in *eTable 1*. The duration of the training programs varied between 1 month and 6 months (in one case 12 months [27]). The effects were mostly measured directly after the end of the training phase. Follow-up data for periods ranging from 2.5 to 6 months were provided in six studies (18, 21–23, 26, 30). Existing medications were continued.

Instruments

eTable 2 shows the test procedures and instruments used to calculate the effect strengths.

Study quality

The quality of the studies was evaluated with regard of statistical and methodological aspects (*Table 2*). In only three studies were the participants randomized by generation of a randomization sequence and masked assignment to groups (21–23). Participants and trainers were mostly not blinded, because a wait-list control group design was often selected. A few studies, however, attempted blinding at the stage of data acquisition. All studies gave reasons for any data loss and drop-outs. In seven studies (16, 21, 23, 25, 27, 35, 37), evaluation according to intention to treat was documented.

In total, the studies employed around 90 different test procedures. The spectrum ranged all the way from ad-hoc instruments to internationally recognized, well validated and normalized methods. Both for the primary and the secondary goals, the procedures used were predominantly classified as adequate.

Overall effects and subgroup analysis

Primary outcome measures

Attention—The overall effect of cognitive training programs on attention was low (SD 0.18, 95% CI = [−0.11; 0.47]) (*Table 3*). Subgroup analysis showed a slight amount of heterogeneity:

- Diagnosis (ADHD/ADD, specific learning disorders, acquired brain injury, healthy): $I^2 = 39\%$
- Treatment type (CTPs versus CBT): $I^2 = 33\%$

TABLE 1

Characteristics of the studies included in the meta-analysis

Study (country)	N: Intervention versus controls (N: drop-outs)	Age (years)	Diagnosis	Type of intervention (see eTable 1 for details)	Primary and secondary training goals	Duration and intensity of intervention (follow-up)
Randomized controlled studies (according to authors)						
(15) Germany	6 versus 6 (0 versus 0)	7–12	ADHD/ADD	CBT according to Lauth and Schlotke (14) versus sensomotor training according to Kiphard	Attention/ executive function/ behavior	9 weeks; 2 × per week, 50 min
(16) Uganda	35 versus 33 (7 altogether)	>5	Brain injury after cerebral malaria	CTP (Captain's Log): all cognition-supporting functions versus normal educational measures	Attention/ executive function/ memory/ behavior	8 weeks; 2 × per week, 45 min
(17) Uganda	32 versus 28 (1 versus 0)	6–16	Brain injury in connatal HIV infection	CTP (Captain's Log): all cognition-supporting functions versus normal educational measures	Attention/ executive function/ memory/ behavior	5 weeks; 2 × per week, 45 min
(18) USA	19 versus 14 (5 altogether)	5–13	ADHD/ADD	CBT (with or without methyl phenidate) versus attention control techniques (with or without methyl phenidate)	Attention/ executive function/ memory/ behavior/ school performance	3 months; 2 × per week, 60 min (3 months)
(19) USA	109 versus 54 (19 versus 2)	6–17	Brain injury after treatment of brain tumor	CTP (Cognitive Remediation Program, CRP): all cognitive functions plus CBT versus individual educational measures	Attention/executive function/ school performance/ self-esteem	4–5 months; 1–2 × per week, 120 min
(20) USA	10 versus 10 (n.d.)	8–12	Specific learning disorder (dyslexia)	Pay Attention! program plus learn to write program versus reading training "Read naturally"	Attention/ executive function/ memory/ school performance	5 weeks; 2 × per week, 30 min
(21) Canada	13 versus 13 (3 altogether)	7–13	ADHD/ADD	CBT versus parental counseling with exercises without CBT techniques	Attention/ executive function/ behavior	10 weeks; 2 × per week, 60 min in the hospital, 120 min at home (5 months)
(22) USA	32 versus 30 (n.d.)	7–11	Healthy children	PC video games to train working memory versus PC presentation of questiona and answers	Attention/ working memory/ intelligence/ behavior	4–6 weeks; 5 × per week, ca. 15 min (3 months)
(23) Germany	15 versus 15 (0 versus 0)	7–12	ADHD/ADD	Child-centered attention training and social training according to Lauth and Schlotke (14) individually and parents in group (according to Döpfner [23]) versus wait-list group	Attention/ behavior	10 weeks; 1–2 × per week, ca. 50 min (10 weeks)
(25) Sweden	7 versus 7 (0 versus 0)	7–15	ADHD/ADD	CTP (Cogmed, RoboMemo): visual and verbal-spatial working memory versus × 10 "low-level" training sessions	Attention/ executive function/ working memory/ intelligence/ school performance	5 weeks; 4–5 × per week, ca. 25 min
(26) Sweden	27 versus 26 (9 altogether)	7–12	ADHD/ADD	CTP (Cogmed, RoboMemo): visual and verbal-spatial working memory versus "low-level" training sessions	Attention/ executive function/ working memory/ behavior/ school performance	5 weeks; 4–5 × per week, ca. 40 min (3 months)
(27) international	99 versus 49 (5 versus 23)	4–20	Mental retardation/ learning impairment	Instrumental enrichment according to Feuerstein. Training of several cognitive functions versus ergotherapy	Intelligence	30–45 weeks; 60 min
(28) Germany	21 versus 16 (n.d.)	7–13	Selective memory disorder (IQ normal)	REMINDER (training of memory techniques and basic functions of retentiveness, including attention) versus wait-list group	Memory	15 weeks; 15 × 60 min
(29) USA	18 versus 15 (0 versus 2)	7–9	ADHD/ADD with comorbid emotional and behavioral disorders	CTP (LocuTour, cognitive rehabilitation): attention and memory versus PC programs to support work at school	Attention/ executive function/ behavior	14 weeks; 1–2 × per week – ca. 3 hours per week
(30) Germany	20 versus 19 (2 altogether)	13–18	Mental retardation/ learning impairment	Small-group training in cognitive techniques (according to Klauer): fluid intelligence versus normal classwork	Fluid intelligence/ learning behavior/ school performance	4 weeks; ca. 3 × per week, ca. 45 min (6 months)

