Executive functions in children and adolescents

Document status and date:
Published: 01/01/2019

DOI:
10.26481/dis.20191016cr

Document Version:
Publisher's PDF, also known as Version of record

Executive functions in children and adolescents

Novel perspectives on assessment and intervention

Christine Resch

Cover & lay-out Steven Frenks
Printed by Ridderprint | www.ridderprint.nl
This thesis is printed on recycled paper
ISBN 978-94-6375-561-0

Printing of this thesis was kindly supported by Maastricht University and BrainGymmer, Dezzel Media BV.

Executive functions in children and adolescents

Novel perspectives on assessment and intervention

PROEFSCHRIFT

Ter verkrijging van de graad van doctor aan de Universiteit Maastricht,
op gezag van de Rector Magnificus, Prof. dr. Rianne M. Letschert,
volgens het besluit van het College van Decanen,
in het openbaar te verdedigen op
woensdag 16 oktober 2019 om 14:00 uur

door

Christine Resch
Geboren 17 januari 1990 te Aken

Promotor
Prof. dr. C.M. van Heugten

Copromotor
Dr. P.P.M. Hurks

Beoordelingscommissie
Prof. dr. C.P.M. van der Vleuten (voorzitter)
Dr. J.G.M. Hendriksen (Laurentius Ziekenhuis Roermond)
Dr. L.M. Jonkman
Prof. dr. J.T. Swaab (Leiden University)

Contents

Chapter 1

General introduction

Executive functions (EF) are a collection of higher-order cognitive functions responsible for goal-directed and purposeful behaviour [1-3]. EF are essential for children's and adolescents' daily life functioning, including academic performance and school behaviour, mental and physical health, participation, career perspectives, and quality of life [2, 4-9]. EF consist of various unique, though interrelated, functions [2, 3, 10]. There is general agreement that there are three core EF: inhibitory control, working memory and cognitive flexibility [3]. Inhibitory control is the ability to withhold prepotent or automatic responses when inappropriate for the context at hand [3, 10-12]. Successful inhibitory control is evidenced, for example, when children and adolescents show focus and concentration in the presence of distraction or display controlled behaviour by waiting for their turn. Working memory can be defined as temporarily cognitively maintaining and simultaneously manipulating information [12, 13]. Working memory is involved in, for example, remembering a series of instructions from a parent or a teacher. Cognitive flexibility is the ability to shift between mental sets and tasks [1, 3]. Cognitive flexibility is required when, for example, children and adolescents meet unexpected challenges in their daily lives that demand novel or alternative ways of thinking. The three core EF are, in turn, thought to underlie more complex EF such as planning, organising, initiating, monitoring, reasoning, and strategy use [1, 11]. Neuroimaging studies show that the collection of EF are mediated by overlapping networks across the brain, including the prefrontal cortex as essential component, collaborating with various posterior cortical regions and subcortical structures [14-16].

Childhood and adolescence are important periods of EF development. Development of EF starts early in childhood (i.e. before age 3) and continues well into adolescence and early adulthood (i.e. approximately until age 30) [1, 14, 17-22]. During these periods of ongoing cognitive and neural maturation, EF show increased sensitivity to environmental influences and experiences. On the one hand, this sensitivity leaves children's and adolescents' EF vulnerable to negative impact to its underlying neural substrates. On the other hand, it provides opportunities to target and improve EF with training and interventions [11].

Process measures of EF task performance

EF are frequently assessed with neuropsychological performance tasks (i.e. paper and pencil tasks or computerised tasks). Common examples of such tasks are verbal fluency tasks [23], design fluency tasks [24], and complex figure tasks (e.g. the Rey-Osterrieth Complex Figure task [25]). In a verbal fluency task, children are instructed to name as many words belonging to a certain category, such as animals, food or words beginning with the letter 'P', within a set time frame (e.g. one minute) [26-28]. Verbal fluency tasks are frequently used as measures of lexico-semantic knowledge, lexical access, and EF such as cognitive flexibility, monitoring and strategy use [28-31]. Design fluency tasks are the non-verbal version of verbal fluency tasks [26, 27]. In a design fluency task, the goal is to create as many unique designs as possible, for example by drawing lines between an array of five dots, within a set time frame (e.g. one minute) [24, 26, 27]. Underlying design fluency performance are motor planning, visuospatial abilities, visuo-constructive skills, and the same EF involved in verbal fluency performance (i.e. cognitive flexibility, monitoring and strategy selection) [31, 32]. Complex figure tasks require children to first copy a complex figure and later recall the figure from memory as accurately as possible [26, 27]. Performance on complex figure tasks relies on visuo-constructional and visual memory skills, and EF such as organising and strategy use [26, 27].

Commonly used outcome measures of these tasks are accuracy scores, reflecting, for example, the total number of correctly named words or created designs, or the accuracy of the complex figure drawing [26, 27]. However, as shown above, the tasks used to assess EF rely on a large variety of cognitive functions. Examining an accuracy score makes it difficult to pinpoint the influence of EF in the task outcomes. To gain insight into the role of EF in performance on these tasks, researchers have begun to explore outcome measures that assess how children approach these tasks, or, in other words, which strategies children use. These so-called 'process measures' are thought to provide valuable insight in the processes underlying task performance. Unfortunately, even though it is known that EF development already begins in early childhood [20, 22], process measures have rarely been explored in children below age 6. Studies in young children will help obtain a more complete overview of the developmental changes in EF that take place during childhood.

Process measures have also been shown to be a potential target in EF interventions for older children. For example, processes underlying task performance during a verbal fluency task were successfully modified using a simple training instructing 9 to 12 year old children on how to efficiently search for words in their semantic brain network [33]. Making the children aware of processes underlying performance on this task enhanced the occurrence of these processes. Similarly, providing instruction on a reasoning task was found to advance the level of strategy use on this task for a group of primary school children with a mean age of 9 years [34]. However, in previous studies, both the training and the assessment included the same task (i.e. the same verbal fluency task or the same reasoning task). It is currently unclear to what extent interventions targeting EF processes on one task can also lead to changes in EF processes on other tasks (i.e. transfer).

EF impairments after paediatric acquired brain injury

Acquired brain injury (ABI) is damage to the brain that has occurred after birth and is not related to congenital or neurodegenerative diseases [35]. ABI knows a variety of causes, such as traumatic brain injury caused by a forceful impact to the head (for example due to a fall or a traffic accident), brain tumours, hypoxia, and infections such as meningitis and encephalitis [36]. In the Netherlands, approximately 19.000 children and adolescents are diagnosed with ABI each year [37]. Per definition, paediatric ABI occurs in the context of EF development, rendering the immature brain and associated cognitive functions particularly vulnerable to the impact of ABI. Consequently, after ABI in childhood or adolescence, impairments of cognitive functioning in general and of EF specifically, are frequent and profound [38-43]. However, there is large individual variation in outcome after paediatric ABI. For other cognitive functions, such as intelligence [44] and social cognition (the ability to understand other people's thoughts and feelings) [45], it has been shown that part of the variability in outcome can be explained by the age of the child or adolescent at the time of occurrence of the injury. More specifically, children injured during early and middle childhood (up to age 9) experience larger negative effects on intelligence than children injured during late childhood [44]. In contrast, impairments of social cognition after ABI only emerge in late adolescence and are most persistent for those injured during adolescence [45]. An explanation for these findings is provided based on the sensitive period model. This model states that cognitive functions, such as EF, intelligence and social cognition, show increased vulnerability to the impact of brain injury when the injury occurs during a peak period of neural and functional development [44, 46-49]. For EF, peak periods in development occur throughout childhood and adolescence [1, 14, 17-22]. However, it remains to be determined whether age-dependent deficits in EF can be identified.

Interventions for EF

The frequent occurrence of EF impairments after paediatric ABI and the negative consequences on other areas of functioning, such as academic functioning, participation, and quality of life [5, 7, 50], highlight the importance of effective interventions to improve EF. EF are known to be malleable and receptive to interventions in typically developing children and adolescents (i.e. children and adolescents without ABI) [11]. Previous studies of interventions targeting EF and other cognitive functions of children and adolescents with ABI have revealed similar results, suggesting that cognitive interventions are a potentially valuable treatment method [36, 51-54]. However, there is currently no clear overview of available interventions and their evidence base.

A recent model of cognitive interventions for children and adolescents with ABI proposes that interventions for cognitive functions in general and EF specifically can consist of various components [55]. These intervention components range from compensatory support from others, to repeated practice of specific cognitive skills such as inhibitory control, working memory or cognitive flexibility, to metacognition (i.e. the general ability to oversee how various tasks can be approached) and strategy use (e.g. using mnemonics to improve memory performance). It is currently unclear which intervention components are most effective in improving functioning of children and adolescents with ABI.

Effects of EF interventions can be examined on the level of functions and on the level of activities [56]. EF on the level of functions refers to performance on an EF task, such as a working memory task. In contrast, EF on the level of activities is related to the use of EF in daily tasks, such as remembering a list of items to pack for a school trip. Additionally, the effects of EF interventions can be measured on other domains of functioning (directly or indirectly) related to EF, such as participation. Participation can be conceptualized as the extent and manner in which children and adolescents are involved in various life situations such as at home, at school or in the community [56]. Participation is a popular emerging outcome of interventions for children and adolescents with ABI. However, since participation is a relatively novel concept, there is no consensus yet as to which instruments are suitable to assess participation, in that they adequately capture the construct of participation and enable reliable and valid assessment.

Aims and outline of this thesis

The main aim of this thesis was to provide novel perspectives on assessment of and interventions for EF in children and adolescents with and without ABI. To achieve this, this thesis addresses the following research questions:

1) Can process measures provide insight in processes underlying EF task performance of young children?
2) Does EF process instruction on one task improve children's use of EF processes on another task?
3) Can age at injury explain individual variability in EF outcome after paediatric ABI?
4) Which interventions are effective in improving EF on the level of functions, EF on the level of activities, and functioning in related domains of children and adolescents with ABI?
5) Which instruments are valid and reliable to assess participation in children and adolescents with ABI?

Outline

- In chapter 2 and 3, we investigate process measures of EF task performance in young children.
- In chapter 4, we describe the results of a randomized controlled trial investigating whether a short instruction on processes underlying EF task performance leads to improvements in these processes on a structurally similar task.
- In chapter 5, we examine whether ABI has differential effects on EF 6 months and 2 years post-injury depending on the child's age at injury.
- In chapter 6, we systematically review studies investigating the effectiveness of cognitive interventions, including interventions for EF, for children with ABI. Our main aim was to compare the effectiveness of the interventions by categorizing them based on their intervention components (e.g. repeated task practice, metacognition, and strategy use).

- In chapter 7, we present a novel cognitive intervention, targeting amongst others EF, for children and adolescents with ABI.
- In chapter 8, we report on a systematic review into measurement properties of instruments to assess participation of children with ABI and other brain injuries.
- In chapter 9, a general discussion is presented, describing the main findings of the studies, methodological considerations, clinical implications and directions for future research.

References

1. Anderson P. Assessment and development of executive function (EF) during childhood. *Child Neuropsychology.* 2002;8(2):71-82.
2. Diamond A. Executive functions. *Annual Review of Psychology.* 2013;64:135-68.
3. Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD. The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology.* 2000;41(1):49-100.
4. Borella E, Carretti B, Pelegrina S. The specific role of inhibition in reading comprehension in good and poor comprehenders. *Journal of Learning Disabilities.* 2010;43(6):541-52.
5. Galvin J, Froude EH, McAleer J. Children's participation in home, school and community life after acquired brain injury. *Australian Occupational Therapy Journal.* 2010;57(2):118-26.
6. Gathercole SE, Pickering SJ, Knight C, Stegmann Z. Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology.* 2004;18(1):1-16.
7. Levin HS, Hanten G, Li X. The relation of cognitive control to social outcome after paediatric TBI: Implications for intervention. *Developmental Neurorehabilitation.* 2009;12(5):320-9.
8. Rosema S, Crowe L, Anderson V. Social function in children and adolescents after traumatic brain injury: A systematic review 1989–2011. *Journal of Neurotrauma.* 2012;29(7):1277-91.
9. Ylvisaker M, Feeney T. Executive functions, self-regulation, and learned optimism in paediatric rehabilitation: a review and implications for intervention. *Pediatric Rehabilitation.* 2002;5(2):51-70.
10. Huizinga M, Dolan CV, van der Molen MW. Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia.* 2006;44(11):2017-36.
11. Diamond A, Ling DS. Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience.* 2016;18:34-48.
12. Jacob R, Parkinson J. The potential for school-based interventions that target executive function to improve academic achievement: A review. *Review of Educational Research.* 2015;85(4):512-52.
13. Baddeley AD, Hitch G. Working memory. *Psychology of Learning and Motivation.* 1974;8:47-89.
14. Casey B, Giedd JN, Thomas KM. Structural and functional brain development and its relation to cognitive development. *Biological Psychology.* 2000;54(1):241-57.
15. Durston S, Thomas KM, Yang Y, Uluğ AM, Zimmerman RD, Casey B. A neural basis for the development of inhibitory control. *Developmental Science.* 2002;5(4):F9-F16.
16. Elliott R. Executive functions and their disorders: Imaging in clinical neuroscience. *British Medical Bulletin.* 2003;65(1):49-59.
17. Ardila A, Rosselli M, Matute E, Guajardo S. The influence of the parents' educational level on the development of executive functions. *Developmental Neuropsychology.* 2005;28(1):539-60.
18. Best JR, Miller PH, Jones LL. Executive functions after age 5: Changes and correlates. *Developmental Review.* 2009;29(3):180-200.
19. De Luca CR, Wood SJ, Anderson V, Buchanan J-A, Proffitt TM, Mahony K, et al. Normative data from the CANTAB. I: development of executive function over the lifespan. *Journal of Clinical and Experimental Neuropsychology.* 2003;25(2):242-54.
20. Jurado MB, Rosselli M. The elusive nature of executive functions: a review of our current understanding. *Neuropsychology Review.* 2007;17(3):213-33.
21. Klenberg L, Korkman M, Lahti-Nuuttila P. Differential development of attention and executive functions in 3-to 12-year-old Finnish children. *Developmental Neuropsychology.* 2001;20(1):407-28.
22. Romine CB, Reynolds CR. A model of the development of frontal lobe functioning: Findings from a meta-analysis. *Applied Neuropsychology.* 2005;12(4):190-201.
23. Troyer AK. Normative data for clustering and switching on verbal fluency tasks. *Journal of Clinical and Experimental Neuropsychology.* 2000;22(3):370-8.
24. Regard M, Strauss E, Knapp P. Children's production on verbal and non-verbal fluency tasks. *Perceptual and Motor Skills.* 1982;55(3):839-44.

25. Rey A. L'examen psychologique dans les cas d'encéphalopathie traumatique [Psychological examination of cases of traumatic encephalopathy]. *Archives de Psychologie.* 1941;28:215-85.

26. Lezak M, Howieson D, Bigler E, Tranel D. *Neuropsychological Assessment.* 5th ed. New York: Oxford University Press; 2012.

27. Strauss E, Sherman EM, Spreen O. *A compendium of neuropsychological tests: Administration, norms, and commentary.* Oxford, UK: Oxford University Press; 2006.

28. Troyer AK, Moscovitch M, Winocur G. Clustering and switching as two components of verbal fluency: evidence from younger and older healthy adults. *Neuropsychology.* 1997;11(1):138.

29. Hurks PP, Schrans D, Meijs C, Wassenberg R, Feron F, Jolles J. Developmental changes in semantic verbal fluency: Analyses of word productivity as a function of time, clustering, and switching. *Child Neuropsychology.* 2010;16(4):366-87.

30. Sergeant JA, Geurts H, Oosterlaan J. How specific is a deficit of executive functioning for attention-deficit/hyperactivity disorder? *Behavioural Brain Research.* 2002;130(1-2):3-28.

31. Van der Elst W, Hurks P, Wassenberg R, Meijs C, Jolles J. Animal Verbal Fluency and Design Fluency in school-aged children: Effects of age, sex, and mean level of parental education, and regression-based normative data. *Journal of Clinical and Experimental Neuropsychology.* 2011;33(9):1005-15.

32. Hurks PP. Administering design fluency tests in school-aged children: analyses of design productivity over time, clustering, and switching. *The Clinical Neuropsychologist.* 2013;27(7):1131-49.

33. Hurks PP. Does instruction in semantic clustering and switching enhance verbal fluency in children? *The Clinical Neuropsychologist.* 2012;26(6):1019-37.

34. Resing WCM, Xenidou-Dervou I, Steijn WMP, Elliott JG. A "picture" of children's potential for learning: Looking into strategy changes and working memory by dynamic testing. *Learning and Individual Differences.* 2012;22(1):144-50.

35. Spreij LA, Visser-Meily J, van Heugten CM, Nijboer TC. Novel insights into the rehabilitation of memory post acquired brain injury: a systematic review. *Frontiers in Human Neuroscience.* 2014;8:993.

36. Slomine B, Locascio G. Cognitive rehabilitation for children with acquired brain injury. *Developmental Disabilities Research Reviews.* 2009;15(2):133-43.

37. de Kloet A, Hilberink S, Roebroeck M, Catsman-Berrevoets C, Peeters E, Lambregts S, et al. Youth with acquired brain injury in The Netherlands: A multi-centre study. *Brain Injury.* 2013;27(7-8):843-9.

38. Anderson V, Catroppa C. Recovery of executive skills following paediatric traumatic brain injury (TBI): A 2 year follow-up. *Brain Injury.* 2005;19(6):459-70.

39. Babikian T, Asarnow R. Neurocognitive outcomes and recovery after pediatric TBI: meta-analytic review of the literature. *Neuropsychology*. 2009;23(3):283.

40. Catroppa C, Anderson V. Neurodevelopmental outcomes of pediatric traumatic brain injury. *Future Neurology.* 2009;4(6):811-21.

41. Mangeot S, Armstrong K, Colvin AN, Yeates KO, Taylor HG. Long-term executive function deficits in children with traumatic brain injuries: Assessment using the Behavior Rating Inventory of Executive Function (BRIEF). *Child Neuropsychology.* 2002;8(4):271-84.

42. Sesma HW, Slomine BS, Ding R, McCarthy ML. Executive functioning in the first year after pediatric traumatic brain injury. *Pediatrics.* 2008;121(6):e1686-e95.

43. van Heugten C, Hendriksen J, Rasquin S, Dijcks B, Jaeken D, Vles J. Long-term neuropsychological performance in a cohort of children and adolescents after severe paediatric traumatic brain injury. *Brain Injury.* 2006;20(9):895-903.

44. Crowe LM, Catroppa C, Babl FE, Rosenfeld JV, Anderson V. Timing of traumatic brain injury in childhood and intellectual outcome. *Journal of Pediatric Psychology.* 2012;37(7):745-54.

45. Ryan NP, Catroppa C, Cooper JM, Beare R, Ditchfield M, Coleman L, et al. The emergence of age-dependent social cognitive deficits after generalized insult to the developing brain: a longitudinal prospective analysis using susceptibility-weighted imaging. *Human Brain Mapping.* 2015;36(5):1677-91.