(31) Sweden	16 versus 17 (2 altogether)	7–12	Healthy children	CTP (Cogmed RoboMemo): Visuospatial working memory inhibition control versus wait-list group	Attention/ executive function/ working memory	5 weeks; 5 × per week, 15 min
(32) Germany	16 versus 16 (n.d.)	10–11	ADHD/ADD	CTP (AixTent in the Cogniplus program): attention according to Sturm	Attention/ executive function	4 weeks; 2 × per week, 60 min
Controlled studies						
(33) Germany	14 versus 14 (2 versus 2)	5–7	Learning disorder	Training in cognitive techniques (according to Klauer) plus training of metacognitive competence according to Lauth and Schlotke (14). Parental counseling versus no special measures	Attention/ executive function/ intelligence	3 months; 1 × per week, 45–60 min
(34) Germany	34 versus 16 (n.d.)	9–10	ADHD/ADD	Training for children with attention disorders according to Lauth and Schlotke (14)	Attention/ executive function/ memory	15 per week; 2 × per week, 90 min
(35) Italy	40 versus 25 (0 versus 0)	6–18	6–10 months post severe head injury	CTP (Rehacom) combined with similar system: all cognitive functions versus no training	Attention/ executive function/ intelligence/ behavior	6 months; 4 × per week, 45 min
(36) Germany	14 versus 13 (0 versus 0)	8–12	ADHD/ADD	CBT and parental counseling versus no training	Attention/ executive function/ intelligence/ behavior	15 weeks; 1 × per week, duration n.d.
(37) Germany	23 versus 15 (4 versus 0)	8–10	Learning difficulties despite normal IQ (underachievers)	Learning competence training according to Lauth and Tänzer plus two information evenings for parents versus no training	Learning behavior/school performance	8 weeks; 2 × per week, 60 min

n.d., no data; CBT, cognitive behavioral therapy; CTP, computer-aided training program

- Study quality: $I^2 = 19\%$
- Medication (with or without methyl phenidate): $I^2 = 0\%$
- Parent counseling (with versus without): $I^2 = 0\%$

Memory—The effect strength for memory was greater, but with a 95% confidence interval that included null and unfavorable effects (SD 0.65, 95% CI = [-0.12; 1.42]). The relatively high point estimators were essentially explained by two studies (25, 28) that were also responsible for the high heterogeneity ($I^2 = 82\%$). While the study by Lepach (28) exhibited methodological weaknesses (no blinded randomization, imprecise description of blinding at the stage of data acquisition and of ITT evaluation), one of the two studies by Klingberg (25), with a small number of cases, broadly fulfilled the usual criteria for methodological quality. In both studies by Klingberg (25, 26) the intervention selected (working memory training) was unusual. The remaining studies showed no effect on memory (SD 0.06, 95% CI = [-0.33; 0.46]), regardless of diagnosis, study quality, type of treatment, or medication.

Executive functions—The effect strengths of cognitive training for executive functions were consistently low (SD 0.17, 95% CI = [-0.12; 0.46]).

Secondary outcome measures

Behavior/psychopathology—The greatest effects were reported in the area of behavior/psychopathology (SD 0.58, 95% CI = [0.31; 0.85]). Testing for possible nonspecific effects revealed stronger effects ($I^2 = 71\%$) in studies with a passive control group (N = 11) (SD 0.80, 95% CI = [0.39; 1.21]) than in those with an ac-

tive control group (N = 11) (SD 0.25, 95% CI = [-0.19; 0.68]).

Intelligence—The overall effect was slight. The only study to show effects whose confidence interval did not include null was that by Lauth (37), in which children with learning difficulties underwent specific training in learning competence.

School performance—Here too, the effects were slight. The overall positive effect is explained purely by the Lauth study (37), the only one to investigate patients with specific learning disorders.

The treatment effects of studies with active and passive control groups were also compared for these secondary outcome measures. The differences were small (school performance: $I^2 = 31\%$; intelligence: $I^2 = 0\%$).

ADHD subgroup analysis

Subgroup analysis was performed only for patients with ADHD. Our reason for this was the fact that most of the studies were carried out in children with ADHD, coupled with the high level of public interest in this disorder. The pattern was almost identical:

- Slight effects on attention (SD 0.38, 95% CI = [-0.13; 0.90]) and executive functions (SD 0.23, 95% CI = [-0.11; 0.58])
- Moderate effect on memory (SD 0.51, 95% CI = [-0.16; 1.17])

The effects on memory were restricted to training programs using the learning program RoboMemo to improve working memory. Favorable effects on behavior were also found in children with ADHD (SD