46. Anderson V, Spencer-Smith M, Coleman L, Anderson P, Williams J, Greenham M, et al. Children's executive functions: are they poorer after very early brain insult. *Neuropsychologia.* 2010;48(7):2041-50.

47. Anderson V, Spencer-Smith M, Wood A. Do children really recover better? Neurobehavioural plasticity after early brain insult. *Brain.* 2011;134(8):2197-221.
48. Dennis M, Spiegler BJ, Simic N, Sinopoli KJ, Wilkinson A, Yeates KO, et al. Functional plasticity in childhood brain disorders: When, what, how, and whom to assess. *Neuropsychology Review.* 2014;24(4):389.
49. Kolb B, Pellis S, Robinson TE. Plasticity and functions of the orbital frontal cortex. *Brain and Cognition.* 2004;55(1):104-15.
50. van Tol E, Gorter JW, DeMatteo C, Meester-Delver A. Participation outcomes for children with acquired brain injury: A narrative review. *Brain Injury.* 2011;25(13-14):1279-87.
51. Laatsch L, Harrington D, Hotz G, Marcantuono J, Mozzoni MP, Walsh V, et al. An evidence-based review of cognitive and behavioral rehabilitation treatment studies in children with acquired brain injury. The *Journal of Head Trauma Rehabilitation.* 2007;22(4):248-56.
52. Limond J, Leeke R. Practitioner review: cognitive rehabilitation for children with acquired brain injury. *Journal of Child Psychology and Psychiatry.* 2005;46(4):339-52.
53. Robinson KE, Kaizar E, Catroppa C, Godfrey C, Yeates KO. Systematic review and meta-analysis of cognitive interventions for children with central nervous system disorders and neurodevelopmental disorders. *Journal of Pediatric Psychology.* 2014;39(8):846-65.
54. Ross KA, Dorris L, McMillan T. A systematic review of psychological interventions to alleviate cognitive and psychosocial problems in children with acquired brain injury. *Developmental Medicine & Child Neurology.* 2011;53(8):692-701.
55. Limond J, Adlam AR, Cormack M. A model for pediatric neurocognitive interventions: Considering the role of development and maturation in rehabilitation planning. *The Clinical Neuropsychologist*. 2014;28(2):181-98.
56. Organization WH. *International Classification of Functioning, Disability and Health: ICF*: World Health Organization; 2001.

Chapter 2

Analysis of young children's abilities to cluster and switch during a verbal fluency task

Resch, C., Martens, R., & Hurks, P. (2014).
The Clinical Neuropsychologist, 28(8), 1295-1310.

Abstract

To investigate developmental changes that take place in verbal fluency (VF) performance during early childhood, a VF task was administered to 225 healthy, Dutch-speaking children aged between 4.14 and 6.89 years. Three categories of VF outcome measures were included: i.e. word productivity, mean cluster size, and number of switches. Age influenced performance on all VF outcome measures linearly; i.e. older children produced more words, made longer clusters, and switched more. Higher levels of intelligence were associated with increased VF word productivity, but not with measures of switching and clustering. When leaving intelligence out of these analyses, we additionally found an interaction between level of parental education (LPE) and sex on total word productivity, i.e. girls with parents who had lower LPE produced fewer words than the other children. Furthermore, a similar interaction of LPE and sex was found for the number of switches: i.e. girls who had parents with lower LPE made less switches than the other children. Findings suggest that even in 4-6-year-old children important changes take place over time in VF and in processes underlying successful performance. Attention should be paid to age-extrinsic factors, such as LPE and sex, since these have been found to influence VF performance in young children.

Introduction

Verbal fluency (VF) tasks are widely used in clinical practice as well as in research settings [1, 2]. In VF tasks, the goal is to name as many words as possible from a certain category (e.g. animals, food, words beginning with the letter 'S') within one minute [3]. In general VF tasks are believed to be valid tools for measuring a variety of cognitive abilities, such as lexico-semantic knowledge and lexical access [4], and executive functioning, including cognitive flexibility, monitoring, and strategy use [3, 5, 6]. VF task performance has been linked to the frontal lobe functioning [7-9] as well as to temporal lobe functioning [9].

In the last years, VF tasks have been increasingly used as a tool in paediatric neuropsychological research [10]. For one, researchers have found that VF performance (i.e. total words generated over 60 seconds) improves with age, as studied in samples of children aged 6 to 16 [5, 10-13]. Surprisingly, however, children younger than 6 years of age were rarely included in these studies [5, 11-14]. To be able to obtain a more complete overview of the developmental changes that take place in VF performance during childhood, the present study aimed to investigate VF performance of children as young as 4-6 years of age more in depth.

The few studies that have investigated VF performance in children younger than 6 years found that the total number of words generated over 60 seconds increased in children from age 3 onward [8, 15, 16]. Furthermore, previous studies showed that a large developmental spurt in executive functioning (i.e. the cognitive functions underlying VF performance) can be observed between age 5 and at least age 8 [8, 17]. Unfortunately, the above-mentioned studies on early childhood VF performance [8, 15, 16] only took into account the classical quantitative method of scoring VF performance, namely counting the number of correct words generated over 60 seconds. As described previously, VF tasks tap into a variety of cognitive functions, among which are lexico-semantic knowledge, cognitive flexibility, and self-monitoring [3-6]. The classical scoring method does not allow a differentiation between these underlying cognitive processes. Past research has shown that by looking at the systematic organization of information (i.e. clustering and switching), valuable insights can be obtained with regard to underlying processes involved in VF [3, 18-21].

Clustering is a reflection of the ability to recall three or more associated words together [3, 20, 21]. It can be quantified by calculating the mean size of the clusters generated within 60 seconds [5, 11-13]. In an animal VF task with the objective to name as many animals as possible, a cluster can for example consist of 'insects' or 'birds'. The ability to cluster words involves accessing and using words from memory and is generally seen as a measure of lexico-semantic knowledge [3, 9].

Switching on the other hand can be defined as the ability to initiate clustering and to switch to new categories [3, 5, 10]. It involves search processes that are assumed to depend on executive functions, such as response initiation, monitoring, set shifting, and cognitive flexibility [3, 5, 11]. To assess switching, the total number of switches made between clusters, between clusters and single words, and between single words has to be counted [3, 5, 11]. However, since the calculation of the number of switches also includes switches to and among single words, it has been suggested that this score is actually an indication of an inability to cluster, rather than a reflection of an executive shifting process [14, 22]. To overcome this problem, an alternative measure of switching which does not include single words can be used (i.e. the number of clusters) [5, 11, 14]. By calculating the number of clusters, an indication can be given of the ability to initiate the use of an associative strategy [5, 14]. The number of clusters can therefore be seen as a useful addition for evaluating strategy use in VF performance, and as an essential component of alternative qualitative analysis of VF performance next to the number of switches and the mean cluster size.

To validate the use of these alternative VF scoring methods, researchers have compared results of a VF task to results of, for example, a design fluency (DF) task [5, 22]. The DF task is a non-verbal fluency test with the objective to draw as many abstract designs as possible within 60 seconds [6]. Since performance on a DF task is also thought to depend strongly on strategy use [1], this task has been used to assess the construct validity of the VF outcome measures clustering and switching. Research comparing quantitative and qualitative performance components of VF tasks to performance on a DF tasks found that correlations between these two tasks were high [5, 22]. Furthermore the developmental trajectories described above for VF clustering and switching components are highly comparable to those seen in the DF task [5]. Therefore, it can be concluded that the measures of clustering and switching that are used in the alternative scoring method of the VF task are valid measures of specific cognitive functions, at least in older children.

The measures of clustering and switching have been studied as an alternative scoring method of VF tasks in paediatric neuropsychological research in older children [5, 10-13]. However, to the authors' knowledge, no studies have used this alternative method to evaluate performance of children below the age of 5. The second aim of the present study was therefore to include the alternative scoring method of VF tasks in the assessment of young children's performance. It was expected that these alternative outcome measures (i.e. the mean cluster size, the number of clusters and the number of switches) would correlate at least to some degree with VF word productivity over 60 seconds, since the cognitive processes that these alternative outcome measures rely on are suggested to be important for optimal overall VF performance [5, 11-14]. Studies including older children have led to important insights and results. For one, when studying children between the ages 6 to 15, an increase in the number of clusters was found until at least 12 to 13 years of age, while the number of switches increased until at least 14 years of age [5] . Similar increases in the number of clusters and switches with age were also reported by several other studies [11, 13, 14]. Mean cluster size has been reported to increase with age until at least 11 years of age

[5, 11, 12]. Based on these findings, one may conclude that cluster size, a measure of lexico-semantic organization, is established earlier in development than switching, a measure of executive functioning. In accordance with studies on VF performance in older children, we hypothesized that, as early as 4 to 6 years of age, an age-related increase would be seen in the total number of correctly generated words, the mean cluster size, the number of clusters and the number of switches. Since the greatest period of development in executive functions is reported to be between the ages 5 and 8 [17, 20], it was expected that changes in these functions as measured by the various qualitative components of the VF task could already be detected in children between age 4 and 6.

Next to analysing quantitative and qualitative scores of the VF task, the current study aimed to contribute to the growing body of research that has reported significant effects of several child-related factors, such as age, sex, and intelligence, on changes in VF performance [5, 6, 15, 16, 23]. Past studies on VF performance in primary school children have often not included such age-extrinsic factors, even though they are thought to explain subtle differences in cognitive development [5, 16]. The present study included such factors (i.e. age, level of parental education (LPE), sex, and intelligence) to achieve an even broader view on VF performance at a young age.

In previous studies, a higher LPE was found to have a positive influence on VF performance – at least on the total number of words produced over 60 seconds [15, 16, 19]. When using the above-mentioned alternative scoring methods, a previous study found a positive effect of higher LPE on mean cluster size, while there was no influence on the number of clusters or the number of switches in children aged 6 to 16 [5]. These results seem to indicate that LPE is positively associated with lexico-semantic knowledge and lexical access, as measured by the mean cluster size, while the influence of LPE on executive functioning, as assessed by the number of clusters and the number of switches, is less. In accordance with previous studies [5, 15, 16], it was hypothesized that a higher LPE would be associated with a larger mean cluster size and a higher total number of correct words generated. In line with a previous study [5], it was expected that a higher LPE would have no effect on the measures of switching.

Next, studies on the association between sex and VF performance are still inconclusive [2, 5, 14, 24]. Although many studies did not find an effect of sex on VF performance [6, 19, 25, 26], other studies have reported significant results in this field. Some studies found that boys outperform girls on VF tasks [15, 23], while others reported that girls perform better than boys [16]. Given the inconsistent past findings regarding the effect of sex on VF performance, this variable was included in the present study to examine its influence on the various components of a VF tasks in young children.

A third age-extrinsic factor was taken into account in the present study, i.e. intelligence quotient (IQ). Previous research in children has found that children's intelligence level is positively associated with both the total number of words generated on a VF task [27] and tests of executive functions [28]. No studies have been conducted regarding the relationship between intelligence and VF clustering and switching. However, based on studies including tests of executive function other than the VF task, we hypothesized that intelligence has a positive influence on VF outcome measures total number of correct words, number of clusters and number of switches.

In sum, the primary goal of the present study was to investigate VF performance in a sample of healthy 4-6-year-old children. Next to the quantitative outcome measure of the total number of correctly generated words, three alternative qualitative VF scores were included, i.e. mean cluster size, number of clusters, and number of switches. To our knowledge, this was the first study that applied this alternative scoring method of VF tasks in a sample of children as young as age 4-6 years. Age-extrinsic factors (i.e. sex, LPE, and intelligence) were also considered when examining the development of VF performance in young children, since the influence of these factors might contribute to the observed inconsistencies in results of previous studies.

Method

Procedure and participants

All children enrolled in grade 1 or 2 of 24 Dutch primary schools were invited to participate in the present study. In the Netherlands, all children aged 4 years and older have to attend primary school, which is a compulsory form of education. In grades 1 and 2 of this primary school, the children do not yet receive formal instructions in reading, writing and/or mathematics. Caregivers of the children were given an information package, distributed via the schools, and were asked to give written consent for the participation of their child in the study. In addition, they were requested to fill in a questionnaire about the development and medical history of their child, and about their own educational background.

In total, 24% of all caregivers responded to the invitation for participation in the study. After consent of the caregiver was obtained, the children were screened based on exclusion criteria that might have an influence on test performance, i.e. not speaking Dutch fluently, the presence of neurological disorders (e.g. absence epilepsy) or the use of medication (e.g. antihistamines). In the Netherlands, health care professionals are highly hesitant to use DSM labels to classify the behavioural patterns of young children (i.e. children younger than 7). Therefore, we expected that the percentage of children classified as having a DSM diagnosis would be very low in our sample. Indeed, during a one year follow-up of the children included in our sample, only five children in our sample (i.e. 2% of the sample) had received a DSM-IV diagnosis (i.e. dyslexia or attention deficit hyperactivity disorder) [29]. During this follow-up, these five children were still attending regular primary schools and were in the appropriate grade for their age. Based on these follow-up data, we decided not to include these DSM-IV diagnoses as an exclusion criterion in the present study.

The final sample consisted of 225 children (110 boys) aged 4.14 to 6.89 years *(M* = 5.16, *SD* = 0.61). As mentioned above, caregivers completed a questionnaire in which they, among others, had to indicate their highest completed level of parental education (LPE), ranging from primary school (1) to university degree (8) [30, 31]. This scaling method is comparable to the International Standard Classification of Education (United Nations Educational Scientific and Cultural Organization[32]. Next, LPE scores obtained in the present study were recoded into low (1 and 2), mid (3, 4, and 5), and high (6, 7, and 8) levels of education [29]. If the LPE differed between the mother and the father, the highest level of education was chosen. Of all children included in our sample, 6% could be classified as having caregivers with a low LPE, 37% as those with caregivers having a mid LPE, and 57% as those having caregivers with a high LPE. The average LPE in the current sample was slightly higher than the (estimated) distribution of educational levels in the Dutch adult population. Indeed, data published by the Buro of Statistics in the Netherlands (in Dutch: Centraal Bureau voor de Statistiek) [33] indicates that 35% of the Dutch adults can be classified as having a low educational level, 40% as mid-level, and 32% as high level. Furthermore, in *n* = 130 cases (58%) of our sample, the LPE was the identical for the mother and the father. For *n* = 82 children, the LPE was different for the mother and the father. In *n* = 77 of these cases, the LPE differed no more than one category (i.e. LPE low vs. mid, or LPE mid vs. high). In *n* = 40 cases (18%), the mother obtained a higher LPE than the father. In *n* = 42 cases (19%), the father obtained a higher LPE than the mother. Additionally, for *n* = 9 children (4%), the LPE used in the present study was obtained from the mother due to an unknown LPE of the father. For *n* = 2 children (1%), the LPE of the father was used in the present study since the LPE of the mother was unknown. Lastly, for *n* = 2 children (1%), information about LPE was lacking for both caregivers.

The Ethics Committee of the Faculty of Psychology of Maastricht University approved the research protocol. Well-trained research assistants administered the semantic VF task and the Raven's CPM, as a measure of intelligence, in the same order for each child in a stimulus-free room at the participating schools.

Measures

Verbal fluency (VF) task. Participants were required to generate as many animals as possible. This variant is frequently used [6, 10, 13], which is advantageous when comparing the results to research done in other age groups or in clinical populations (e.g. children with attention deficit hyperactivity disorder[18]). In the present study, the main outcome measure was the total number of correctly generated words over 60 seconds. This outcome measure did not include the number of perseverations (e.g. cat and cats) and incorrect words (i.e. non-animals words such as 'car', or names of an animal, such as 'Sally') [21]. If perseverations and incorrect responses were to be included, the total number of words (i.e. 6) of a child who repeated many words (e.g. cat, cats, dog, dogs, cow, cows) would seem higher than the total number of words (i.e. 3) of a child who named the same words without repetition (e.g. cat, dog, cow), even though the number of unique words is the same for both children (in both cases, number of unique words produced = 3). Therefore, repetitions and incorrect words were not counted while estimating the total number of correctly generated words.

Apart from the total number of correctly generated words, the mean cluster size, the number of switches, and the number of clusters were calculated. In the present study, a cluster was defined as a group of successively generated words consisting of at least three categorically related words[3, 20]. Various criteria can be used to define a category. Categories in the current research were based on zoological families (e.g. birds, insects, primates), living environment (e.g. Africa, farm) or human use (e.g. pets) [3].

Mean cluster size. Mean cluster size was computed by counting all the words which are related by clusters and dividing them by the number of clusters [3]. For example, in the following list – *walrus, fur seal, sea lion,* monkey, *hen, rooster, goose,* whale, *fly, cockroach, beetle,* snake, *pigeon, seagull, owl, canary* – the number of words related by cluster is 13 (list adapted from Hurks et al., 2010 [5]). The number of clusters is 4. Therefore, the mean clusters size in this example is 13 divided by 4. Perseverations, as defined earlier, were included when calculating the number of words related by cluster, the number of clusters [21]. In general, children do not name the same word twice in a row. However, an animal can be part of different categories, for example, a *rooster* can belong in the category *farm animals* while it can also be a part of the category *birds*. Therefore, it is possible that a child first names a number of farm animals, including *rooster* (e.g. pig, *rooster*, cow, horse), and later on names the same animal while listing animals from a different category (e.g. canary, eagle, *rooster*, pigeon). By not including these perseverations, mean cluster size or the number of clusters (since only two words belonging to the same category would not meet the criteria of a minimum of three words for a cluster) would decrease while the words were actually named as part of a cluster. To obtain a reliable measure of the mean cluster size, it is thereby more important to recognize this clustering ability than to exclude the repetition of a word.

The number of clusters. The number of clusters was calculated by counting the number of clusters generated within one minute. For example, in the example list from Hurks et al. (2010) [5], 4 clusters can be identified: sea animals, birds, insects, and cluster of birds. Perseverations, as defined earlier, were included in the clusters [21].

The number of switches. The number of switches was defined as the number of switches made between two clusters, between a cluster and a single word, or between two single words. For example, in the example listed above, 6 switches were made. When calculating the number of switches, perseverations and incorrect words were included [21] since they provide information about how often a child names a single word or begins naming words from a new category.

Raven's Coloured Progressive Matrices (Raven's CPM). The Raven's CPM [34] is a measure of intelligence. This test consists of 36 items. The child is shown a pattern with a missing piece and from 6 possible pieces the child has to select the piece that completes the pattern. Items gradually increase in difficulty. One point is awarded per correct answer, with a maximum total raw score of 36. The total raw score obtained on this test was used in the analyses. The measure has been shown to have a satisfactory reliability [1].

Statistical Analysis

Firstly, bivariate correlation analyses were performed to investigate the degree to which the independent (i.e. age, sex, LPE, and intelligence) and dependent variables (i.e. total number of correct words, mean cluster size, number of clusters and number of switches) were associated. This not only allowed us to assess the strength of the relationship between independent and dependent variables, for example between age and VF clustering, but also the association among the dependent variables themselves, for example the VF number of clusters and the number of switches. These potential associations among the variables discussed above were tested using Pearson's correlations. The only exceptions here are those potential associations involving LPE. Due to the categorical nature of LPE (with 3 categories: low, mid and high), associations involving this variable were tested using Spearman's non-parametric correlation statistics.

Secondly, to study the added effect of one independent variable on VF performance over and above the effects of the other independent variables, multiple linear regression analyses were conducted [6]. By using this type of analysis, the combined influence of various demographic predictors on the outcome variables can be investigated. First, the predictor variables age, sex (coding: girls = 0, boys = 1), LPE, and score on the Raven's CPM were entered simultaneously in the initial analyses. LPE was dummy coded with two dummies (LPE low and LPE high) and LPE mid as a reference category. Furthermore, all two-way interactions between age, sex, and LPE dummies were entered as predictors in the regression models. To avoid multicollinearity, age was centred before computing the interactions [35]. For each model, the data were tested for multicollinearity by calculating the Variance Inflation Factors (VIF), which should not exceed 5, and the Condition Indices (CIs), which should not exceed 15 [36]. These assumptions were met in all regression models. However, since higher VIF values and CIs might bias the regression model [37], it was aimed to keep these values as low as possible. Therefore, to achieve small VIF values and CIs, the number of correlated predictors in the model was decreased. Thus, instead of keeping all the entered predictors in the model, the full regression models were reduced in a step-down hierarchical procedure. This step-down procedure has been described as the only appropriate method for theory testing [38], since it is not influenced by random variation in the data, thereby making it possible to find replicable results with retesting. More recently, however, this method has recently been criticized since it increases the chance of coincidentally finding a significant relationship between the dependent variable and independent variables (i.e. Type I error) [39]. A good method to avoid this increase in Type I error rate is to perform a Bonferroni-correction for each of the models, taking into account the number of predictors [40]. The significance-level was therefore determined for each model by dividing the nominal α-level of 0.05 by the number of predictors in the model [40]. For example, for a model with 5 predictors, the α-level was 0.05/5 = 0.010. Since computer-controlled stepwise procedures often produce results that are difficult to replicate [41], the predictor that was found most non-significant was manually excluded from the model. This procedure was repeated until only significant predictors were left. Note, however, that a predictor was not deleted from the model as long as it was part of a higher-order predictor in the model to avoid arbitrariness of the *p*-value [42]. For example, age was never removed if an interaction involving age was still in the model [2]. Since the LPE dummies (LPE low and LPE high) both represent the effect of the categorical predictor LPE, they were always kept in or deleted from the model together. Furthermore, the interactions of the LPE dummies were also either both included or excluded from the model[2].

All analyses that included the Raven's CPM scores were based on the raw scores of 223 children, since the administration of this task could not be completed for two children in the sample. Furthermore, for two children, information about LPE was missing. Therefore, all analyses including LPE were also based on the data of 223 children. Analyses including both the Raven's CPM and LPE were based on the data of 221 children.

Results

Correlations among VF outcome measures

In terms of correlations among the VF measures, the total number of correct words correlated positively with the mean cluster size, the number of clusters, and the number of switches, showing that optimal overall VF performance depends on a variety of cognitive processes. The number of clusters correlated positively with the mean cluster size. This suggests that children who are able to initiate clustering successively generate more associated words (i.e. produce larger mean cluster size). A significant negative correlation was found between the mean cluster size and the number of switches, indicating that the longer the clusters, the less switches take place. The number of clusters and the number of switches were not correlated, implying that even though they are both thought to be measures of executive functions, they are dependent on unrelated cognitive functions. A complete overview of the correlations can be found in Table 1.

Table 1. Correlations between age, sex, level of parental education, Raven's CPM score and verbal fluency measures

Variables	1	2	3	4	5	6	7	8
1. Age	-							
2. Sex	.04	-						
3. LPE	-.14*	-.07	-					
4. Raven's CPM	.49***	.06	.14*	-				
5. Total correct words	.41***	-.11	.00	.39***	-			
6. Mean cluster size	.21**	.02	-.01	.16*	.42***	-		
7. Number of clusters	.29***	.12	-.01	.20**	.65***	.60***	-	
8. Number of switches	.25***	.03	-.04	.24***	.65***	-.21**	.07	-

Note. LPE = level of parental education, Raven's CPM (Raven's Coloured Progressive Matrices [35]) = a measure of intelligence; * p <.05, ** p <.01, *** p <.001.

Influence of sex, LPE, and intelligence on VF performance

Total word productivity. An overview of the results of the final regression analyses is presented in Table 3. In terms of total VF scores, Raven's CPM, $t(222) = 3.62$, and age, $t(222) = 4.12$, were found to be significant predictors of the number of correct words generated within 60 seconds. In other words, higher scores in terms of intelligence and a higher age were both associated with higher VF word productivity. When the intelligence measure (i.e. Raven's CPM) was left out of the regression models, results changed. More specifically, next to age, $t(219) = 6.83$, the dummy variable for low LPE, $t(219) = -2.63$ and the interaction between the low LPE dummy and sex, $t(219) = 2.82$, became significant. Together, these results seem to indicate that children are negatively affected by low LPE, in that they produce less correct words when their parents are lower educated. However, this effect seems to apply only to girls.

Mean cluster size, number of clusters and number of switches. While examining the qualitative VF scores (i.e. clustering and switching), mean cluster size could only be predicted linearly by age, $t(223) = 3.24$. Older children produced more words belonging to a cluster. Age was also found to be the only predictive variable for the number of clusters, $t(222) = 4.58$, meaning that the number of clusters increases as the children grow older.

Finally, with regard to the number of switches, age, $t(219) = 3.80$ was found to be of significant predictive value. Furthermore, a sex by low LPE interaction, $t(219) = 2.74$ was associated with the number of switches, in that girls with lower educated parents make less switches.

Table 2. Final multiple linear regression models of the verbal fluency measures

Verbal fluency measure	Predictor	B	SE B	β	R^2
Total correct words	Raven's CPM	0.17	0.05	0.25***	0.21*** [a]
	Age	1.48	0.36	0.28***	
Total correct words (excluding Raven's CPM from the analyses)	Age	2.17	0.32	0.42***	0.22*** [b]
	Sex	-0.55	0.63	-0.09	
	Low LPE	-3.07	1.17	-0.24**	
	High LPE	0.43	0.58	0.07	
	Sex by Low LPE	4.64	1.64	0.26**	
	Sex by High LPE	-0.55	0.81	-0.08	
Mean cluster size	Age	0.73	0.23	0.21**	0.05** [c]
Number of clusters	Age	0.38	0.08	0.29***	0.09*** [d]
Number of switches	Age	1.09	0.29	0.25***	0.10** [e]
	Sex	-0.30	0.57	-0.06	
	Low LPE	-1.94	1.05	-0.18	
	High LPE	0.09	0.52	0.02	
	Sex by Low LPE	4.06	1.48	0.27**	
	Sex by High LPE	-0.12	0.73	-0.02	

Note. LPE = level of parental education, Raven's CPM (Raven's Coloured Progressive Matrices [35]) = a measure of intelligence; [a] $F(2, 222) = 29.62$, MSE = 7.90, [b] $F(6, 216) = 10.19$, MSE = 8.07, [c] $F(1, 223) = 10.49$, MSE = 4.16, [d] $F(1, 223) = 20.99$, MSE = 0.58, [e] $F(6, 216) = 3.84$, MSE = 6.55; * $p < .05$. ** $p < .01$. *** $p < .001$.

Discussion

The aim of the present study was to investigate VF performance in 4-6-year-old children using both a traditional, quantitative measure (i.e. total number of correct words) and an alternative qualitative scoring method (i.e. mean cluster size, number of clusters and number of switches). Qualitative VF outcome measures are thought to be of great value for investigating the cognitive processes that underlie VF task performance, such as lexico-semantic knowledge, cognitive flexibility and strategy use. Since early childhood (i.e. younger than age 7) is a period where a developmental spurt occurs in many of these cognitive functions [8, 17], an increase with age in performance on both quantitative and qualitative VF measures was expected. Additionally, the effects of sex, LPE, and intelligence were examined to discover the influence of these factors on VF performance in young children.

First, we found that the mean cluster size, the number of clusters and the number of switches were positively related to the total number of correct words produced on the VF task (in line with studies that include older children [11, 14]. The correlations between the qualitative VF outcome measures themselves were found to be (only) moderately high. Taken together these results indicate that at age 4-6, fluency performance already depends on various functions, such as lexico-semantic knowledge, cognitive flexibility, and use of word association strategies. This is an important finding, since the present study shows that next to lexico-semantic knowledge, strategy use already has a beneficial influence on

VF task performance from the age of 4 onward. Thus, even in very young children, VF tests can already provide valuable information about development of various cognitive functions. Furthermore, compared to younger, 4-year-old children, older, 6-year-old children generated more words during a VF task. Additionally, they clustered more words, named more words in one cluster (i.e. the mean cluster size increased), and switched more than 4-year-old children. Increases in these VF outcome measures between the ages 4 and 6 showed that the functions underlying VF performance are already developing at an early age.

Next, our findings revealed that two of the VF outcome measures, i.e. total number of correct words and number of switches, were also influenced by age-extrinsic factors. Analyses showed that VF total word productivity (i.e. a quantitative VF measure) was positively associated with intelligence. This is in line with previous studies indicating that a higher intelligence level has a positive influence on quantitative VF performance [27]. In the present study, Raven's CPM was chosen as the measure for intelligence. This instrument has been generally acknowledged as a valid and reliable measure of fluid intelligence [43]. Fluid intelligence can be defined as "the ability to solve novel problems by using reasoning" (Kaufman, 2012 [44], p. 119). Compared to measures that assess crystallized intelligence (i.e. "a knowledge-based ability that is highly based on education and acculturation"; Kaufman, 2012 [44], p.119), scores on the Raven's CPM depend less on academic knowledge and language[45]. However, it has to be noted that both fluid and crystallized intelligence contribute to the intellectual level of children. Therefore, Raven's CPM may differ in its relationships to VF performance compared to measures that assess crystallized intelligence (e.g. Wechsler Intelligence Scale for Children[46]). For example, previous research has reported that parents influence fluid intelligence less strongly than crystallized intelligence [47, 48]. Future research into the relationship between VF performance and intelligence in young children should take these different intelligence measure into account.

While our measure of intelligence was found to have a positive influence on total word productivity, it did not affect the qualitative VF measures in our study. For the qualitative VF outcomes (i.e. mean cluster size, the number of clusters, and the number of switches), Raven's CPM score was deleted from the regression models since no predictive value of this score was found. Thus, the final models pertaining to the qualitative VF measures described in this study have not been controlled for intelligence. Nonetheless, among researchers examining executive functioning in children, no consensus has been reached yet as to whether intelligence (i.e. fluid or crystallized) should be taken into account when investigating these higher order functions in children [28, 49-51]. Results of a study in children with attention deficit hyperactivity disorder indicated that the effect of the disorder on tasks of executive functioning (as is the VF task included in our study) is different for children with average and high IQ . [28] To ensure unbiased results, it might therefore be important to take IQ into account when examining performance on these kinds of tasks. On the other hand, other researchers have suggested that correcting for variation in IQ might lead to overcorrected results [50].

It has previously been suggested that analyses with an executive functioning measure, such as a VF task, as a dependent variable should be carried out with and without including intelligence to explore whether results would substantially differ [51]. Therefore, we (re-) examined the influence of age, sex, LPE, and their interactions on the total number of correct words produced on the VF task, while leaving out Raven's CPM. In contrast to the result of the first analysis (described above), where the total number of words could be predicted by age and intelligence, our findings now revealed that, when intelligence was not taken into account, both age and LPE (especially low LPE) had a significant influence on total word productivity. The finding that lower parental education is connected to lower quantitative VF performance is in line with previous research [15, 16, 19]. Furthermore, an interaction between sex and low LPE was found to be predictive for VF total word productivity. Taken together, results indicated that girls whose parents have a low LPE produce less correct words than all other children.

The finding that the outcome of the analysis changed by excluding intelligence shows that, as long as there is no consensus whether intelligence should be a covarying factor when examining cognitive development (and executive functioning more specifically) in children, researchers should carefully consider the exclusion or inclusion of intelligence in their analyses and outcomes should be interpreted cautiously. In our study, LPE correlated moderately with the scores on the intelligence measure. Also, the total variance explained by the model including Raven's CPM and by the model including LPE effects (without Raven's CPM) are highly comparable. These findings suggest that intelligence and LPE overlap in their influence on the total word productivity of young children and that LPE might be merely a surrogate for the effects of intelligence on VF performance in young children. This association between Raven's CPM and LPE would (at least partially) explain why no significant effects of LPE were found for VF total word productivity when including Raven's CPM in the analysis. In other words, part of the variance of the total number of correct words that is associated with LPE might have been removed by entering intelligence in the model.

Next to the effect of LPE alone, an interactive effect of LPE and sex on the total word productivity emerged. A similar effect of LPE and sex, as discovered on the total word productivity, was found on the number of switches. Girls with lower educated parents made less switches than other children. Taking the results together, it seems that the low LPE only has influence on information retrieval processes and the use of switching strategies in girls. In line with previous studies [6, 19, 25, 26, 52], sex did not influence any of the VF outcome measures directly. Further research into the interaction between sex and LPE is necessary to determine the origin of this effect on total word productivity and number of switches.

It was surprising that switching (and the higher-order cognitive processes that are thought to underlie this VF outcome) was affected by LPE, since results from studies in older children have suggested that LPE mainly affects the total number of correctly generated words and the mean cluster size, which are thought to underlie lower-order cognitive functions such as lexico-semantic knowledge [5, 19]. LPE can be seen as a proxy for other factors. For example, research in young children has found that there is a strong positive relationship between the level of education of the mother and the amount of time the mother interacts with the child [53, 54]. Furthermore, LPE has been shown to have a positive influence on the availability of reading material and behaviour at home [55]. The associations found in the present study between LPE and VF outcomes measures might thus be mediated by these parent-child behaviours and therefore form an interesting starting point to further investigate the relationship between young children's VF performance and parent-related factors. Furthermore, since average LPE in our study was higher than the LPE estimates obtained for the general Dutch population, further examination of children's VF performance is required, specifically directed at children whose parents have lower LPE.

In conclusion, the present study gathered important information on the animal VF task for Dutch 4-6-year-old children, which helps to elucidate the cognitive development of young children. To our knowledge, this is the first study reporting data for children between age 4 and 6 while using a variety of VF outcome measures (i.e. the total number of correct words, mean cluster size, number of clusters and number of switches). It is now relevant to investigate the clinical utility of this scoring method in the selected age group. By examining VF performance of young children suffering from a pathological condition, for example autism, attention deficit hyperactivity disorder or Down-Syndrome, knowledge can be acquired about the executive and associative processes important for VF performance in these specific groups of children.

References

1. Lezak M, Howieson D, Bigler E, Tranel D. *Neuropsychological Assessment.* 5th ed. New York: Oxford University Press; 2012.
2. Van Der Elst W, Van Boxtel MP, Van Breukelen GJ, Jolles J. Normative data for the Animal, Profession and Letter M Naming verbal fluency tests for Dutch speaking participants and the effects of age, education, and sex. *Journal of the International Neuropsychological Society*. 2006;12(1):80-9.
3. Troyer AK, Moscovitch M, Winocur G. Clustering and switching as two components of verbal fluency: evidence from younger and older healthy adults. *Neuropsychology*. 1997;11(1):138.
4. Sergeant JA, Geurts H, Oosterlaan J. How specific is a deficit of executive functioning for attention-deficit/hyperactivity disorder? *Behavioural Brain Research*. 2002;130(1-2):3-28.
5. Hurks PP, Schrans D, Meijs C, Wassenberg R, Feron F, Jolles J. Developmental changes in semantic verbal fluency: Analyses of word productivity as a function of time, clustering, and switching. *Child Neuropsychology*. 2010;16(4):366-87.
6. Van der Elst W, Hurks P, Wassenberg R, Meijs C, Jolles J. Animal Verbal Fluency and Design Fluency in school-aged children: Effects of age, sex, and mean level of parental education, and regression-based normative data. *Journal of Clinical and Experimental Neuropsychology.* 2011;33(9):1005-15.
7. Baldo JV, Schwartz S, Wilkins D, Dronkers NF. Role of frontal versus temporal cortex in verbal fluency as revealed by voxel-based lesion symptom mapping. *Journal of the International Neuropsychological Society.* 2006;12(6):896-900.
8. Romine CB, Reynolds CR. A model of the development of frontal lobe functioning: Findings from a meta-analysis. *Applied Neuropsychology.* 2005;12(4):190-201.
9. Troyer AK, Moscovitch M, Winocur G, Alexander MP, Stuss D. Clustering and switching on verbal fluency: the effects of focal frontal-and temporal-lobe lesions. *Neuropsychologia*. 1998;36(6):499-504.
10. Hurks PP. Does instruction in semantic clustering and switching enhance verbal fluency in children? *The Clinical Neuropsychologist.* 2012;26(6):1019-37.
11. Kavé G, Kigel S, Kochva R. Switching and clustering in verbal fluency tasks throughout childhood. *Journal of Clinical and Experimental Neuropsychology.* 2008;30(3):349-59.
12. Sauzeon H, Lestage P, Raboutet C, N'Kaoua B, Claverie B. Verbal fluency output in children aged 7–16 as a function of the production criterion: Qualitative analysis of clustering, switching processes, and semantic network exploitation. *Brain and Language.* 2004;89(1):192-202.
13. Tallberg I, Carlsson S, Lieberman M. Children's word fluency strategies. *Scandinavian Journal of Psychology.* 2011;52(1):35-42.
14. Koren R, Kofman O, Berger A. Analysis of word clustering in verbal fluency of school-aged children. *Archives of Clinical Neuropsychology.* 2005;20(8):1087-104.
15. Ardila A, Rosselli M, Matute E, Guajardo S. The influence of the parents' educational level on the development of executive functions. *Developmental Neuropsychology.* 2005;28(1):539-60.
16. Klenberg L, Korkman M, Lahti-Nuuttila P. Differential development of attention and executive functions in 3-to 12-year-old Finnish children. *Developmental Neuropsychology*. 2001;20(1):407-28.
17. Korkman M, Lahti-Nuuttila P, Laasonen M, Kemp SL, Holdnack J. Neurocognitive development in 5-to 16-year-old North American children: a cross-sectional study. *Child Neuropsychology*. 2013;19(5):516-39.
18. Hurks P, Hendriksen J, Vles J, Kalff A, Feron F, Kroes M, et al. Verbal fluency over time as a measure of automatic and controlled processing in children with ADHD. *Brain and Cognition*. 2004;55(3):535-44.
19. Hurks P, Vles J, Hendriksen J, Kalff A, Feron F, Kroes M, et al. Semantic category fluency versus initial letter fluency over 60 seconds as a measure of automatic and controlled processing in healthy school-aged children. *Journal of Clinical and Experimental Neuropsychology*. 2006;28(5):684-95.
20. Robert PH, Lafont V, Medecin I, Berthet L, Thauby S, Baudu C, et al. Clustering and switching strategies in verbal fluency tasks: comparison between schizophrenics and healthy adults. *Journal of the International Neuropsychological Society.* 1998;4(6):539-46.
21. Troyer AK. Normative data for clustering and switching on verbal fluency tasks. *Journal of Clinical and Experimental Neuropsychology*. 2000;22(3):370-8.