TABLE 2

The quality of the studies included in the meta-analysis

Study	Use of a randomization sequence and masked group allocation	Study participants (and trainers) blinded	Data acquisition blinded	Loss of data (if any) explained	Evaluation according to ITT	Evaluation of instruments: primary measures	Evaluation of instruments: secondary measures
Randomized controlled studies (according to authors)							
Banaschewski 2006 (15)	–	?	?	+	–	C+/S+/N–	C+/S+/N+
Bangirana 2009 (16)	+	– (PC)	–	+	+	C+/S+/N+	C++/S+/N+
Boivin 2010 (17)	?	– (PC)	?	+	–	C+/S+/N+	C++/S+/N+
Brown 1986 (18)	?	+	+	+	–	C+/S+/N+	C+/S+/N+
Butler 1986 (19)	?	– (PC)	–	+	–	C+/S+/N+	C++/S+/N+
Chenault 2004 (20)	–	–	?	+	?	C+/S+/N+	C+/S+/N+
Fehlings 1991 (21)	?	–	+	+	+	C+/S+/N–	C++/S+/N–
Jaeggi 2011 (22)	–	?	?	+	–	C+/S+/N+	No tests
Kausch 2002 (23)	?	– (PC)	–	+	+	C+/S+/N+	C+/S+/N+
Klingberg 2002 (25)	?	+	+	+	+	C+/S+/N+	No tests
Klingberg 2005 (26)	+	+	+	+	–	C+/N+/S+	C+/S+/N+
Kozulin 2010 (27)	?	?	+	+	+	No tests	C+S+N+
Lepach 2008 (28)	–	– (PC)	?	+	?	C+/S+/N+	No tests
Lomas 2002 (29)	+	+	+	+	–	C+/N+/S+	C+/S+/N+
Sonntag 2004 (30)	?	– (PC)	+	+	–	C+/S+/N+	C+/S+/N+
Thorell 2009 (31)	?	?	+	+	–	C+/S+/N–	C+/S+/N–
Tucha 2011 (32)	?	?	?	+	?	C+/S+/N+	C-/S-/N–
Controlled studies							
Braun 2000 (33)	–	– (PC)	–	+	–	C+/S+/N+	C+/S+/N+
Dreisörner 2006 (34)	–	– (PC)	?	+	?	C++/S+/N+	No tests
Galbiati 2009 (35)	–	– (PC)	+	+	+	C+/S+/N+	C+/S+/N+
Lauth 1996 (36)	?	– (PC)	?	+	–	C+/S+/N+	C+/S+/N+
Lauth 2006 (37)	–	– (PC)	?	+	+	No tests	C++/S+/N+

PC, passive control group (no blinding of participants and training personnel possible) Instruments (for assessment see text): C/S/N, construct validity/standardization/normalization of at least one relevant test for primary or secondary measures.

TABLE 3

Forest plots for primary and secondary outcome measures

Study or subgroup	Effect strength	SE	Weight	Effect strength IV, randomized. 95% CI	Effect strength IV, randomized. 95% CI
1. Attention					
Bangirana 2009	0.06	0.35	13.4%	0.06 [-0.63; 0.75]	
Boivin 2010	-0.23	0.36	12.8%	-0.23 [-0.94; 0.48]	
Butler 2008	-0.1	0.36	12.8%	-0.10 [-0.81; 0.61]	
Chenault 2004	-0.08	0.64	4.9%	-0.08 [-1.33; 1.17]	
Dreisörner 2006	-0.11	0.44	9.4%	-0.11 [-0.97; 0.75]	
Fehlings 1991	0.24	0.54	6.6%	0.24 [-0.82; 1.30]	
Galbiati 2009	1.3	0.41	10.5%	1.30 [0.50; 2.10]	
Lauth 1996	0.01	0.53	6.9%	0.01 [-1.03; 1.05]	
Lomas 2002	-0.16	0.48	8.1%	-0.16 [-1.10; 0.78]	
Thorell 2009	0.45	0.5	7.6%	0.45 [-0.53; 1.43]	
Tucha 2011	0.76	0.52	7.1%	0.76 [-0.26; 1.78]	
Total (95% CI)			100.0%	0.18 [-0.11; 0.47]	
Heterogeneity: $\tau^2 = 0.04$; $\chi^2 = 12.23$, $df = 10$ ($P = 0.27$); $I^2 = 18\%$					
Test for overall effect: $Z = 1.20$ ($P = 0.23$)					
2. Memory Working memory/retentiveness					
Bangirana 2009	-0.44	0.36	12.6 %	-0.44 [-1.15; 0.27]	
Boivin 2010	-0.28	0.36	12.6 %	-0.28 [-0.99; 0.43]	
Brown 1986 – with Methylphenidat	0.07	0.66	10.1 %	0.07 [-1.22; 1.36]	
Brown 1986 – without Methylphenidat	0.04	0.65	10.2 %	0.04 [-1.23; 1.31]	
Chenault 2004	-0.27	0.63	10.4 %	-0.27 [-1.50; 0.96]	
Klingberg 2002	2.41	0.74	9.4 %	2.41 [0.96; 3.86]	
Klingberg 2005	0.67	0.43	12.1 %	0.67 [-0.17; 1.51]	
Lepach 2008	3.31	0.59	10.7 %	3.31 [2.15; 4.47]	
Thorell 2009	0.78	0.45	11.9 %	0.78 [-0.10; 1.66]	
Total (95%-KI)			100.0 %	0.65 [-0.12; 1.42]	
Heterogeneity: $\tau^2 = 1.10$; $\chi^2 = 43.51$, $df = 8$ ($P < 0.00001$); $I^2 = 82\%$					
Test for overall effect: $Z = 1.64$ ($P = 0.10$)					
3. Executive functions					
Banaschewski 2006	0.45	0.57	6.9%	0.45 [-0.67; 1.57]	
Braun 2000	0.05	0.39	14.7%	0.05 [-0.71; 0.81]	
Brown 1986 – mit Methylphenidat	0.25	0.65	5.3%	0.25 [-1.02; 1.52]	
Brown 1986 – ohne Methylphenidat	0.64	0.64	5.5%	0.64 [-0.61; 1.89]	
Chenault 2004	-0.44	0.62	5.8%	-0.44 [-1.66; 0.78]	
Dreisörner 2006	-0.21	0.44	11.6%	-0.21 [-1.07; 0.65]	
Fehlings 1991	-0.13	0.55	7.4%	-0.13 [-1.21; 0.95]	
Klingberg 2002	1.29	0.74	4.1%	1.29 [-0.16; 2.74]	
Klingberg 2005	0.44	0.43	12.1%	0.44 [-0.40; 1.28]	
Lomas 2002	0.14	0.49	9.3%	0.14 [-0.82; 1.10]	
Thorell 2009	0.25	0.5	9.0%	0.25 [-0.73; 1.23]	
Tucha 2011	0.01	0.52	8.3%	0.01 [-1.01; 1.03]	
Total (95% CI)			100.0%	0.17 [-0.12; 0.46]	
Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 5.71$; $df = 11$ ($P = 0.89$); $I^2 = 0\%$					
Test for overall effect: $Z = 1.13$ ($P = 0.26$)