22. Abwender DA, Swan JG, Bowerman JT, Connolly SW. Qualitative analysis of verbal fluency output: Review and comparison of several scoring methods. *Assessment.* 2001;8(3):323-38.
23. Prigatano GP, Gray JA, Lomay VT. Verbal (animal) fluency scores in age/grade appropriate minority children from low socioeconomic backgrounds. *Journal of the International Neuropsychological Society.* 2008;14(1):143-7.
24. Weiss EM, Ragland JD, Brensinger CM, Bilker WB, Deisenhammer EA, Delazer M. Sex differences in clustering and switching in verbal fluency tasks. *Journal of the International Neuropsychological Society.* 2006;12(4):502-9.
25. Brocki KC, Bohlin G. Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology*. 2004;26(2):571-93.
26. Lanting S, Haugrud N, Crossley M. The effect of age and sex on clustering and switching during speeded verbal fluency tasks. *Journal of the International Neuropsychological Society*. 2009;15(2):196-204.
27. Anderson VA, Anderson P, Northam E, Jacobs R, Catroppa C. Development of executive functions through late childhood and adolescence in an Australian sample. *Developmental Neuropsychology.* 2001;20(1):385-406.
28. Mahone EM, Hagelthorn KM, Cutting LE, Schuerholz LJ, Pelletier SF, Rawlins C, et al. Effects of IQ on executive function measures in children with ADHD. *Child Neuropsychology*. 2002;8(1):52-65.
29. Martens R. *What counts?: Cognitive development and arithmetical performance: the role of child- and environment-related factors.* [Doctoral dissertation] Maastricht University; 2012.
30. De Bie SE. *Standaardvragen 1987: voorstellen voor uniformering van vraagstellingen naar achtergrondkenmerken in interviews* [Standard questions 1987: Proposal for the uniformization of questions regarding background variables and interviews]. 2nd ed. Leiden, The Netherlands: Leiden University Press; 1987.
31. Kalff A, Kroes M, Vles J, Bosma H, Feron F, Hendriksen J, et al. Factors affecting the relation between parental education as well as occupation and problem behaviour in Dutch 5-to 6-year-old children. *Social Psychiatry and Psychiatric Epidemiology.* 2001;36(7):324-31.
32. UNESCO. *International Standard Classification of Education (ISCED)*: Pairs: Author; 1997.
33. Central Buro for Statistics Netherlands. *Stat-line*. Den Haag: Centraal Bureau voor Statistiek; 2012.
34. Raven JC. *Guide to using the coloured progressive matrices.* 1958.
35. Marquardt DW. Comment: You should standardize the predictor variables in your regression models. *Journal of the American Statistical Association.* 1980;75(369):87-91.
36. Kutner MH, Nachtsheim, C. J., Neter, J., & Li, W. . *Applied linear statistical models*. 5th ed. New York, NY: McGraw Hill.; (2005).
37. Bowerman BL, O'connell RT. *Linear statistical models: An applied approach:* Brooks/Cole; 1990.
38. Studenmund A, Cassidy H. *Using econometrics: A practical guide*. Boston, MA: Little Brown; 1987.
39. Millis SR. Statistical practices: The seven deadly sins. *Child Neuropsychology.* 2003;9(3):221-33.
40. Mundfrom J, Perrett D, Schaffer J, Piccone A, Roozeboom M. Bonferroni adjustments in tests for regression coefficients. *Multiple Linear Regression Viewpoints.* 2006;32:1-6.
41. Menard S. *Applied logistic regression analysis.* 2nd ed. Thousand Oaks, CA: Sage; 2002.
42. Aiken LS, West SG, Reno RR. *Multiple regression: Testing and interpreting interactions:* Sage; 1991.
43. Cherkes-Julkowski M, et al. Prompted Cognitive Testing as a Diagnostic Compensation for Attentional Deficits: The Raven Standard Progressive Matrices and Attention Deficit Disorder. *Learning Disabilities: A Multidisciplinary Journal.* 1990;2(1):1-7.
44. Kaufman JC. Self estimates of general, crystallized, and fluid intelligences in an ethnically diverse population. *Learning and Individual Differences*. 2012;22(1):118-22.
45. Naglieri JA, Ronning ME. Comparison of White, African American, Hispanic, and Asian children on the Naglieri Nonverbal Ability Test. *Psychological Assessment.* 2000;12(3):328.
46. Wechsler D. *Wechsler intelligence scale for children–Fourth Edition (WISC-IV).* San Antonio, TX: The Psychological Corporation. 2003.

47. Rindermann H, Flores-Mendoza C, Mansur-Alves M. Reciprocal effects between fluid and crystallized intelligence and their dependence on parents' socioeconomic status and education. *Learning and Individual Differences.* 2010;20(5):544-8.

48. Vista AD, Grantham TC. Effects of parental education level on fluid intelligence of Philippine public school students. *Journal of Psychoeducational Assessment.* 2010;28(3):236-48.

49. Arffa S. The relationship of intelligence to executive function and non-executive function measures in a sample of average, above average, and gifted youth. *Archives of Clinical Neuropsychology.* 2007;22(8):969-78.

50. Dennis M, Francis DJ, Cirino PT, Schachar R, Barnes MA, Fletcher JM. Why IQ is not a covariate in cognitive studies of neurodevelopmental disorders. *Journal of the International Neuropsychological Society.* 2009;15(3):331-43.

51. Shanahan MA, Pennington BF, Yerys BE, Scott A, Boada R, Willcutt EG, et al. Processing speed deficits in attention deficit/hyperactivity disorder and reading disability. *Journal of Abnormal Child Psychology.* 2006;34(5):584.

52. Riva D, Nichelli F, Devoti M. Developmental aspects of verbal fluency and confrontation naming in children. *Brain and Language.* 2000;71(2):267-84.

53. Hoff E. The specificity of environmental influence: Socioeconomic status affects early vocabulary development via maternal speech. *Child Development.* 2003;74(5):1368-78.

54. Hoff E, Tian C. Socioeconomic status and cultural influences on language. *Journal of Communication Disorders*. 2005;38(4):271-8.

55. Davis-Kean PE. The influence of parent education and family income on child achievement: the indirect role of parental expectations and the home environment. *Journal of Family Psychology.* 2005;19(2):294.

Chapter 3

Young children's performance on a design fluency task: longitudinal data on total design productivity, clustering and switching

Resch, C., Keulers, E., Martens, R., van Breukelen, G., van Heugten, C., & Hurks, P.

Submitted for publication.

Chapter 4

Does strategy instruction on the Rey-Osterrieth Complex Figure task lead to transferred performance improvement on the Modified Taylor Complex Figure task? A randomized controlled trial in school-aged children

Resch, C., Keulers, E., Martens, R., van Heugten, C., & Hurks, P. (2019).
The Clinical Neuropsychologist, 33(1), 108-123.

Abstract

Providing children with organizational strategy instruction on the Rey-Osterrieth Complex Figure (ROCF) has previously been found to improve organizational and accuracy performance on this task. It is unknown whether strategy instruction on the ROCF would also transfer to performance improvement on copying and the recall of another complex figure. Participants in the present study were 98 typically developing children (aged 9.5-12.6 years, *M* = 10.6). Children completed the ROCF (copy and recall) as a pretest. Approximately a month later, they were randomized to complete the ROCF with strategy instruction in the form of a stepwise administration of the ROCF or again in the standard format. All children then copied and recalled the Modified Taylor Complex Figure (MTCF). All productions were assessed in terms of organization, accuracy and completion time. Organization scores for the MTCF did not differ for the two groups for the copy production, but did differ for the recall production, indicating transfer. Accuracy and completion times did not differ between groups. Performance on all measures, except copy accuracy, improved between pretest ROCF and posttest MTCF production for both groups, suggesting practice effects. Findings indicate that transfer of strategy instruction from one complex figure to another is only present for organization of recalled information. The increase in RCF-OSS scores did not lead to a higher accuracy of or a faster copy or recall.

Introduction

The Rey-Osterrieth Complex Figure (ROCF) [1, 2] is a neuropsychological instrument widely used in clinical practice as well as in research [3]. In the ROCF task, a complex geometrical figure first has to be copied and then immediately reproduced from memory as accurately as possible in an unannounced recall trial [1, 2, 4]. A second, longer delay recall condition (e.g. 20 minutes after the first recall condition) can also be used in this task. That condition was not used in the present study, and therefore, all references to 'recall' throughout the manuscript are related to the immediate recall condition.

While the standard procedure of the ROCF task is as described above, the task can also be administered in a stepwise manner. More specifically, the complex figure can be divided into logical steps that highlight the figure's hierarchical organizational framework [5-8]. Studies have shown that this stepwise instruction for the ROCF improved copy and immediate recall performance in terms of organization and accuracy (see below for more information on these different scores) on the ROCF, in children aged six to seventeen years with and without learning disabilities [5-8]. This stepwise administration format is often used to disentangle the sources of poor task performance: if children perform better with the stepwise administration format, this is likely a consequence of the stepwise administration supporting the application of metacognitive processes involved in the complex figure task, such as selecting strategies, planning and organizing. Administering the figure in a stepwise manner can also be considered strategy training. More specifically, by presenting the figure in steps, children are trained to use an organizational strategy which they are not always able to produce on their own. Of particular interest when examining the effects of strategy training is the transfer of performance improvement. More specifically, children have to be able to apply what they learned to a different context, for the learned material to be valuable for their development [9]. Transfer of performance after the strategy instruction on the ROCF to a different task or context would provide evidence for the usefulness of a stepwise administration of complex material in training healthy, typically developing children to use strategies. In adults, strategy training in the form of stepwise administration of the ROCF has been found to lead to significant improvements in performance not only on the trained task, but also on another complex figure [10]. In children, it remains to be determined whether the improvements in their performance caused by the strategy instruction on the ROCF are also transferable e.g. to other complex figures.

The present study investigated the transfer of performance improvement from one complex figure to another comparable, though still unique figure. The Modified Taylor Complex Figure (MTCF, see Figure 1) [11, 12] has been found to be comparable to the ROCF with regard to its accuracy scores (see below), and its relationship with other tests (e.g. other measures of visual spatial abilities) [11-15]. Standard instructions for both the ROCF and the MTCF are the same [4, 11]. Importantly, the MTCF is composed in a similar manner as the ROCF in terms of the global and essential elements (i.e. a large rectangle/square, horizontal and vertical centrelines). In addition to these global elements, both figures contain a number of externally attached elements and internal components. Given the structural resemblance of the ROCF and the MTCF, the stepwise strategy instruction as used in previous studies could be applied for both figures. However, it remains to be determined whether children are able to transfer the strategy instruction provided for the ROCF to the MTCF, thereby enhancing their performance on both figures.

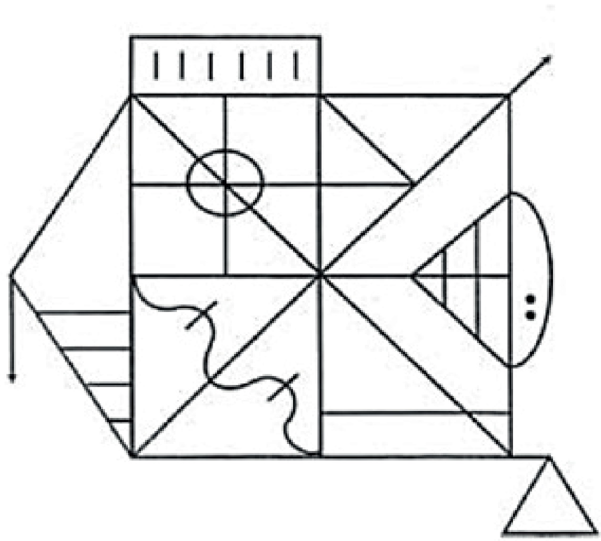

Figure 1. Modified Complex Taylor Figure. Copyright © 1996, 1998 Anita M. Hubley [11-12]. All rights reserved. Reproduced by permission from Anita M. Hubley.

As described above, the stepwise strategy instruction for the ROCF is mainly directed at supporting organizational (i.e. executive) processes by sequentially highlighting essential organizational elements. To assess the success of the strategy instruction in improving complex figure task performance, different task parameters can be investigated: organization, accuracy, and completion time. The organization of the complex figure can be quantified by assessing the order in which children copy and/or recall the various elements of the complex figure, whereby starting with the more global elements (e.g. large rectangle/square, horizontal and vertical centrelines) reflects a better organizational process. To assess the accuracy of the reproduced complex figure, the similarity of the reproduction with the original figure, irrespective of the order in which the figure's elements were drawn, is examined. Previous studies have found that a better organization is strongly related to a better accuracy as well [8, 16]. Finally, the success of the instruction can be inferred by examining completion time of the complex figure task. The completion time reflects the amount of time a child needs to complete the copy and/or recall of the complex figure. The influence of strategy instruction on complex figure task completion time has not yet been investigated. However, highlighting the organizational framework of the complex figure might enable children to reproduce the complex figure more efficiently (i.e. in less time).

In sum, with the present study, we investigated whether a stepwise strategy instruction on the ROCF would lead to transferred improvement on the MTCF. It was predicted that children presented with the stepwise instruction would perform better on the MTCF in terms of 1) better organization, and as a consequence of this improved organization, 2) higher accuracy, and 3) lower completion times during copy and recall than children who were administered ROCF in the standard manner.

Table 1. Characteristics of the participants per instruction group

	Stepwise instruction (*n* = 45)	Standard administration (*n* = 53)	*df*	*F* / *χ*	*p*
Age, *M* (SD)	*10.65* (0.66)	*10.56* (0.74)	1, 96	.43	.52
Male, *n* (%)	*19* (42)	*26* (49)	1	.46	.50
LPE, *M* (SD)	*5.80* (1.24)	*5.90* (1.54)	1, 96	.13	.72
IQ, *M* (SD)	*101.07* (12.84)	*103.34* (13.10)	1, 96	.75	.39
Days, *M* (SD)	*28.69* (10.11)	*28.45* (7.39)	1, 96	.02	.89

Note. M = mean, SD = standard deviation, LPE = Highest level of parental education, IQ = Estimated IQ score, Days = number of days between pretest and posttest.

Method

Participants and sampling

In total, 221 children aged ten to twelve years were invited to participate. All children had previously participated in a four-year longitudinal study of Maastricht University into cognitive development [17]. During those four years, all children were consistently administered the same test-batteries, making all children comparable in their history of experience with neuropsychological assessments. The ROCF had been administered to all children before, i.e. more than 3 years before the present study took place. None of the children was previously administered the MTCF and none of them had received the stepwise instruction before. Caregivers of 141 children agreed to their child's participation in this follow-up, corresponding to a response rate of 64%. In the initial study [17], the children had already been screened based on exclusion criteria, i.e. not speaking Dutch fluently, the presence of neurological disorders (e.g. epilepsy) or the use of medication (e.g. antihistamines). For the present study, 19 children (13%) who had been diagnosed with a neuropsychiatric or neurodevelopmental disorder (e.g. dyslexia, attention deficit hyperactivity disorder) or were not attending regular education were excluded. Furthermore, for 15 other children the proposed tasks could not be administered, e.g. due to scholastic absence at the agreed upon testing dates.

Children were randomly assigned to either the stepwise instruction group (*n* = 54) or the standard administration group (*n* = 53). For nine children in the stepwise instruction group, technical problems during the assessment compromised the reliability of their data. Therefore, the final sample consisted of 98 children (45 stepwise instruction group) aged 9.48 to 12.63 years (*M* = 10.60, *SD* = 0.70). An overview of the characteristics of the participants per group can be found in Table 1. No significant differences were found between the two groups in terms of age, sex, level of parental education, estimated IQ, or number of days between pretest and posttest. Level of parental education ranged from primary school (1) to university degree (8) [18, 19], on a scaling comparable to the International Standard Classification of Education [20]. IQ of the children was estimated by combining the Vocabulary and Block Design subtests of the most recent Dutch translation of the Wechsler Intelligence Scales for children – third edition [21, 22] into one IQ score [23, 24].

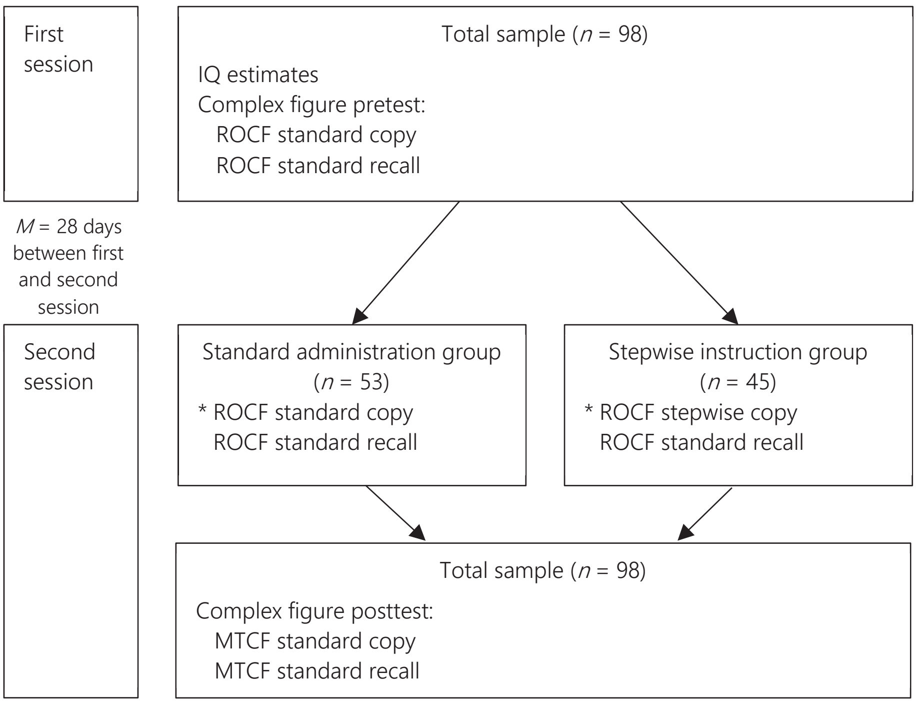

Figure 2. Overview of the assessment procedure. *Note.* * This administration of the ROCF only functioned as a means to introduce the strategy instruction to the stepwise instruction group. Therefore, performance on these drawings was not assessed or analysed. Abbreviations: MTCF = Modified Taylor Complex Figure, ROCF = Rey-Osterrieth Complex Figure.

Procedure

The ethics committee of the Faculty of Psychology and Neuroscience of Maastricht University approved the research. After consent of the caregiver was obtained, well-trained research assistants administered the tests reported in the present article as part of a larger test battery. All tests were performed in the same order for each child in a stimulus free room at the schools of the participating children. Testing took place in two sessions. An overview of the testing procedure is given in Figure 2.

Children's pretest organizational abilities were assessed in the first session using the standard ROCF administration, [1, 4]. In the second session, children in the standard administration group were administered the ROCF in the standard manner. For the stepwise instruction group, the parts of the ROCF were presented in three hierarchically organized steps (see Figure 3) [5, 7, 8]. For each step, the children were first asked to point out the parts shown in that step in the complete ROCF and then to copy these elements. If they pointed the elements out wrong, the examiner would point to the correct elements. No feedback was given if they did not copy the elements correctly. In both instruction/administration formats, instructions did not include any mention of a timely completion of the drawings. After they had finished copying the ROCF in three consecutive steps, children were asked to reproduce the figure in an unannounced recall condition. Since this second administration of the ROCF only functioned as a means to introduce a repeated performance of the ROCF with or without strategy instruction, these drawings were not assessed in terms of organization, accuracy or completion time. To evaluate the effects of the strategy instruction, the MTCF, administered in the standard way [4] in the second session, was used as the posttest measure.

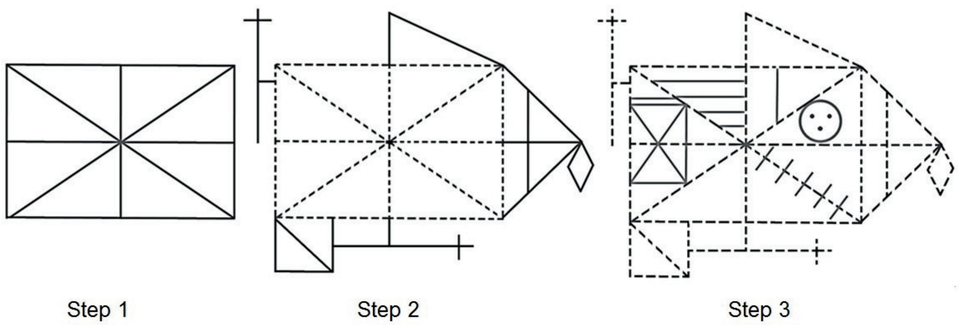

Figure 3. Stepwise instruction format for the Rey-Osterrieth Complex Figure *Note.* The complete Rey-Osterrieth Complex Figure as presented in step 3 was derived from *Le Test de Copie d'Une Figure Complexe* [2]; in the public domain. Elements added in step 1, 2, and 3 were coloured red, blue, and green, respectively.

Materials and scoring

For the standard administration of the ROCF and the MTCF, children were presented with the complete figure on an A4 sized paper. During the stepwise instruction, three cards, each depicting parts of the elements of the ROCF, were consecutively shown (see Figure 3). As the stepwise instruction progressed, new elements were added in a different color. Three outcome measures were included for the copy as well as the recall of the complex figures: organizational level, the accuracy score and completion time.

Organization. The organization of the ROCF and the MTCF was assessed with the Rey Complex Figure Organizational Strategy Score (RCF-OSS) [25]. The RCF-OSS is a process-oriented scoring approach to the ROCF that takes into account the sequence in which various elements of the complex figure are drawn. The RCF-OSS has been shown to be a valid method to measure organizational skills in children, as indicated by the significant linear relationships with other measures that rely on organization skills [25]. Furthermore, it has good inter-rater reliability [16, 25, 26] and an acceptable one-week intra-rater reliability [25] when used to assess ROCF performance.

During the assessment sessions, the research assistant who was administering the complex figure task kept track of the order in which the child drew the lines by numbering them. The first author (C.R.) scored all complex figures with the RCF-OSS, blinded to group membership. By analyzing the order in which the elements of the complex figures are drawn, each drawing was rated on a 7-point scale, where a higher number represents a higher level of organization: i.e. level 1 = unrecognizable drawing or substitution, level 2 = poor organization, level 3 = random organization, level 4 = piecemeal/fragmented organization, level 5 = part-configural organization, level 6 = conceptual organization, and level 7 = excellent organization (for a description of the scoring criteria for each level, see Anderson et al., 2001). In the RCF-OSS, the elements that contribute most to the organizational level are the base rectangle and the vertical and horizontal midlines, since they play an important role in the correct placement of the internal sections and outside attachments (for definitions, see Anderson et al., 2001). The RCF-OSS was originally developed as a scoring system for the ROCF. However, given the structural resemblance of the ROCF and the MTCF (as described in the introduction), we believe that the RCF-OSS can easily be applied to the MTCF, without significant alterations of the scoring instructions set for scoring the ROCF. Our version of the RCF-OSS, adapted to the MTCF, is presented in Supplemental material 1. Changes to the original RCF-OSS pertained only to definitions of elements of the figure (e.g. the main element of the ROCF is a rectangle, the main element of the MTCF is a square) and not to the scoring criteria for the various organizational levels. Given that this was the first time that the RCF-OSS was applied to the MTCF, inter-rater reliability of the scoring was assessed. To that extent, a well-trained early-career neuropsychologist scored 20% of the figures with the RCF-OSS. These scores were compared to the scores previously given by the first author (C.R.). Guidelines characterize a reliability coefficient from 0 to 0.20 as slight, from 0.21 to 0.40 as fair, from 0.41 to 0.60 as moderate, from 0.61 to 0.80 as substantial, and over 0.81 as excellent agreement [27]. Using weighted kappa analyses, moderate inter-rater reliability of the RCF-OSS was found for the copy condition of the ROCF, κ_w 0.50, p = .002, and the MTCF, κ_w 0.55, p = .002. Substantial agreement was reached in the recall condition of the ROCF, κ_w 0.80, $p < .001$, and the MTCF, κ_w 0.74, $p < .001$. Even though the inter-rater reliabilities were similar for the RCF-OSS for the ROCF and the MTCF, it was surprising that the agreement in the copy condition was only moderate, in contrast to previous studies who found higher inter-rater reliability [16, 25, 26]. Following up on these findings, we examined the origins of the differential ratings. Recommendations for future use and some additions to the scoring system will be discussed in the discussion section.

Accuracy. The accuracy scoring system was used to evaluate the accuracy of copy and recall ROCF and MTCF performance [4, 11, 12, 28]. A score of 0, 0.5, 1 or 2 is given for the accuracy and correctness of placement of 18 elements of the figure, independent of the order in which they were drawn. This score is given irrespective of the order in which the elements are drawn and leads to a sum score ranging between 0 and 36 points, with a higher score reflecting a higher similarity of the drawn figure (either copied or recalled) to the original ROCF or MTCF. Inter-rater reliability has previously been found to be excellent [29, 30]. In the present study, accuracy scoring was performed by the first and last author (CR and PH) and three well-trained, early-career neuropsychologist, who each scored a separate set of complex figures.

Completion time. Completion time for all figures was recorded by starting the timer as soon as the task instruction was completed and stopping the timer when the child indicated to have finished drawing the figure.

Statistical analysis

To investigate the degree to which the accuracy scores, organizational levels and completion times on the copy and recalled reproduction of the ROCF and the MTCF are associated with each other (thus potentially measuring the same underlying constructs), bivariate correlation analyses were performed for the standard administration group. The influence of strategy instruction on performance on a complex figures task was examined using repeated measures mixed ANOVA, with pretest (ROCF) and posttest (MTCF) scores (i.e. RCF-OSS, accuracy, and completion time for copy and recall) as within-subject factor and administration group (i.e. standard versus stepwise) between-subjects factor. Partial η squared (η_p^2) was computed as measure for effect size. One outlier (defined as a score of more than 3 standard deviations above or below the variable mean) was identified and subsequently excluded from all analyses. Analyses were carried out with IBM SPSS Statistics 24, α was set at .05.

Results

Bivariate correlation analyses

For the standard administration group, organizational levels were consistently correlated across conditions (i.e. copy and recall) and sessions (i.e. pretest and posttest). Similarly, copy and recall as well as pretest and posttest were correlated for the two other complex figure outcome measures, i.e. accuracy score and completion time. Within one session, organizational level and accuracy score are positively correlated (with the exception of the posttest copy condition). No relations were found between organizational level and completion time or between accuracy and completion time. Given these findings, influence of the strategy instruction, which was mainly directed at improving organization level, was more likely to occur on the RCF-OSS and the accuracy score but not for completion time. An overview of the correlations for the standard instruction group can be found in Table 2.

Influence of strategy instruction on complex figure task performance

An interaction between administration group and time of measurement (i.e. pretest and posttest) was found for the recall of the complex figure $F(1, 95) = 9.10$, $p = .003$, $\eta_p^2 = 0.09$ (see Figure 4). Simple effects analyses revealed that improvement from pretest to posttest was larger for the stepwise instruction group ($p < .001$, $\eta_p^2 = 0.46$) than for the standard administration group ($p = .003$, $\eta_p^2 = 0.16$). Consequently, average organizational level differed between groups at posttest, $F(1, 44) = 7.74$, $p = .007$, $\eta_p^2 = 0.08$. Descriptive details for the scores are displayed in Table 3. No interaction between administration group and time of measurement was found for copy organization, $F(1, 94) = 0.01$, $p = .93$, $\eta_p^2 = 0.00$, copy accuracy, $F(1, 94) = 3.25$, $p = .075$, $\eta_p^2 = 0.03$, recall accuracy, $F(1, 95) = 1.26$, $p = .27$, $\eta_p^2 = 0.01$, copy completion time, $F(1, 95) = 0.51$, $p = .478$, $\eta_p^2 = 0.005$, or recall completion time, $F(1, 95) = 1.524$, $p = .220$, $\eta_p^2 = 0.016$. There was a main effect of time for copy organization, $F(1, 95) = 18.35$, $p < .001$, $\eta_p^2 = 0.16$, recall accuracy, $F(1, 95) = 9.57$, $p = .003$, $\eta_p^2 = 0.09$, copy completion time, $F(1, 95) = 160.04$, $p <.001$, $\eta_p^2 = 0.628$, and recall completion time, $F(1, 95) = 98{,}28$, $p <.001$, $\eta_p^2 = 0.508$, indicating that performance on these parameters improved over time across administration groups. Finally, there was a main effect of group on recall completion time, $F(1, 95) = 5.26$, $p = 0.024$, $\eta_p^2 = 0.052$, indicating that the stepwise instruction group recalled the figures faster than the standard administration group across pretest and posttest.

Table 2. Correlations between complex figure outcomes (i.e. RCF-OSS, accuracy score and completion time) during pretest and posttest for the standard administration group ($n = 45$)

		Pretest						Posttest					
		Copy			Recall			Copy			Recall		
		RCF-OSS	Accuracy score	Completion time	RCF-OSS	Accuracy score	Completion time	RCF-OSS	Accuracy score	Completion time	RCF-OSS	Accuracy score	Completion time
Pretest													
Copy	RCF-OSS	-											
	Accuracy score	.421**	-										
	Completion time	-.109	.067	-									
Recall	RCF-OSS	.609***	.512***	-.026	-								
	Accuracy score	.465**	.550***	.058	.717***	-							
	Completion time	.208	.228	.521***	.202	.301*	-						
Posttest													
Copy	RCF-OSS	.381**	.187	-.199	.314*	.207	-.065	-					
	Accuracy score	.173	.500***	.331*	.368**	.517***	.449**	.151	-				
	Completion time	-.031	-.045	.649***	-.147	-.192	.504***	-.150	.136	-			
Recall	RCF-OSS	.276*	.387**	-.086	.515***	.348*	.167	.444**	.408**	-.213	-		
	Accuracy score	.275*	.359**	.193	.513***	.583***	.369**	.246	.528***	-.135	.613***	-	
	Completion time	.028	.067	.570***	-.103	.009	.590***	-.169	.383**	.611***	-.050	.103	-

Note. RCF-OSS = Rey Complex Figure Organizational Strategy Score; * $p < .05$, ** $p < .01$, *** $p < .001$.

4

Table 3. Complex figure task performance for the stepwise instruction and the standard administration group

		Copy		Recall	
		Pretest *M* (SD) [range]	Posttest *M* (SD) [range]	Pretest *M* (SD) [range]	Posttest *M* (SD) [range]
RCF-OSS	Stepwise	*4.38* (0.78) [1] [3–6]	*4.80* (0.50) [1] [3–6]	*3.22* (1.36) [2] [2–6]	*4.60* (0.99) [2] [2–6]
	Standard	*4.15* (0.94) 1 [2–6]	*4.54* (0.75) [1] [3–6]	*3.42* (1.26) [2] [1–6]	*3.96* (1.24) [2] [2–5]
Accuracy	Stepwise	*25.09* (3.96) [16.00–33.00]	*26.79* (3.47) [19.00–33.50]	*12.57* (5.93) [1] [3.50–23.00]	*15.18* (5.22) [1] [4.00–25.00]
	Standard	*24.93* (6.00) [10.50–35.00]	*24.68* (4.11) [17.00–32.00]	*12.67* (6.12) [1] [2.50–26.00]	*13.89* (5.92) [1] [2.50–29.00]
Completion time (seconds)	Stepwise	*223.27* (74.87) [1] [62.00–421.00]	*137.20* (41.83) [1] [72.00–255.00]	*130.96* (47.80) [1] [48.00–243.00]	*90.71* (28.81) [1] [46.00–185.00]
	Standard	*228.60* (81.59) [1] [121.00–478.00]	*151.71* (54.97) [1] [72.00–310.00]	*154.65* (59.55) [1] [54.00–285.00]	*102.96* (35.00) [1] [36.00–183.00]

Note. The stepwise group consisted of 45 children. In the standard administration group, 53 children participated, of which one was removed from subsequent analyses due to its outlying scores. *Abbreviations:* M = mean, SD = standard deviation, RCF-OSS = Rey Complex Figure Organizational Scoring System (see Anderson, Anderson & Garth, 2001) [25]. [1] Main effect of time of measurement: better performance at posttest than at pretest across administration groups. [2] Interaction between administration group and time of measurement: more improvement from pretest to posttest for stepwise administration group than for standard administration group.

Discussion

The present study investigated whether a stepwise strategy instruction on one complex figure would lead to transferred improvement on another complex figure. Results show that transfer of performance improvement from one complex figure to another, as elicited by a stepwise strategy instruction, occurs only for recall organization. In a relatively 'easy' task such as copying the complex figure, children show spontaneous improvement in organization of the figure irrespective of whether they received a stepwise instruction or not (which will be discussed in more detail below). In a more demanding task, such as recall of the complex figure, spontaneous improvement in organization of information also occurs, but improvement is greater when strategy instruction is provided. These findings are in line with previous studies into effects of strategy instruction on performance on the same complex figure, indicating that stepwise strategy instruction for the ROCF has a greater impact on recall organization than on copy organization [6-8].

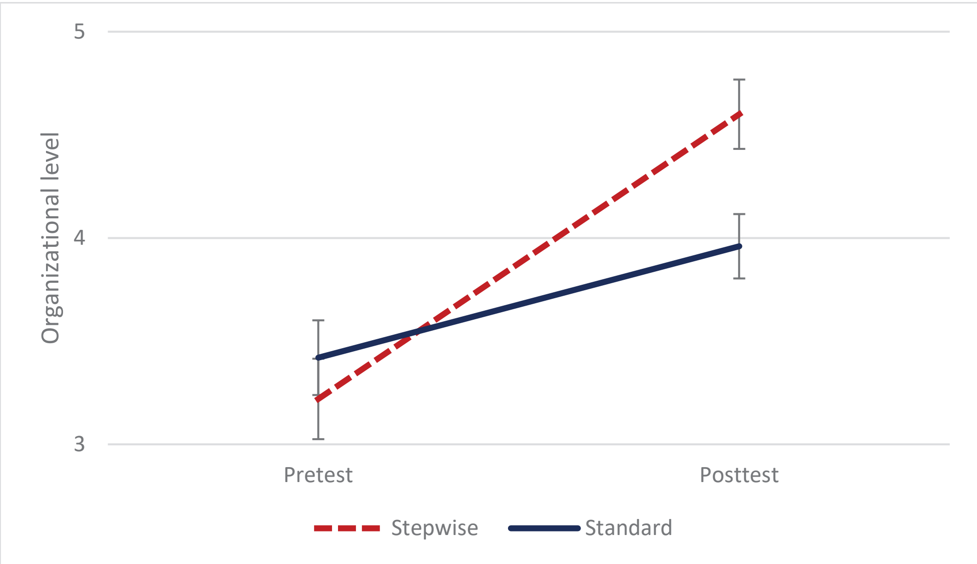

Figure 4. Graphic representation of the influence of strategy instruction on organizational recall performance. *Note.* Organizational level was assessed with the Rey Complex Figure Organizational Strategy Score [25]. Scores could range van 1 to 7. The difference between standard and the stepwise administration was significant at posttest.

According to Waber et al. (1994), the stepwise complex figure instruction aids children to apprehend the organizational framework of the complex figure by removing distracting details, thereby improving the encoding of the major organizational elements. Findings of the present study suggest that children can transfer this strategy to a task condition where the distracting details are already minimal, namely in the recall condition, since children are unlikely to remember all the details [31]. During the copy condition, the task at hand (i.e. to copy the figure as accurately as possible) makes it necessary to also pay attention to elements that are not pivotal for the organization of the figure. This required focus on details seems to prevent the transfer of the stepwise strategy.

Since children's organizational level was found to be correlated positively with complex figure accuracy score but not with completion time, it seemed more likely that the positive effect of the strategy instruction on recall organization would also positively influence recall accuracy (but not completion time). This expectation was only partly met: the positive influence of strategy instruction on recall organization neither led to a higher accuracy of recalled information or to a more efficient production of the drawing. These findings can be explained by a utilization deficiency [32], meaning that the children were not able to effectively apply the strategy to enhance recall accuracy on a parallel figure. Future research should take into account the developmental stage of children when applying strategy instruction, since this might influence the instruction's effectiveness. Additionally, the lack of correlation between complex figure organization and task completion time should be further examined. Emphasizing accuracy as well as speed during the task instruction might lead to differential results.

Limitations and future directions

As mentioned above, results showed that children were able to spontaneously (i.e. even without strategy instruction) adapt their organizational approach to a complex figure during copy and recall, thereby achieving a higher organizational level during posttest. Similarly, at posttest, recall accuracy scores were higher and copy and recall completion times were lower than at pretest. The findings are in line with results by Waber and colleagues [8], indicating improvement in children's ROCF organization with repeated exposure to the task. Our study adds to these findings by showing that this improvement even occurs when a different complex figure is used as outcome measure. It is possible that the children learned from previous complex figure task performance (i.e. either ROCF administration during pretest or posttest) and spontaneously adapted their posttest (organizational) strategy accordingly. In research as well as in clinical contexts, executive function tasks, such as copying and recalling complex figures, are often administered repeatedly. Therefore, it is important that researchers and clinicians take the potential practice effects into account. In the present study, the mean interval between pretest and posttest assessment was 28 days, which is likely to be shorter than the standard interval between repeated assessments in clinical practice. Future research could determine whether the practice effects diminish or disappear when the time period between the first and second administration is increased.Alternatively, improvements in the standard administration group may not have been caused by practice effects but by a test effect, with the MTCF being easier to organize than the ROCF. Given the comparability of geometrical properties and main organizational elements of the two figures [13, 14], we expect this (if at all) to only minimally affect our results. Unfortunately, due to the design of the present study, it is not possible to differentiate practice effects from test effects because all participants received the same test (i.e. ROCF) at pretest and the same test (i.e. MTCF) at posttest. Future research could supplement our findings by making sure that half of the children first perform the ROCF followed by the MTCF, while the other half of the children receive the tasks in the opposite order (i.e. first the MTCF, then the ROCF). Alternatively, practice effects could be assessed by asking children to reproduce the same complex figure multiple times, either with or without strategy instruction, and assess whether task performance improves. However, since the main topic of interest in the present study was the transfer effect of strategy instruction, this was not assessed. Lastly, by investigating the transfer of performance improvement from one complex figure to another, we were only able to examine near transfer effects, i.e. transfer to a task that is structurally similar to the task the instruction was based on. Future studies should investigate whether strategy instruction can also lead to far transfer effects, i.e. transfer to other tasks assessing children's organizational abilities that are structurally dissimilar to the instructed tasks.