0.57, 95% CI = [0.18; 0.97]), albeit only in studies with a passive control group. No effects were found for the remaining secondary outcome measures (intelligence: SD 0.15, 95% CI = [-0.44; 0.74]); school performance: (SD -0.08, 95% CI = [-0.81; 0.65]).

Long-term effects

Five studies (18, 21–23, 26) provided data on treatment effects not just straight after the intervention but also from follow-up visits 2.5 to 5 months thereafter. The pooled treatment effect on executive functions was greater immediately after treatment than later (treatment difference SD 0.21, 95% CI = [-0.07; 0.50]), but this was not the case for behavior/psychopathology (treatment difference SD 0.04, 95% CI = [-0.22; 0.30]).

Discussion

The primary aim of cognitive training programs is the improvement of specific cognitive functions such as attention, memory, and executive functions. The effects on attention—consistently across all studies—were

slight; the 95% confidence intervals of the pooled effect included superiority of the control group. The overall effect on memory was greater, albeit with pronounced heterogeneity. No effect was observed in the majority of investigations, but in three studies (33, 34, 36) an effect was discernible, possibly explained by the particular characteristics of the training programs involved. With regard to the secondary outcome measures there were overall moderately favorable effects on behavior, but these may not be specific to cognitive behavioral therapy.

A few individual studies on the efficacy of cognitive training programs showed “significant” improvement of certain parameters. The principal strength of a meta-analysis is systematic evaluation and quantification of all available studies on the given topic: in this case, the effect strengths of various tests were standardized, using their respective standard deviations, and rendered comparable. Although earlier reviews were also based on systematic research (10, 11, 13, 39), the observed effects could not be compared or summarized quantitatively.

For the clinician, the results with regard to the primary outcome measures were sobering. One single study (35) showed a clear-cut effect on attention; all others revealed minimal effects or no effect at all. This study had a distinctive patient population and type of treatment: children with attention disorders following severe head injury underwent 6 months of training of all aspects of cognition with the CTP Rehacom. Its statistical power is limited by its lack of randomization. Three studies (25, 26, 28) found distinct effects on memory. These studies varied in the quality of their methods. The study by Lepach (28) lacked well-defined randomization and it was unclear whether the results were determined in a blinded fashion or whether there was an ITT analysis, so the validity of the findings is questionable. The first study by Klingberg (25) showed strong effects and the 95% confidence interval did not include null effects; the quality of the study was limited solely by uncertainty with regard to randomization. When the authors attempted to confirm their results in a larger study of equally high quality (sole weakness: lack of ITT evaluation), the effect was smaller and its 95% confidence interval included null effects (26). The distinguishing feature of the two Klingberg studies was training of working memory with the CTP RoboMemo. This particular treatment thus seems potentially effective. This is confirmed by a study by Thorell et al. that used the same training instrument in healthy individuals (31) and was also of high quality apart from the lack of ITT evaluation. With regard to executive functions, most studies, with the exception of the above-mentioned study by Klingberg (25), showed only slight effects or none at all.

Favorable impact on the secondary measures (behavior, school performance, intelligence) would be of particular clinical relevance. The favorable overall effect of cognitive therapy on behavior reflected the results in studies with a passive control group (no treatment); this effect was not found in studies with an active control group. It therefore seems likely that the favorable effect on behavior represented a nonspecific effect of attention in the form of treatment. No consistently favorable effects were demonstrated on the other secondary measures (school performance and intelligence). Only one study (37) showed positive effects on both intelligence and school performance.

These effects may reflect the fact that in this study—which displayed several methodological deficiencies—patients with a clearly defined learning disorder underwent targeted training in learning competence.

A potential limitation of this meta-analysis lies in the heterogeneity of the underlying diseases, treatments, and intensity and duration of the interventions and tests employed. Earlier systematic reviews, in contrast, often focused on defined underlying diseases (10, 11, 13). Inclusion of a broad spectrum of underlying diseases seems justified, however, because the interventions analyzed do not treat the underlying disease but are intended to ameliorate specific functional deficits. These

specific functions represent the primary outcome measures of our meta-analysis. This is confirmed by the subgroup analysis of children with ADHD, which showed a pattern identical with that of the overall analysis including all underlying diseases. Application of uniform criteria for various test procedures enabled comparison of their quantitative results. Potentially differing effects of specific treatments can be identified in forest plots. Indeed, individual specific treatments seem to be probably more effective than the other procedures used.

One conspicuous finding was the low discontinuation rate for all treatments. This indicates high acceptance of CBT or CTP lasting several weeks. Therefore, repeated courses of training seem appropriate if there are discernible favorable effects on the outcome measures.

Conclusion

Cognitive training in its various forms represents one potential element of a comprehensive program of treatment with involvement of parents/guardians and consideration of the patients' general circumstances. This meta-analysis showed favorable but probably nonspecific effects on behavior, a secondary outcome measure. The effects on the specific primary measures were only slight; the 95% confidence intervals included null and negative effects. Only for particular individual training programs and treatment indications were specific effects demonstrated. Painstaking neuropsychological evaluation is required to identify patients who fulfill these specific indications.

Conflict of interest statement

The authors declare that no conflict of interest exists.

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KEY MESSAGES

- Cognitive training in its various forms represents one potential element of a comprehensive program of treatment with involvement of parents/guardians and consideration of the patients' general circumstances.
- In Germany, the Regulations Governing the Prescription of Remedies permit cognitive training to be prescribed in the form of cognitive behavioral therapy or computer-aided training programs.
- These interventions do not treat underlying diseases; rather, they train specific cognitive functions such as attention, memory, and executive functions, with the intention of improving skills at school and in daily life.
- A meta-analysis showed no overall favorable effects of cognitive training programs on cognitive functions. Favorable effects on behavior were demonstrated but represent nonspecific effects of treatment.
- Clear-cut effects were demonstrated only for individual selected interventions and indications. This underlines the necessity of proper neuropsychological evaluation to identify the patients for whom cognitive training is indicated.

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ORIGINAL ARTICLE

The Efficacy of Cognitive Training Programs in Children and Adolescents

A Meta-analysis

Dieter Karch, Lucia Albers, Gerolf Renner, Norbert Lichtenauer, Rüdiger von Kries

Methods

Patient collective/indications

The literature survey involved no etiological restrictions. We searched for interventions in children with acquired brain injury, e.g., following craniocerebral trauma (e1), as a result of treatment of leukemia, and after brain tumor (e2) or CNS infection; interventions in children with attention disorders in ADD/ADHD or with specific learning difficulties or mental retardation/learning impairment; and interventions to improve cognitive performance in healthy children.

Interventions and goals

With regard to cognitive training, we restricted ourselves to interventions in the behavioral therapy setting (cognitive behavioral therapy) and computer-aided training programs. Studies that exclusively reported medicinal treatment or principally described pedagogic concepts or settings and family-centered programs were excluded.

The primary outcome measures of this meta-analysis were attention, retentiveness and memory, visuospatial perception, and executive functions. Meta-analysis of visuospatial perception turned out to be impossible, however, because explicit instruments to measure this aspect were used in only a small number of studies. Attention is a basic function underlying many cognitive processes and is thus fundamental to all practical and intellectual activity; it represents one of the crucial preconditions for learning processes. To what extent disorders of attention (comprising the functions alertness, sustained attention, selective attention, and divided attention) differ between ADHD and acquired brain injury has not yet been established (e3). Memory performance is extremely complex and embraces the assimilation and retention of information together with recall of memory content. Disorders of memory can be global or specific to a given modality, process, or system. The capacities for self-regulation (emotional, social, motivated, and targeted) of behavior and for reflective problem-solving considering moral and legal requirements represent a core element of the so-called executive functions. They are less well developed in children with ADHD (e4) and selectively disturbed in those with acquired brain lesions (11, e5, e6).

The secondary outcome measures were effects on behavioral disorders and other psychopathological findings together with intelligence and school performance.

Controls

Controls from the same patient collective were either a passive control group (no treatment) or an active control group (treatment with a different postulated mechanism of effect). If a study included both a passive and an active control group, the data of the passive control group were used for analysis.

Outcome assessment

The search strategy featured no restrictions on outcome assessment. Assessment of outcome at the conclusion of treatment was necessary for evaluation of the immediate treatment effect. The persistence of any treatment effect was judged on the basis of follow-up measurements. The measurement instruments used in the studies were assigned to the outcome measures and assessed for construct relevance, normalization, and standardization (Table 2 and Table B). In addition to the mean values, the standard deviations of the outcome measures had to be either given or calculable from the data provided. The results were evaluated on the following criteria:

Construct relevance and construct representativeness: C+: Of particular importance is the relevance of the given instrument for the construct in question. The primary consideration was the substantive validity of the construct. Procedures that can be seen as indicators of the relevant construct and fulfill the minimal criteria. C++: Instruments that cover several facets of the construct and thus exhibit substantial construct representativeness. C?: Instruments whose construct validity seems dubious or for which there is insufficient information for assessment.

Standardization: S+: Standardization in the sense of high objectivity of study conduct and evaluation. S-: Nonstandardized procedures. S?: Procedures for which there was insufficient information for assessment.

Normalization: To achieve normalization the raw data are transformed so that they can be compared with the data from a reference group. Although normalization is not necessary for group comparisons in controlled studies, it shows that the procedure was used in a large sample so that as a rule further information on reliability and validity will be available. N+ and N- show whether normalization was performed or not. N? refers to procedures for which no reliable information was found or for which the data in the original document did not clearly reveal whether a normalized variant was used.

Search strategy

A systematic search of the literature in the databases Medline, Embase, PsycINFO, PSYINDEX, and ERIC databases was carried out. Publications up to 5 March 2012 were eligible. The search terms were those listed below; there were no restrictions on type of study or year of publication; languages were German and English:

- (child OR children OR childhood OR preschool age) AND
- (cognitive behavior therapy OR cognitive therapy OR neuropsychological therapy OR neuropsychological training OR concentration training OR occupational therapy OR rehabilitation training) AND
- (attention deficit OR attention deficit disorder OR ADHD OR memory deficit OR visuoconstructive deficit OR visuospatial deficit OR executive function OR executive deficit OR problem solving OR cognitive deficit OR perception deficit)

The selection of studies was based on a review protocol. A total of 1 661 publications that had one or more of the search terms in their title or abstract were inspected to identify treatment studies with the outcome parameters memory, working memory, attention, visuospatial perception function and visuomotor performance, executive functions, and learning behavior. Diagnosis, intervention, control groups, and outcome parameters were as already described; no restrictions were imposed on study duration and age of the children; sample size had to be at least five.