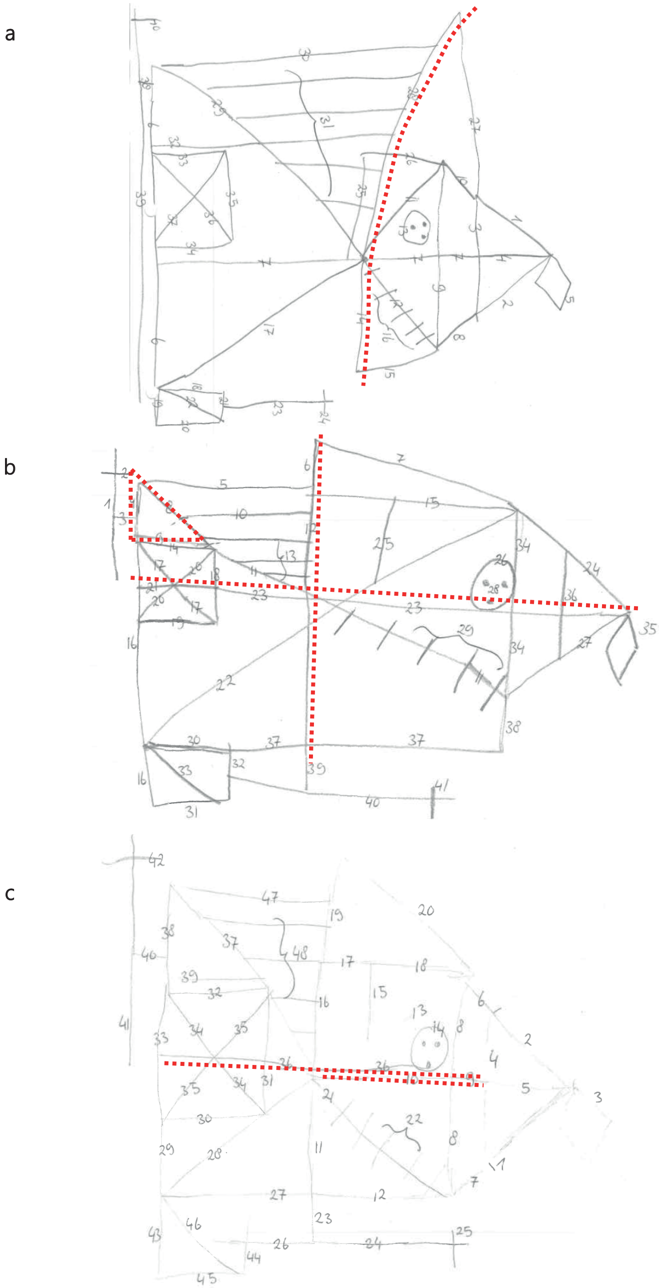

Figure 5. Examples of children's drawings with commonly seen points of discussion regarding the Rey Complex Figure Organizational Strategy Score (RCF-OSS). *Note.* **(a)** Centerline or not? Lines 14 and 28 together are here seen as the vertical centerline, but this might lead to discussion given the curving of line 28. (ROCF copy, level 5). **(b)** Piecemeal or not? Drawing has characteristics (e.g. left corner) of piecemeal but is rated level 5 due to presence of 2 complete centerlines. (Rey-Osterrieth Complex Figure [ROCF] copy, level 5). **(c)** Connecting or not? Lines 36 and 10 were not considered to be connecting (i.e. form a complete horizontal centerline together), since they were more than 3mm apart. (ROCF copy, level 4).

References

1. Rey A. L'examen psychologique dans les cas d'encéphalopathie traumatique [Psychological examination of cases of traumatic encephalopathy]. *Archives de Psychologie.* 1941;28:215-85.
2. Osterrieth PA. Le test de copie d'une figure complexe: Contribution a l'etude de la perception et de la memoire [Copying a complex figure: Contributions to the study of perception and memory]. *Archives de Psychologie.* 1944;30:206-356.
3. Lezak M, Howieson D, Bigler E, Tranel D. *Neuropsychological Assessment.* 5th ed. New York: Oxford University Press; 2012.
4. Strauss E, Sherman EM, Spreen O. *A compendium of neuropsychological tests: Administration, norms, and commentary.* Oxford, UK: Oxford University Press; 2006.
5. Chen CC, Cermak SA, Murray EA, Henderson A. The effect of strategy on the recall of the Rey-Osterrieth Complex Figure in children with or without learning disabilities. *The Occupational Therapy Journal of Research.* 1999;19(4):258-79.
6. Frisk V, Jakobson LS, Knight RM, Robertson B. Copy and recall performance of 6–8-year-old children after standard vs. step-by-step administration of the Rey-Osterrieth Complex Figure. *Child Neuropsychology.* 2005;11(2):135-52.
7. Kirkwood MW, Weiler MD, Bernstein JH, Forbes PW, Waber DP. Sources of poor performance on the Rey–Osterrieth complex figure test among children with learning difficulties: A dynamic assessment approach. *The Clinical Neuropsychologist.* 2001;15(3):345-56.
8. Waber DP, Isquith PK, Kahn CM, Romero I, Sallan SE, Tarbell NJ. Metacognitive factors in the visuospatial skills of long-term survivors of acute lymphoblastic leukemia: An experimental approach to the Rey-Osterrieth complex figure test. *Developmental Neuropsychology.* 1994;10(4):349-67.
9. Klahr D, Chen Z. Finding one's place in transfer space. *Child Development Perspectives.* 2011;5(3):196-204.
10. Chen P, Hartman AJ, Galarza PC, DeLuca J. Global processing training to improve visuospatial memory deficits after right-brain stroke. *Archives of Clinical Neuropsychology.* 2012;27(8):891-905.
11. Hubley AM. Modification of the Taylor complex figure: A comparable figure to the Rey-Osterrieth figure? *Edgeworth Series in Quantitative Behavioural Science,* Paper No ESQBS-96-71996.
12. Hubley AM. *Scoring system for the Modified Taylor Complex Figure (MTCF).* Unpublished research University of Northern British Columbia, Prince George, BC. 1998.
13. Hubley AM, Jassal S. Comparability of the Rey-Osterrieth and Modified Taylor Complex Figures using total scores, completion times, and construct validation. *Journal of Clinical and Experimental Neuropsychology.* 2006;28(8):1482-97.
14. Hubley AM, Tremblay D. Comparability of total score performance on the Rey–Osterrieth complex figure and a modified Taylor complex figure. *Journal of Clinical and Experimental Neuropsychology.* 2002;24(3):370-82.
15. Yamashita H. Comparability of the rey-osterrieth complex figure, the taylor complex figure, and the modified taylor complex figure in a normal sample of Japanese speakers. *Psychological Reports.* 2006;99(2):531-4.
16. Davies SR, Field AR, Andersen T, Pestell C. The ecological validity of the Rey–Osterrieth Complex Figure: Predicting everyday problems in children with neuropsychological disorders. *Journal of Clinical and Experimental Neuropsychology.* 2011;33(7):820-31.
17. Martens R. *What counts? Cognitive development and arithmetical performance: The role of child- and environment-related factors:* Maastricht University [Doctoral dissertation]. 2012.
18. De Bie SE. *Standaardvragen 1987: voorstellen voor uniformering van vraagstellingen naar achtergrondkenmerken in interviews* [Standard questions 1987: Proposal for the uniformization of questions regarding background variables and interviews]. 2nd ed. Leiden, The Netherlands: Leiden University Press; 1987.
19. Kalff A, Kroes M, Vles J, Bosma H, Feron F, Hendriksen J, et al. Factors affecting the relation between parental education as well as occupation and problem behaviour in Dutch 5-to 6-year-old children. *Social Psychiatry and Psychiatric Epidemiology.* 2001;36(7):324-31.

20. UNESCO. *International Standard Classification of Education (ISCED).* Paris: Author; 2011.
21. Kort W, Schittekatte M, Dekker P, Verhaeghe P, Compaan E, Bosmans M, et al. *WISC-III NL wechsler Intelligence Scale for Children. Derde Editie NL. Handleiding en Verantwoording* [Third Edition NL. Manual]. Amsterdam: Hartcourt Test Publishers/Nederlands Instituut voor Psychologen; 2005.
22. Wechsler D. *Manual for the Wechsler Intelligence Scale for Children - third edition.* San Antonio, TX: Psychological Corporation; 1991.
23. Sattler J. *Assessment of children: WISC-III and WPPSI-R supplement.* San Diego, CA: Author; 1992.
24. Sattler J. *Assessment of children: Cognitive applications.* 4th ed. San Diego, CA: Author; 2001.
25. Anderson P, Anderson V, Garth J. Assessment and development of organizational ability: The Rey complex figure organizational strategy score (RCF-OSS). *The Clinical Neuropsychologist.* 2001;15(1):81-94.
26. Martens R, Hurks P, Jolles J. Organizational Strategy Use in Children Aged 5–7: Standardization and Validity of the Rey Complex Figure Organizational Strategy Score (RCF-OSS). *The Clinical Neuropsychologist.* 2014;28(6):954-73.
27. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychological Bulletin.* 1979;86(2):420.
28. Taylor EM. *Psychological appraisal of children with cerebral defects.* Cambridge, MA: Harvard University Press; 1959.
29. Loring DW, Martin RC, Meador KJ, Lee GP. Psychometric construction of the Rey-Osterrieth complex figure: Methodological considerations and interrater reliability. *Archives of Clinical Neuropsychology*. 1990;5(1):1-14.
30. Shorr JS, Delis DC, Massman PJ. Memory for the Rey-Osterrieth Figure: Perceptual clustering, encoding, and storage. *Neuropsychology.* 1992;6(1):43.
31. Akshoomoff NA, Stiles J. Developmental trends in visuospatial analysis and planning: II. Memory for a complex figure. *Neuropsychology.* 1995;9(3):378-9.
32. Miller PH. Individual differences in children's strategic behaviors: Utilization deficiencies. *Learning and Individual Differences.* 1994;6(3):285-307.

Supplemental material 1. Adapted definitions of complex figure elements for the Modified Taylor Complex Figure

Element	Definition
Square	refers to large square and is a configural component of the figure
Centrelines	refers to vertical and horizontal bisectors of square. Centrelines are also configural components of figure, and separately drawn portions must connect
Contour	refers to outline of figure. This may (or may not) include total outline, such as arrows, semi-circle including two dots, triangle, or small rectangle on top of the figure
Diagonals	refers to diagonals of square. Diagonals do not have to be completed as single whole lines and sections of each diagonal do not have to connect
Outside attachments	refers to all sections of figure external to square, includes arrows; large triangle attached on left side of the figure; small rectangle on top of the figure; semi-circle with two dots; triangle on the right
Internal sections	refers to all internal sections of large square which could be divided into half, quarters or eights. This includes: short horizontal and short diagonal line in upper right quadrant; triangle on the ride with two vertical lines; horizontal line in lower right quadrant; wavy line with two short lines; horizontal and vertical lines in upper left quadrant; circle in upper left quadrant; four horizontal lines within triangle on the left
Alignment	refers to an "attempt" (i.e. perfect execution not necessary) to align or connect outside attachments and internal sections with centrelines. Alignment of diagonals refers to an "attempt" to connect sections of each diagonal at midpoint junction of vertical and horizontal centrelines

Note. The original definitions of the complex figure elements and instructions on how to use them to quantify organizational strategy performance were developed and first published by Anderson et al., 2001, p. 86-87. When applying the original instructions to assess performance on the Modified Taylor Complex Figure [11], the word *rectangle* has to be substituted by the word *square*, and the adapted definitions have to be used for the other elements.

4

Chapter 5

Age-dependent differences in the impact of paediatric traumatic brain injury on executive functions: A prospective study using susceptibility-weighted imaging

Resch, C., Anderson, V., Beauchamp, M., Crossley, L., Hearps, S., van Heugten, C., Hurks, P., Ryan, N., & Catroppa, C. (2019). *Neuropsychologia, 124*, 236-245.

Abstract

Childhood and adolescence represent sensitive developmental periods for brain networks implicated in a range of complex skills, including executive functions (EF; inhibitory control, working memory, and cognitive flexibility). As a consequence, these skills may be particularly vulnerable to injuries sustained during these sensitive developmental periods. The present study investigated 1) whether age at injury differentially affects EF 6 months and 2 years after TBI in children aged 5-15 years, and 2) whether the association between brain lesions and EF depend on age at injury. Children with TBI (*n*=105) were categorized into four age-at-injury groups based on previous studies and proposed timing of cerebral maturational spurts: early childhood (5-6 years, *n*=14), middle childhood (7-9 years, *n*=24), late childhood (10-12 years, *n*=52), and adolescence (13-15 years, *n*=15). EF were assessed with performance-based tasks and a parent-report of everyday EF. TBI patients' EF scores 6 months and 2 years post-injury were compared to those of typically developing (TD) controls (*n*=42). Brain lesions were identified using susceptibility-weighted imaging (SWI). Results indicated that inhibitory control performance 2 years post-injury was differentially affected by the impact of TBI depending on age at injury. Follow-up analyses did not reveal significant differences within the age groups, preventing drawing strong conclusions regarding the contribution of age at injury to EF outcome after TBI. Tentatively, large effect sizes suggest that vulnerability is most apparent in early childhood and adolescence. Everyday inhibitory control behaviour was worse for children with TBI than TD children across childhood and adolescence at the 2-year assessment. There was no evidence for impairment in working memory or cognitive flexibility after TBI at the group level. Given small group sizes, findings from analyses into correlations between EF and SWI lesions should be interpreted with caution. Extent, number and volume of brain lesions correlated with adolescent everyday EF behaviour 6 months post-injury. Taken together, the results emphasize the need for long-term follow-up after paediatric TBI during sensitive developmental periods given negative outcomes 2-year post injury. Inhibitory control seems to be particular vulnerable to the impact of TBI. Findings of associations between EF and SWI lesions need to be replicated with larger samples.

Introduction

Traumatic brain injury (TBI) is a common cause of childhood disability, affecting 691 per 100.000 children and adolescents per year across Western countries [1]. Paediatric TBI is associated with long-term cognitive impairments, with difficulties in the area of executive function (EF) being frequent and profound [2-7]. EF are cognitive functions important for purposeful, goal-directed behaviour [8, 9]. They are essential for children's academic success and mental and physical health [10-12]. Their disruption can impact social participation and quality of life [13-17]. EF consist of three separable though interrelated constructs: inhibitory control, working memory and cognitive flexibility [18, 19]. Inhibitory control refers to the ability to withhold dominant and pre-potent responses in contexts where they are not appropriate [18, 19]. Working memory is a cognitive system which temporarily maintains and manipulates information [20, 21]. Cognitive flexibility is the ability to shift attentional focus between tasks and mental sets [8, 19]. Although more severe TBI often leads to worse executive dysfunction [2, 4, 22-24], outcomes vary widely and the relationship between injury severity and degree of EF impairment cannot yet be fully explained [2, 4]. Age at injury, as a proxy for brain and cognitive development, has received increasing attention in the literature as a potential influence on post-injury outcomes; however, research on its relationship to EF after paediatric TBI is still scarce.

Paediatric TBI occurs at a time of ongoing cognitive and neural development [2, 25-27]. The sensitive period model states that higher cognitive functions, such as EF, are particularly vulnerable when the insult occurs at times of rapid neural maturation of the function itself and its underlying networks [27-29]. For the three main EF components discussed above, development continues well into adolescence and early adulthood [8, 30, 31]. Although each of the three EF components has a unique developmental trajectory, early and middle childhood (preschool up to approximately 9 years) has been identified as a key period for each [8, 32-34]. During this stage, prior to the full maturation of EF, children have been argued to be particularly vulnerable. In support of this sensitive period model, a recent study found that children who sustained TBI in early (before 6 years) or middle childhood (7-9 years) demonstrated lower intellectual abilities than those with TBI in late childhood (10-12 years) [28]. Other studies have also reported age-dependent cognitive outcomes, including EF, in groups of children following paediatric brain injury (e.g. TBI, congenital injuries, stroke), highlighting increased vulnerability if children were injured at an age when EF were emerging [23, 35].

Despite protracted EF development throughout childhood and into adulthood [8, 30, 31], the impact of age at injury has rarely been investigated in patients beyond late childhood. Results of these studies seem to indicate that impact of TBI diminishes after early and middle childhood [8, 28, 32-34]. However, the sensitive period model would predict that EF are at heightened risk for disruption during adolescence as well, since brain regions involved in these skills are undergoing rapid maturation [36, 37]. In typically developing (TD) children, adolescence is identified as a sensitive period, characterised by rapid decrease in cerebral grey matter paralleled by increases in white matter, indicating synaptic pruning and myelination and resulting in functional maturation [36, 37]. Immaturities in adolescent EF and underlying brain substrates are clearly apparent in, for example, enhanced risk-taking behaviour as a consequence of limited inhibitory control [38-40]. In the TBI literature, a recent study employed a global EF index, combining performance test scores and parent-ratings of EF, found that children with severe injuries during adolescence (13-15 years) had greater impairment than children injured during late childhood (10-12 years), and similar impairments to those injured in early or middle childhood [41]. Adolescents showed almost no recovery over the two years post insult. Generalization of these results is difficult, however, due to small sample size and inability to determine specific EF profiles [41]. Further investigation in larger studies is warranted, to better characterise the nature of EF impairment and its association with age at injury and injury severity.

Recent evidence suggests that EF components are supported by anatomically distributed brain networks (i.e. in frontal, temporal, parietal and subcortical regions) [42-45]. A promising technique to establish a link between TBI related brain lesions and EF outcomes is susceptibility-weighted imaging (SWI). SWI makes use of a three-dimensional T2*-weighted gradient recalled echo sequence that is highly susceptible to the magnetic properties of extracellular and extravascular blood [46, 47]. This technique is more sensitive than conventional imaging techniques in detecting focal as well as diffuse haemorrhagic pathology [48, 49]. Moreover, SWI is superior to other neuroimaging techniques such as computed tomography or conventional magnetic resonance imagining sequences in detecting micro-haemorrhages because it has increased sensitivity for revealing small traumatic axonal injuries, which may be more typical of mild TBI [47, 50, 51]. Detecting the presence of SWI lesions can be done by visual examination, for example by radiologists, making it a useful clinical tool for diagnosis. The number and volume of lesions across the brain detected with (sub)acute SWI analyses have been found to be predictive of general intellectual abilities from 6 months to 3 years post-injury as well as for a general neuropsychological functioning index including verbal and nonverbal memory, information processing, attention and language skills) 1 to 3 years post-injury [50]. The relationship between lesions detected with SWI and EF after paediatric TBI remains to be determined.