Thirty-seven studies fulfilled these criteria and were subjected to full-text analysis. Further relevant studies were found in their reference lists and included in the meta-analysis. The full-text analysis adhered to the CONSORT guidelines and checklists for

nonpharmacological treatment studies (38).

Some studies reported no data or did not include the information necessary for calculation of the effect strengths (means and standard deviations). Twenty-two studies were left for analysis (*eFigure*).

All steps of study selection (D.K. and L.A.) and assessment of test procedures (D.K. and G.R.) were carried out by two authors independently. The final decision on which studies to include in the meta-analysis was made by all authors in consensus.

Statistical evaluation strategy/calculation of effect strengths

Because values in the intervention group and the control group could differ before the intervention, and thus changes relative to the pre- intervention measurements were compared, the treatment effect was calculated as the difference between the intervention group and the control group in mean pre- and postintervention measurements. To render the different tests used in the various studies comparable, normalization was carried out with the pooled standard deviation (*e7*), using Cohen's *d* (*e8*) to estimate the relative change as standardized mean difference. To enhance precision, Cohen's *d* was transformed to Hedge's *g* (*e9*) or Glass's Δ (*e10*) by multiplication with a correction factor *J* (*e7*). The relative changes in the control group calculated with Glass's Δ can be explained by the spontaneous course, as a training effect, and in a control group with nonspecific training as an indirect training effect. To obtain the pure effect of the intervention, the relative change in the control group must be subtracted from the relative change in the intervention group (*eBox*).

eBOX

Equations for calculation of effect strength and weighting of studies in the meta-analysis

The following equation is obtained as estimator for the effect strength::

$$EF = J[\Delta_I - \Delta_C] = J \left[\frac{M_{I,post} - M_{I,pre}}{SD} - \frac{M_{C,post} - M_{C,pre}}{SD} \right]$$

$M_{I,post}$ and $M_{I,pre}$ are the mean values of the intervention group at the post- and preintervention measurements.
SD is the pooled standard deviation of the preintervention measurements in the intervention group and the control group:

$$SD = \sqrt{\frac{(n_I - 1)SD_{I,pre}^2 + (n_C - 1)SD_{C,pre}^2}{n_{I,pre} + n_{C,pre} - 2}}$$

Here n_I and n_C are the number of probands in the intervention group and the control group respectively. $SD_{I,pre}$ and $SD_{C,pre}$ give the standard deviation of the pre- and post intervention measurements in the intervention group and the control group.

The correction factor J is given as:

$$J = 1 - \frac{3}{4(n_{I,pre} + n_{C,pre} - 2) - 1}.$$

The variance of this effect strength can be estimated as (e7):

$$V = J^2 \left[\frac{n_{I,pre} + n_{I,post}}{n_{I,pre} n_{I,post}} + \frac{\Delta_I^2}{2(n_{I,pre} + n_{I,post})} + \frac{n_{C,pre} + n_{C,post}}{n_{C,pre} n_{C,post}} + \frac{\Delta_C^2}{2(n_{C,pre} + n_{C,post})} \right]$$

If a study includes more than one test of one aspect of cognition (e.g., attention), the mean of the individual effect strengths is calculated (see Chap. 24 of [e7]).

The software Review Manager 5.1 was used to calculate overall effect from these effect strengths with the aid of the random effect model. The inverse variance method was chosen for weighting of the studies. The heterogeneity of the test statistic is given by:

$$Q = \sum_{i=1}^n w_i (EF_i - \hat{\theta})^2, \text{ where } w_i = \frac{1}{(SE_i)^2}$$

which represents the weighting of study i ; $\hat{\theta}$ is the overall effect of all of the studies included in the meta-analysis.
 I^2 is calculated by:

$$I^2 = \max(100\% \cdot \frac{Q - (k - 1)}{Q}, 0)$$

where k is the number of studies included in the meta-analysis.

To enable assessment of the persistence of the effect, analogous to the calculation of the effect strengths and variances after training (EF_{post} , V_{post}) as described above, the effect strengths and variances at follow-up ($EF_{follow-up}$, $V_{follow-up}$) were calculated and the difference between these effect strengths ($EF_{post} - EF_{follow-up}$) was generated. A small effect strength difference indicates a persistent effect; the greater the difference, the less persistent the effect.

eFIGURE

Flow diagram

eTABLE 1

Cognitive training techniques included in the meta-analysis

Name	Goals	PC-aided technique	Authors or evaluation studies
AixTent (CogniPlus)	Attention: selective, divided, focused and constant attention (according to Sturm) (www.cogniPlus.de)	Yes	Tucha 2011 (32)
Captain's Log	Cognitive training (attention, working memory, visuomotor function, problem solving) (www.braintrain.com)	Yes	Bangirana 2009 (16), Boivin 2010 (17)
Cognitive Remediation Program (CRP)	Cognitive training: attention, metacognitive strategies, cognitive behavioral training and memory (www.cognitive-remediation.com)	Yes	Butler 2008 (19)
Cogmed (RoboMemo)	Training of visuospatial and spatioverbal working memory with tasks of increasing difficulty (www.cogmed.com)	Yes	Klingberg 2005 (26)
CogniPlus	Attention, working memory, visuomotor function, executive functions, long-term memory (www.cogniPlus.de)	Yes	Tucha 2011 (32)
Klauer cognitive training	Inductive cognition (fluid intelligence): memory processes, categorization, combination, planning etc. Klauer differentiates various cognitive operations according to distinguishing characteristics or relationships, depending on whether sameness, difference, or both are concerned; this yields six different cognitive operations that are applied to verbal, visual, geometric-figural, and numerical tasks.	No	Sonntag 2004 (30)
Feuerstein Enrichment	Cognitive training at school and in everyday life in the area of the figural-visuomotor modality, recognition, organization and description of simple visual representations, spatial orientation, identification of emotions aroused by pictures; includes perception, self-regulation, planning, speech comprehension, and understanding of emotional and social behavior.	No	Kozulin 2010 (27)
Cognitive behavioral therapy (CBT) adapted from Meichenbaum et al. (1971) Variant	Attention (selective, focused), behavior in several phases – "What should I do?"; perceive what has to be done and gather information – perform the tasks: step by step; thinking aloud – self-monitoring: "Have I done it all correctly?" – self-reinforcement: "I did that well!"	No	Lauth 1996 (36), Lauth und Schlottke 2002 (2), Banaschewski 2006 (15), Braun 2000 (33), Dreisörner (2006) (34), Kausch (2002) (23) Brown 1986 (18), Fehlings 1991 (21)
Training in learning competence	Cognitive facilitation: memory processes, categorization of verbal information, strategies for writing an essay, learning a poem, and text comprehension	No	Lauth 2006 (37)
LocuTour cognitive rehabilitation: Attention and Memory Version 1.3	Acoustic, visual, and verbal attention, executive functions, acoustic and visual memory (www.locutour.com)	Yes	Lomas 2002 (29)
RehaCom	Cognitive training: attention, memory, executive functions, visuomotor function (vigilance, attention, concentration, response behavior) (www.hasomed.de)	Yes	Galbiati 2009 (35)
PC video games training	Working memory training: PC video games ("spatial single n-back") Presentation of stimuli: 10 × every 3 s in six random positions Press a button when the stimuli appear in the same position twice in a row	Yes	Jaeggi 2011 (22)
REMINDER	Retentiveness/memory: CBT- and PC-aided: storage and recall strategies: chaining, focusing, multimodal registration, symbolic coding, visualization, verbalization, rehearsal, categorical organization	Partially	Lepach 2009 (28)
Pay Attention	Additional stimulation of attention during PC training programs (www.lapublishing.com/pay-attention)	Yes	Chenault 2004 (20)

eTABLE 2

Assessment of the test procedures and instruments used to calculate effect strengths

Study	Instrument	Assessment
Banaschewski & Rothenberger 2006 (15)	Cognition	
	<i>Executive functions</i>	
	– Matching Familiar Figures Test (MFFT)	C+/S+/N–
	Behavior/psychopathology	
	– Child Behavior Checklist (CBCL), parent rating	C++/S+/N+
Bangirana 2009 (16)	– Conners Abbreviated Symptom Questionnaire, Hyperkinesis Index	C+/S+/N+
	Cognition	
	<i>Attention</i>	
	– Cogstate neuropsychological tests	C+/S+/N+
	– Identification Task	
	<i>Memory</i>	
	– Cogstate neuropsychological tests	C+/S+/N+
	– One Back Working Memory Task	
	– Cogstate neuropsychological tests	C+/S+/N+
	– One Card Learning Task	
	– Cogstate neuropsychological tests	C+/S+/N+
	– Croton Maze Learning Task	
Boivin 2010 (17)	Behavior/psychopathology	
	– Child Behavior Checklist (CBCL), parent rating	C++/S+/N+
	Cognition	
	<i>Attention</i>	
	– Cogstate neuropsychological tests	C+/S+/N+
	– Identification Task	
	<i>Memory</i>	
	– Cogstate neuropsychological tests	C+/S+/N+
	– One Back Working Memory Task	
	– Cogstate neuropsychological tests	C+/S+/N+
	– One Card Learning Task	
Brown 1986 (18)	– Cogstate neuropsychological tests	C?/S+/N+
	– Croton Maze Learning Task	
	Behavior/psychopathology	
	– Child Behavior Checklist (CBCL), parent rating	C++/S+/N+
	Cognition	
	<i>Executive functions</i>	
	– Matching Familiar Figures Test (MFFT)	C+/S+/N–
	<i>Attention</i>	
	– Children's Checking Task	C+/S+/N–
	<i>Memory</i>	
	– Detroit Tests of Learning Ability (DTLA): subtests	C++/S+/N+
	– Auditory Attention Span for Unrelated Words	
	– Auditory Attention Span for Related Words	
	– Visual Attention Span to Letters	
	<i>School performance</i>	
	– Wide Range Achievement Test (WRAT): subtests	C++/S+/N+
	– Reading, Arithmetic, Spelling	
	– Durrell Analysis of Reading Difficulty: subtest – Listening Comprehension	C+/S+/N+
	Behavior/psychopathology	
	– Conners' Parent Rating Scale (CPRS)	C+/S+/N+
	– Hyperactivity Index	
	ADD-H Comprehensive Teachers' Rating Scale (ACTeRS)	C+/S+/N+