The present study extends previous research in two important ways. Firstly, given previous research has focused predominantly on severe TBI, we studied the impact of TBI across the entire spectrum of injury severity (i.e. mild, moderate, severe TBI), occurring from early childhood to adolescence. We hypothesised that, children sustaining TBI in key sensitive developmental periods including early and middle childhood and adolescence, would also demonstrate poorer EF at 6 months and 2 years post-injury. Secondly, we investigated the relations between EF outcomes after TBI and neuropathology as detected with SWI. To that end, we examined lesions in terms of extent (i.e. how many individual regions of the brain were affected, and thus how diffuse the lesions were), number and volume. We hypothesized that a greater extent, number and volume of SWI lesions would be associated with worse EF outcomes, and that the association would be stronger for children who were injured during early and middle childhood and adolescence (i.e. when the damage to the networks underlying EF occurred during a sensitive period of EF development) than for children injured during late childhood.

Method

Participants

This study represents a sub-study of a prospective, longitudinal cohort study of children's cognitive and social functioning after TBI [52, 53]. Children and adolescents with TBI were recruited at time of injury on presentation to the Emergency Department of a tertiary paediatric hospital, the Royal Children's Hospital (RCH), Melbourne, Australia. Participants represented consecutive admissions to the RCH. Children and adolescents in the TD group were recruited via local schools. Inclusion criteria for the TBI group were: 1) aged between 5.0 and 15.0 years at time of injury; 2) documented evidence of closed head injury; 3) sufficient information (i.e. Glasgow Coma Scale, neurological and radiological findings) in medical records to determine severity of injury; 4) no documented history of neurological or developmental disorders, non-accidental injury, or previous TBI; and 5) English speaking. The TD group was required to meet inclusion criteria 1, 4 and 5 and was matched on age and sex to the group of children with TBI [52, 53].

For the present study, all children (i.e. those with TBI as well as TD children) were categorized into four age groups, i.e. early childhood (5 to 6 years), middle childhood (7 to 9 years), late childhood (10 to 12 years) and adolescence (13 to 15 years). The categorization is based on timing of cerebral maturational spurts as described in the literature [36, 37, 54-56] and has previously been used in investigations of cognitive outcomes, including EF, following paediatric TBI [28, 41, 57].

Materials

Demographics and injury variables. Demographic information was retrieved from a parent questionnaire. The Australian Socioeconomic Index 2006 was used to assign a score of 0 (e.g. labourer) to 100 (e.g. medical practitioner) to parents' occupation [58], of which the highest score served as a measure for socio-economic status (SES). Parents were interviewed at both assessments regarding the amount and type of treatment their child had received up to that point. Injury data (i.e. cause of injury, severity of injury, neurological signs, loss of consciousness, and length of hospital stay) were extracted from medical records.

EF outcomes. Three performance-based tests and one parent-rated measure of EF were selected to assess the three main EF constructs 6 months and 2 years post-injury.

Inhibitory control. Walk/Don't Walk Test of Everyday Attention for Children (TEA-Ch) [59]. Children are instructed to mark a box on a sheet of paper after a target tone (i.e. 'walk' sound) is presented, but not when a non-target tone (i.e. 'don't walk' sound) is presented. The tones are presented in a rhythmic fashion with the 'don't walk' sound occurring unpredictably within the sequence. Scaled score (M=10, SD=3) calculated with the official manual [59] was used as the outcome parameter.

Working memory. The Digit Span (Wechsler Intelligence Scale for Children) [60]. Only the digits backward trials were used, where the participant is required to repeat a sequence of digits (from 0-9) in the reverse order as the examiner. The length of the sequence gradually increases in difficulty. The scaled score (M=10, SD=3) functioned as the outcome parameter.

Cognitive flexibility. Creature Counting task (TEA-Ch). Children are asked to count a number of stimuli (i.e. 'creatures'). During the task, they have to switch between counting forward and backward, as indicated by arrows pointing up or down. Before the test, the ability to count up to and down from 12 is assessed. Scaled scores (M=10, SD=3) for the total number of correct trials and the timing score (i.e. the total time taken to complete all correct trials divided by the total number of switches made during the correct trials) were computed and functioned as cognitive flexibility outcomes. Unlike the other measures, the timing score of the Creature Counting task depends to a large extent on processing speed. To control for potential influences of group differences (i.e. TBI vs TD) in processing speed on the timing measure, we assessed processing speed as a potential covariate.

Processing speed. The Processing Speed Index (M=10, SD=3) from the Wechsler Intelligence Scale for Children–IV (WISC-IV) [60], was administered to assess speed of information processing and included as a possible covariate.

Parent-report on everyday EF. The Behavior Rating Inventory of Executive Function (BRIEF:parent) [61] was used as a measure of everyday EF. T-scores on subscales corresponding to the EF as measured with the performance tests ('Inhibitory Control', 'Working Memory' and 'Shift/Flexibility') and Global Executive Composite' (GEC) were analysed. Higher scores represent more problems with everyday EF.

Susceptibility-weighted imaging (SWI). The three main SWI outcome parameters used in the present study were the extent (total number of independent brain regions affected), total number of lesions and total lesion volume.

Imaging acquisition. MR images were acquired on a 3 Tesla Siemens Trio Scanner (Siemens Medical Systems, Erlangen, Germany) fitted with a 32-Channel matrix head coil. Conventional MR sequences were performed using a standardized imaging protocol that included a SWI sequence [49]. SWI is a variant of the standard 3D FLASH sequence that exploits the signal loss from shortened T2* characteristics of calcium- and deoxyhemoglobin-containing lesions. The images are T2* weighted because of the range of acceptable TEs used in the acquisition (18–22ms). The increased sensitivity to shortened T2* lesions is owed to the employed image reconstruction methods. Both magnitude and phase images are reconstructed from the data set. The phase images display a high sensitivity to local susceptibility variations and are used as an image mask to be combined with the magnitude data set. The combined data set is then reconstructed using a sliding window (eight individual slices compressed into one image), minimum intensity projection data set. The total acquisition time for the MRI protocol was 31 minutes 53 seconds.

SWI analysis. SWI images were visually reviewed to determine the quality of the scan. Scans were coded for neuroanatomical location of lesions by a paediatric neuroradiologist and a neuropsychologist blind to patients' clinical details. Lesions were identified through visual inspection and coded according to location (frontal, extrafrontal, subcortical) based on a modified Coffey system [51, 62]. More specifically, signal changes in grey and white matter were coded in the following cortical and subcortical regions: frontal/temporal/parietal/occipital lobes, cerebellum, hippocampus, amygdala, corpus callosum (CC), thalamus, and basal ganglia. Scans rated positive for lesions on SWI were further investigated by manual segmentation using ITK snap [63]. Lesion counts were conducted using a connected component analysis of lesion masks, accounting for the possibility of the presence of multiple lesions in any independent region of the brain. Repeatability of segmentation was checked by re-segmenting 5 scans after a delay of greater than 6 months and comparing volumes using intra-class correlation (ICC). Lesion extent was calculated as the total number of brain regions showing signal abnormality [64], thereby providing a measure of extent of TBI related structural abnormalities. Given that this measure takes into account the number of affected areas across the brain independent of the location of these lesions, it is thought to be sensitive to diffuse neuropathology [64] and has previously successfully been used as such [53, 65].

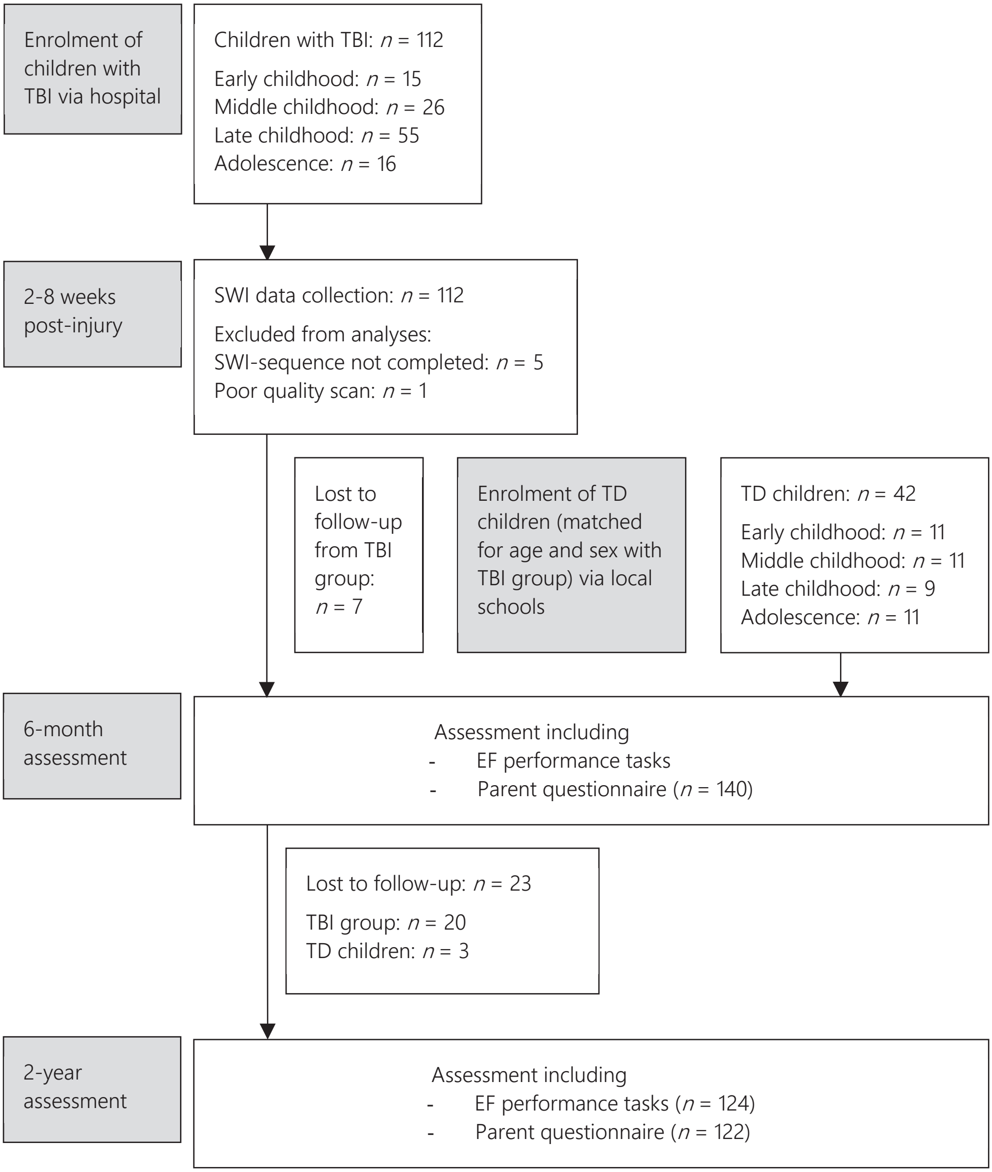

Figure 1. Participant flow and procedure for enrolment and assessment.

Procedure

The study was approved by the RCH Human Research Ethics Committee. All participants were ascertained between 2007 and 2010. Informed consent was obtained from all parents regarding their child's participation in the study. From children older than 8 years, verbal assent was provided.

Data reported were collected at two time points: for the TBI group at 6 months and 2 years post-injury, for the TD group on recruitment and 18 months later. EF tasks were administered by trained researcher assistants. Parents completed a questionnaire regarding demographic variables and on their child's everyday EF behaviour. SWI data were collected for children with TBI between 2 and 8 weeks post-injury (*M* = 39.25, *SD* = 27.64 days). See Figure 1 for a flow-chart of the procedure.

Statistical analyses

Analyses were conducted with IBM SPSS Statistics 24. For all analyses; α was initially set at .05 and corrected for multiple testing when applicable (i.e. α divided by the number of comparisons made). All data were checked for assumptions. Since non-normal distributions were found for some dependent variables, these data were transformed before analysis (see Supplemental material 1 and 2). The few identified outliers (i.e. 3 in total, distributed over the 9 dependent variables and 2 time points) were trimmed to 3 SD from the mean. Comparability of the age groups regarding demographic and injury-related variables (i.e. sex, SES, processing speed, severity of injury, neurological signs, loss of consciousness, length of hospital stay and post-TBI care) was assessed using one-way analyses of variance (ANOVA), χ^2 tests for independence or Kruskal-Wallis nonparametric tests. Similarly, children with TBI and TD were compared per age group on all but the injury-related variables mentioned above.

The influence of age group and TBI (i.e. TBI or TD) on EF performance 6 months and 2 years post-injury was examined using one-way ANOVA for the 6 months-outcome and ANCOVA for the 2-year outcome, adjusting for the 6-months outcome [66]. In the analyses pertaining to the timing score of the Creature Counting task, processing speed (i.e. score on PSI) was entered as covariate. To examine effect sizes, partial η squared (η_p^2) was computed and evaluated according to Cohen's guidelines (i.e. .01 = small, .059 = medium, .138 = large) [67]. Due to violation of the assumption of homogeneity of variances, the influence of age and TBI on the number of correct responses on the TEA-Ch Creature Counting test as well as on the BRIEF GEC at 6 months was examined using negative binomial regression.

Given the non-parametric distributions of the SWI parameters, Kruskal-Wallis tests were used to assess whether the extent, number or volume of SWI lesions differed between the age groups in children with TBI. Kendall's Tau-b rank-order correlations were used to investigate associations between neuropathology detected with SWI (quantified by three

5

separate indices, i.e. extent, number and volume of lesions) and EF outcomes per age group. Negative correlations were expected between SWI parameters and performance tasks (indicating that more neuropathology is related to worse EF performance), while positive correlations were expected between SWI outcomes and the BRIEF (indicating that more neuropathology is related to more EF problems in daily life). The size of the associations was evaluated according to Cohen's guidelines: .10 = small, .30 = medium, .50 = large [68].

Table 1. Characteristics of TBI and TD age groups

	Early childhood		Middle childhood		Late childhood		Adolescence		Statistics
	TBI	TD	TBI	TD	TBI	TD	TBI	TD	
Demographics									
n	14	11	24	11	52	9	15	11	
Sex [male], n (%)	7 (50)	7 (63)	16 (67)	4 (36)	36 (69)	7 (78)	13 (87)	5 (45)	NS
SES M (SD)[1]	74.38 (18.16)	80.43 (6.12)	63.44 (23.86)	75.77 (18.66)	63.16 (23.96)	70.72 (18.16)	76.90 (18.46)	79.53 (10.15)	TBI vs TD: $F(1, 144) = 5.048$, $p = .026$, $\eta_p^2 = .034$
Age at injury	6.28 (0.33)	-	8.23 (0.86)	-	11.36 (0.85)	-	13.92 (0.44)	-	-
Age at 6-month assessment	6.82 (0.36)	6.70 (0.49)	8.77 (0.84)	8.60 (0.82)	11.86 (0.84)	11.56 (1.07)	14.46 (0.46)	14.27 (0.73)	-
Age at 2-year assessment	8.24 (0.44)	8.27 (0.58)	10.24 (0.86)	10.14 (0.84)	13.27 (0.78)	12.96 (1.03)	15.74 (0.70)	15.67 (0.69)	-
Injury characteristics									
Lowest GCS in 24 hours	10.71 (4.32)	-	13.17 (2.81)	-	13.06 (2.91)	-	11.57 (4.13)	-	NS
Neurological signs	1.07 (0.27)	-	1.42 (0.78)	-	1.44 (0.67)	-	1.20 (0.41)	-	NS
Injury cause									
Falls, n (%)	10 (71)	-	15 (63)	-	28 (54)	-	10 (67)	-	NS
MVA, n (%)	3 (21)	-	4 (17)	-	14 (27)	-	3 (20)	-	NS
Others, n (%)	1 (7)	-	5 (21)	-	10 (19)	-	2 (13)	-	NS

Note. GCS = Glasgow Coma Score, MVA = Motor vehicle accident, SES = Socio-economic status, M = mean, SD = standard deviation, TBI = children with traumatic brain injury, TD = typically developing children.
[1] Significant difference between TBI and TD.

Results

Sample characteristics

A total of 154 children, 112 with TBI and 42 TD controls, participated in this study. Given that our analyses pertained to children who had at least participated in the 6-month assessment, we excluded the 7 children who dropped out before the 6-month assessment from all further description. Figure 1 shows the flow of participants throughout the study.

Demographics and injury-related details are displayed in Table 1. There were no sex differences between groups. Given differences between children with TBI and TD children in terms of SES, main analyses included SES as a covariate. For children with TBI, age groups did not differ regarding number of neurological signs, duration of loss of consciousness, length of hospital stay, and number of post-TBI interventions (e.g. speech pathologist, psychologist, occupational therapist) up to the 6-month as well as the 2-year assessment. The proportion of children who had required surgical intervention was the same across all age groups.

Participants with TBI were categorized as 1) mild TBI (n = 52): Glasgow Coma Scale (GCS) [69] between 13 and 15, no signs of mass lesion on clinical MRI or CT (SWI not taken into account for classification); 2) complicated mild TBI (n = 14) : GCS 13 to 15, signs of mass lesion on clinical MRI or CT; 3) moderate TBI (n = 25): GCS between 9 and 12, and/or signs of mass lesion or other evidence of specific injury on clinical MRI or CT, and/or neurological impairment; 4) severe TBI (n = 14): GCS 3 to 8, and/or evidence of mass lesion or other specific injury on clinical MRI or CT, and/or neurological impairment. Age groups of children with TBI did not differ in terms of injury severity, χ^2 (3) = 4.802, p = .187. Given significant differences between children with TBI and TD children in terms of PSI score 6 months (F(1, 144) = 6.390, p = .013, η_p^2 = .043) and 2 years (F(1, 121) = 16.664, p<.001, η_p^2 = .122) post-injury, this score was added as a covariate in the analyses of the Creature Counting timing score, which partially depends on processing speed.

Between the 6-month and 2-year assessment, 23 participants (3 TD) dropped out from the study, leaving a sample of n=124 to analyse for the 2-year assessment. Participants and drop-outs were comparable on all variables depicted in Table 1, except for age of the TD children: the three drop-outs were significantly older than the children who still participated. However, without these three TD children, the age of TD children and children with TBI remained comparable in all age groups. There was some missing data for parent questionnaire: the number of questionnaires included in the analysis was n=140 at 6 months, and n=122 at 2 years.

EF outcomes

EF performance tests. Mean scores per age group on the performance-based EF tests are displayed in Table 2. Inhibitory control at the 2-year assessment was influenced by an age by TBI interaction, $F(3, 112) = 3.269$, $p = .024$, $\eta_p^2 = .080$. Simple effects analyses corrected for multiple testing revealed no significant differences between children with TBI and TD children. Visual inspection of the results and examination of the effect sizes suggested that the result in the main analysis was driven by differences between children with TBI and TD children in the early childhood group, $F(1, 18) = 4.773$, $p = .042$, $\eta_p^2 = .210$, and in the adolescence group, $F(1, 19) = 4.231$, $p = .054$, $\eta_p^2 = .182$, with children with TBI performing worse than TD children. No other interactions between age and TBI or main effects of TBI were found. For more details on the results of the analyses, see Supplemental material 1.