Butler 2008 (19)	Cognition	
	<i>Executive functions</i>	
	– Stroop Color-Word Test	C+/S+/N+
	– Trail Making Test B	C?/S+/N?
	<i>Attention</i>	
	– CPT-II	C+/S+/N+
	Behavior/psychopathology	
Chenault (2004) (20)	– Conners CPRS:LV-R (inattention, hyperactivity)	C+/S+/N+
	– Conners CTRS:LV-R (inattention, hyperactivity)	C+/S+/N+
	Cognition	
	<i>Executive functions</i>	
	– Delis-Kaplan Executive Function System (Letter Fluency, Inhibition/Switching)	C+/S+/N+
	– NEPSY (Tower)	
	<i>Attention</i>	
	– Cognitive Assessment System (CAS), Receptive Attention	C+/S+/N+
	– NEPSY (Auditory Attention, Response Set)	C+/S+/N+
	<i>Memory</i>	
	– WISC-III Digit Span	C+/S+/N+
	<i>School performance</i>	
	– WIAT (Written Expression)	C+/S+/N+
	– Process Assessment of the Learner PAL (Alphabet 15 s, Copy A, Copy B)	C+/S+/N+
	– WJ-III (Writing Fluency)	C+/S+/N+
	– WRAT-3 (Spelling)	C+/S+/N+
	– WIAT-2 (Spelling)	C+/S+/N+
	– GORT-3 (Rate, Accuracy)	C+/S+/N+
Fehlings 1991 (21)	Cognition	
	<i>Executive functions</i>	
	– Matching Familiar Figures Test (MFFT)	C+/S+/N-
	Behavior/psychopathology	
	– Behavior Problem Checklist (BPC; subscale Attention Problems) (parent and teacher ratings)	C+/S+/N-
	– Self-control Rating Scale (SCRS) (parent and teacher ratings)	C+/S+/N-
Jaeggi 2011 (22)	– Modified Werry Weiss Activity Scale (parent questionnaire)	C+/S+/N-
	Cognition	
	<i>Intelligence</i>	
	– Test of Nonverbal Intelligence (TONI-3)	C+/S+/N+
Kausch (2002) (23)	– Raven's Standard Progressive Matrices Test (SPM)	C+/S+/N+
	Cognition	
	<i>Intelligence</i>	
	– CFT	C+/S+/N+
Klingberg 2002 (25)	Behavior/psychopathology	
	– Conners Rating Scale Teacher/ Parents	C+/S+/N+
	Cognition	
	<i>Executive functions</i>	
	– Stroop Test	C+/S+/N-
	<i>Memory</i>	
	– Trained version of the visuospatial working memory task	C?/S+/N-
	– Span board	C?/S+/N-

Klingberg 2005 (26)	Cognition	
	<i>Executive functions</i>	
	– Stroop Test	C+/S+/N-
	<i>Memory</i>	
	– Digit span	C?/S+/N-
	– Span board	C?/S+/N-
Kozulin 2010 (27)	Behavior/psychopathology	
	– Conners Rating Scale Teacher/ Parents	C+/S+/N+
Lepach 2008 (28)	Cognition	
	<i>Memory</i>	
	– BASIC-MLT short form (visual and auditive learning, visual and auditive memory)	C+/S+/N+
Lomas 2002 (29)	Cognition	
	<i>Executive functions</i>	
	– WCST	C+/S+/N+
	<i>Attention</i>	
	– Conners CPT	C+/S+/N+
	Behavior/psychopathology	
	– CPRS-R: L	C++/S+/N+
Sonntag 2004 (30)	– CTRS-R: L	C++/S+/N+
	Cognition	
	<i>Intelligence</i>	
	– CFT 20	C+/S+/N+
	<i>School performance</i>	
Braun 2000 (33)	– Specific goal-oriented test	C+/S+/N-
	Cognition	
	<i>Executive functions</i>	
	– MFFT	C+/S+/N-
	<i>Intelligence</i>	
	– CFT 1	C+/S+/N+
Dreisörner 2006 (34)	– K-ABC	C++/S+/N+
	Cognition	
	<i>Executive functions</i>	
	– Test battery for attention (TAP; subtest Incompatibility)	
	<i>Attention</i>	
	– Test battery for attentions (TAP; subtests Divided Attention, Go/No-go, Visual Scanning)	C++/S+/N+
Galbiati 2009 (35)	– d2 test of attention and performance	C+/S+/N+
	Cognition	
	<i>Attention</i>	
	– Conners CPT II	C+/S+/N+
	<i>Intelligence</i>	
	– WISC-R/WAIS-R	C++/S+/N+

Lauth 1996 (36)	Behavior/psychopathology	
	– Vineland Adaptive Behavior Scale (VBAS)	C+/S+/N+
	Cognition	
	<i>Attention</i>	
	– CPT (Continuous Performance Test; Knye et al.)	C+/S+/N+
Lauth 2006 (37)	<i>Intelligence</i>	
	– CFT 1 / CFT 2	C+/S+/N+
	Cognition	
	<i>Intelligence</i>	
	– K-ABC	C++/S+/N+
	<i>School performance</i>	
Thorell 2009 (31)	– General school performance test AST 2 / AST 3	C++/S+/N+
	Behavior/psychopathology	
	– Teacher questionnaire on learning behavior in class	C?/S+/N–
	Cognition	
	<i>Executive functions</i>	
	– Day-Night Stroop Task	C+/S+/N–
	<i>Attention</i>	
	– Go/No-go Task	C+/S+/N–
	– NEPSY Auditory Continuous Performance Task	C+/S+/N+
	<i>Memory</i>	
	– WAIS-RNI span board task	C?/S+/N–
Tucha 2011 (32)	– Word span task according to Thorell (comparable with Digit Span Subtest WISC III)	C+/S+/N–
	<i>Intelligence</i>	
	– WPPSI-R Block Design	C+/S+/N–
	Cognition	
	<i>Executive functions</i>	
	– TAP (subtest Flexibility)	C++/S+/N+
	<i>Attention</i>	
	– TAP (subtests Tonic and Phasic Alertness, Vigilance, Divided Attention, Visual Scanning)	

ORIGINAL ARTICLE

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eReferences

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