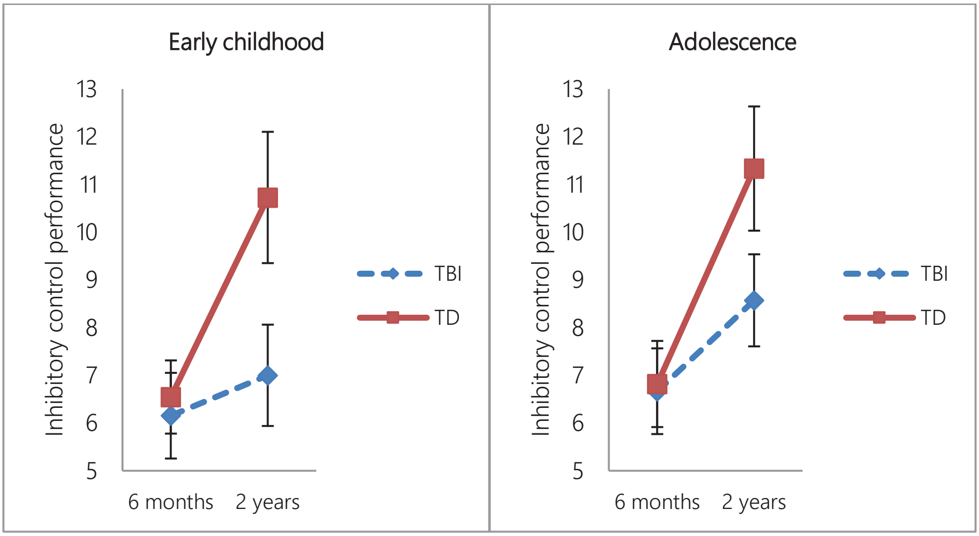

Figure 2. Inhibitory control performance for the early childhood and adolescence groups over time, separate for children with traumatic brain injury (TBI) and typically developing (TD) children.

Parent-report on everyday EF. Mean scores on the BRIEF subscales per age group can be found in Table 3. For the Inhibitory Control scale at the 2-year assessment, there was main effect of TBI, $F(1, 108) = 4.778$, $p = .031$, $\eta_p^2 = .042$, with scores indicating that children with TBI have more inhibitory problems than TD children. No further effects of age by TBI or TBI alone were found. For more details, see Supplemental material 2.

Table 2. Scores on performance-based EF test per age group, M (SD)

		Early childhood		Middle childhood		Late childhood		Adolescence	
		TBI	TD	TBI	TD	TBI	TD	TBI	TD
Inhibitory control (Walk/Don't Walk)	6-month assessment	6.15 (3.24)	6.55 (2.54)	7.29 (3.17)	8.45 (4.32)	8.24 (3.74)	8.00 (4.56)	6.67 (3.48)	6.82 (2.99)
	2-year assessment[1]	**7.00 (3.52)**	**10.73 (4.56)**	**8.33 (4.06)**	**8.64 (3.80)**	**8.32 (3.20)**	**6.88 (3.09)**	**8.57 (3.61)**	**11.33 (3.91)**
Working memory (Digit Span Backward)	6-month assessment	10.62 (2.69)	10.64 (2.83)	9.67 (2.46)	10.00 (2.65)	9.10 (2.69)	9.44 (3.50)	8.07 (2.60)	10.55 (2.07)
	2-year assessment	9.27 (2.49)	9.73 (2.76)	10.50 (3.26)	10.18 (2.56)	9.27 (3.15)	8.63 (3.85)	8.57 (2.47)	11.22 (3.35)
Cognitive flexibility (Creature Counting Correct)	6-month assessment	8.23 (3.09)	10.09 (4.28)	10.08 (3.17)	9.00 (3.58)	9.57 (3.47)	12.44 (1.42)	12.60 (2.13)	12.18 (2.32)
	2-year assessment	9.72 (2.37)	11.45 (3.14)	10.83 (2.20)	10.81 (2.93)	10.93 (2.32)	10.13 (2.70)	11.07 (2.53)	12.44 (1.67)
Cognitive flexibility (Creature Counting Timing Score)	6-month assessment	8.17 (2.64)	10.57 (2.44)	8.87 (3.82)	11.00 (3.64)	8.89 (3.09)	10.56 (2.24)	9.33 (3.85)	11.09 (1.70)
	2-year assessment	9.91 (3.05)	11.00 (2.36)	11.17 (3.28)	11.82 (2.99)	10.64 (3.04)	11.13 (2.30)	10.57 (2.82)	11.44 (1.01)

Note. The values displayed pertain to the standard scores of the untransformed variables. EF = executive function, M = mean, SD = standard deviation, TBI = children with traumatic brain injury, TD = typically developing children. [1] p = .024 for the interaction between TBI/TD and age group.

5

Table 3. BRIEF scores per age group, M (SD)

		Early childhood		Middle childhood		Late childhood		Adolescence	
		TBI	TD	TBI	TD	TBI	TD	TBI	TD
Inhibitory Control	6-month assessment	47.43 (10.27)	49.64 (7.07)	47.95 (9.16)	44.82 (5.29)	51.72 (12.45)	48.56 (5.48)	50.00 (15.12)	46.18 (4.81)
	2-year assessment[1]	**49.18 (11.75)**	**46.27 (4.63)**	**48.78 (9.60)**	**42.64 (3.72)**	**51.80 (13.71)**	**49.00 (5.53)**	**51.23 (15.28)**	**45.33 (6.34)**
Working Memory	6-month assessment	50.93 (9.86)	44.46 (11.77)	47.14 (6.34)	44.55 (5.91)	53.84 (11.15)	47.00 (8.90)	48.73 (12.46)	54.00 (10.87)
	2-year assessment	51.36 (11.63)	44.64 (7.06)	47.44 (8.49)	43.73 (5.18)	52.97 (12.65)	49.63 (8.90)	52.15 (14.08)	49.44 (8.59)
Shift/Flexibility	6-month assessment	49.64 (10.51)	45.18 (6.23)	47.19 (8.23)	43.73 (8.82)	47.91 (12.19)	46.67 (7.00)	48.27 (12.29)	47.27 (7.96)
	2-year assessment	51.73 (12.28)	44.64 (10.09)	44.56 (7.17)	44.81 (6.65)	47.46 (9.70)	46.13 (6.31)	51.46 (13.57)	44.67 (5.00)
GEC	6-month assessment	48.23 (9.29)	46.00 (3.64)	45.10 (6.35)	43.91 (4.09)	51.53 (11.42)	46.89 (7.56)	48.20 (11.74)	50.00 (5.87)
	2-year assessment	49.27 (10.85)	43.09 (3.72)	44.17 (7.70)	43.82 (4.92)	51.05 (12.34)	48.00 (9.01)	49.77 (11.94)	46.11 (6.05)

Note. The values displayed pertain to the standard scores of the untransformed variables. BRIEF = Behavior Rating Inventory of Executive Function, GEC = Global Executive Composite, M = mean, SD = standard deviation, M = mean, SD = standard deviation, TBI = children with traumatic brain injury, TD = typically developing children. [1] p = .031 for difference between TBI and TD across age groups.

Neuroanatomical location of lesions detected using SWI

Of the participants with TBI, five did not complete the SWI sequence. One scan was rejected due to poor quality and this participant's data were excluded from further analyses incorporating SWI findings. Thus, data from 106 participants with TBI are reported. Lesions were detected in 37 patients (35%) across all severity groups. Lesions were most prominent in frontal regions (frontal only = 15 patients, frontal+extrafrontal = 6, frontal+ other regions [CC = 1, deep grey+CC = 1, cerebellum = 1, cerebellum+CC = 1]), followed by extrafrontal regions only (*n* = 6). A small number of patients (*n* = 4) had lesions in several areas (frontal+extrafrontal+cerebellum = 2, frontal+extrafrontal+deep grey = 1, frontal+extrafrontal+CC = 1). Very few patients had lesions solely in the CC (*n* = 1), cerebellum (*n* = 1) regions. The number of lesions varied from 1 to 70. Segmentation procedures were reliable, with an intra-rater ICC score of .987 (95% confidence interval = .911 – .999).

The proportion of children with SWI lesions was similar across age groups, χ^2 (6) = 4.413, *p* =0.657. There were no differences between age groups in terms of extent of the lesions (i.e. number of individual brain regions affected), χ^2 (3) = 0.438, *p* = .932, number of lesions, χ^2 (3) = 0.541, *p* = .910, or volume of the lesions, χ^2 (3) = 1.000, *p* = .801.

Associations between EF outcomes and neuropathology. Correlation coefficients are reported in Supplemental material 3. For small samples (such as in our individual age groups) it is especially important to not only pay attention to the size of the correlations but also to the test of significance, to decrease the chance of spurious findings. None of the correlation analyses were significant after correction for multiple testing. Results significant at an α-level of .05 will be discussed in more detail, but should be interpreted with caution. In the middle childhood group, number of lesions was significantly positively associated with the score on the Digit Span Backward test at the 6-month assessment, suggesting that children who were injured during middle childhood had a higher working memory score if they had more lesions. In the adolescence group, medium to large correlations were found between all SWI variables (i.e. extent, number and volume of lesions) and the Working Memory, Shift/flexibility, and General Executive Component scores of the BRIEF at 6-month post-injury, indicating more everyday EF problems in these domains and/or overall with more neuropathology. These associations were not found 2 years post-injury.

Discussion

In this study, we tested the sensitive period model for EF outcomes in a sample consisting of children and adolescents with TBI, and we explored the value of SWI in relation to EF outcomes. Consistent with the sensitive period model [27-29] and results from previous studies [23, 28, 35, 41], we hypothesized that children who sustained TBI during early or middle childhood or adolescence (i.e. sensitive periods for EF development) would show worse EF performance compared to controls than children who were injured during late childhood.

First, results indicate that, of the three EF assessed, inhibitory control was most sensitive to the impact of the injury. For inhibitory control performance, differences between children with TBI and TD children seemed to depend on age at injury (to be discussed below), while the standardized parent report measures indicated that 'everyday' inhibitory control was significantly poorer than TD controls regardless of age at injury. Both for the performance measure and for the parent report measure, the difference between children with TBI and TD children only emerged at the 2-year assessment. These results suggest that clinicians should closely monitor the potential risk of inhibitory control impairments in children across the spectrum of TBI severity, even among children with milder generalised injuries. On the other hand, working memory and cognitive flexibility, when assessed as separate EF components, were not impaired at the group level. Different EF seem to be differentially affected by TBI, which is in line with previous findings of (long-term) EF outcomes after paediatric TBI [49].

While the main analyses of inhibitory control performance revealed an interactive effect of TBI and age at injury on this specific EF outcome, simple effects analyses showed no significant differences within the four individual age groups. Discussion of the following results is therefore based on the large effect sizes that we found for differences between children with TBI and TD children in the early childhood group and the adolescence group, but not in the middle childhood group and late childhood groups. The results should be interpreted with caution and we further reflect on this when discussing the limitations of the present study below.

Partly in line with our hypotheses, the interaction between age at injury and TBI on 2-year inhibitory control outcome seemed to emerge due to differences between children with TBI and TD children in the early childhood and adolescence groups, but not for children injured during middle and late childhood. More specifically, compared to TD controls, the early childhood and the adolescence TBI groups seemed to have poorer inhibitory control but only at the 2-year assessment. When inspecting the scores within the age groups (see Figure 2), TD children in both the early childhood group and the adolescence group seemed to make progress from the 6-month to the 2-year assessment. For children with TBI, this 'maturation' effect was not as apparent or pronounced. This finding is in line with the sensitive period model stating that impact during a period of rapid neural network development has detrimental consequences for the maturation of the cognitive functions underlying these developing networks [27, 29, 35]. The emergence of this effect only at the 2-year assessment corresponds with the notion that after paediatric brain injury, deficits in higher-order skills may emerge later in development when these skills are expected to be at a stage of becoming established and consolidated [54, 70]. Inhibitory control has been known to develop and mature in early childhood [32, 34] explaining the vulnerability of children injured during this developmental period to the impact of TBI. Our finding that next to early childhood, adolescence seems to be a vulnerable period for impact on inhibitory control supports further the notion that EF continue to develop throughout adolescence and even adulthood [8, 30, 31].

Summing up: i) maturation and establishment of inhibitory control may be particularly vulnerable to the effects of TBI; ii) there is a need for long-term (minimum 2 years) follow-up following TBI as EF difficulties (particular in terms of inhibitory control) may not be evident acutely; iii) both early childhood and adolescence could be periods during which EF are sensitive to disruption due to injury. Studies into the effect of TBI should consider investigating these children as vulnerable groups, separately from children who are injured during e.g. middle or late childhood. However, larger group studies are warranted to confirm the vulnerability of these particular age groups.

Associations of EF outcomes with neuropathology

Our findings showed that children with more (i.e. higher number) and more diffuse (i.e. greater extent) TBI-related neuropathology had worse EF outcomes compared to children with less (distributed) neuropathology, when injured during adolescence. This is in line with previous studies reporting associations between greater lesion burden and poorer cognitive functioning, such as intellectual ability [50, 71] and social cognitive abilities [53]. However, EF outcomes between children with TBI and TD children sometimes differed, independent of SWI indices. Previous studies have shown that SWI markers (i.e. number, volume and/or extent of lesions) combined with data on age at injury and injury severity (i.e. GCS) only explain 6.5% to 29.7% of outcome variance in measures of intellectual ability and cognitive functioning (including EF) [50, 71]. Combined with the results of our study, these findings suggest that other non-injury related factors (e.g. pre-injury child factors, environment [26, 72, 73]) may be important determinants of (long-term) cognitive (e.g. EF) outcomes after TBI.

A contra-intuitive correlation emerged between a greater number of lesions and a higher working memory performance 6 months (but not 2 years) post-injury in children who sustained a TBI during middle childhood. Similarly, in a previous study, children aged 8 to 15 with mild complicated TBI (i.e. showing abnormalities on an MRI scan) were found to perform better on a working memory task than children with mild TBI without indications of neural pathology [74]. These results suggest that for outcomes in some cognitive domains, injury related factors alone are not sufficient to explain variability in outcome and recovery post-TBI. Again, this emphasizes the importance of taking into account non-injury related factors as potential contributors to EF outcomes.

Study strengths and limitations

A particular strength of our study was the inclusion of adolescence as a separate age group. As our results indicate, TBI sustained during adolescence might have long-term negative impact on EF outcomes. This should be taken into account in clinical practice or future research after paediatric TBI. Second, we compared children with TBI to matched control groups of TD children. In contrast to previous studies that did not include a control group when investigating EF outcomes after TBI over time [41], this enabled us to control for practice effects that might occur when the same tasks or questionnaires are repeatedly completed. Finally, we included performance-based tasks as well as an ecologically valid, parent-reported measure for EF. Including both types of measurements is important, given that they are not always highly correlated [75], and are sometimes even thought to assess different aspects of EF [35, 57].

Results of the present study also have to be interpreted in the light of a number of limitations. Firstly, in order to evaluate the sensitive period model in relation to EF outcomes, we divided our sample into four age groups based on timing of cerebral maturational spurts [36, 37, 54-56]. This approach has a strong theoretical basis in developmental biology, with brain and cognitive development best being conceptualized in a stage-based manner characterized by peaks and plateaus of rapid neural development and refinement in neural networks [55]. Additionally, age group categories are of clinical utility when making clinical decisions related to treatment and (long-term) follow-up. However, age is inherently a continuous variable and using age categories leads to arbitrary (though well-founded) division of the sample. Future studies may consider analysing the influence of age at injury on EF using age at injury as a continuous predictor to better take this into account.

Second, while our overall sample was large (i.e. 105 children with TBI and 42 TD children included in the analyses), age-at injury findings should be interpreted with caution due to smaller sample sizes of the various developmental age groups. For example, while the main analysis of the inhibitory control score 2 years post-injury yielded a significant interaction between age group and TBI, post hoc tests were insufficiently powered. Similarly, correlation coefficients between EF outcomes and SWI variables are based on a small number of children per group, potentially leading to missing important correlations because they did not reach significance on the one hand, as well as increasing the possibility of chance findings on the other hand (e.g. the contra-intuitive correlation between a greater number of lesions and a higher working memory performance in middle childhood). Given the limited sample size of the present study, we were not able to perform regression analyses to investigate predictive influence on EF outcomes of a large number of predictors such as SWI markers, age at injury, injury severity, pre-injury abilities and family functioning. Future studies could consider building on our findings that SWI markers may be valuable, in addition to other factors, when aiming to identify children at risk for negative EF outcomes.

Third, previous studies investigating age-dependent effects of TBI included children from age 3 on in the early childhood group, while in the present study only children from age 5 on were included. Age range in the present study was based on available social and neurodevelopmental measures. Third, the performance tests of the TEA-Ch, used to measure inhibitory control and cognitive flexibility, were originally designed only for children and adolescents up to age 16 [59]. While all participants were below that age at time of entering the study, eight adolescents (5 with TBI, 3 TD) had passed that age at the 2-year assessment, with their age ranging from 16.00 to 16.83 years. In the present study, 5 of these participants (3 with TBI, 2 TD) achieved the highest possible number of correct items on the Creature Counting test, potentially suggesting ceiling effects on this test. On the other EF tests, these participants did not reach the highest possible score. Since the highest score on the Creature Counting test was achieved roughly as often by TD adolescents as by adolescents with TBI, it is not expected that ceiling effects had a large influence on our findings. However, future studies might want to use tests that are intended for older children, particularly when investigating vulnerability of children injured during adolescence. Lastly, children participated in the SWI procedure between 2 and 8 weeks post-injury. TBI is associated with both primary and secondary injury mechanisms that may affect the developmental trajectory underlying EF outcome. Results of neuroimaging may differ depending on the timing of scanning. While age-at-injury groups did not differ in terms of mean time between injury and scanning, earlier scanning to detect micro-haemorrhagic lesion in the acute phase may potentially be more valuable in predicting EF outcome.

Conclusions

Inhibitory control measured with a performance task as well as rated by a parent is particularly vulnerable to the long-term impact of TBI, with children with TBI scoring worse than TD children 2 years post-injury. Early childhood and adolescence seem to be developmental stages during which children are particularly vulnerable to the negative impact of brain injury, supporting a non-linear relationship between age at injury and outcome, and thus a 'sensitive period' model. However, these results need to be confirmed in future studies and larger sample. Relations between neuropathology as detected with SWI and EF outcomes (i.e. everyday EF behaviour) seem to be strongest during sensitive developmental periods, in this case of EF middle childhood and adolescence. SWI analyses are based on visual inspection of scans, not requiring extensive amounts of sophisticated analyses. SWI is a useful clinical tool for acute TBI diagnosis, and our results suggest that it might be of added value for predicting EF outcomes of adolescents who sustain a TBI. Considering both age at injury and neuropathology detected with SWI may help identify those at a higher risk for negative (long-term) EF outcomes.

Acknowledgements

This research was supported by the Victorian Neurotrauma Initiative and the Victorian Government Operational Infrastructure Scheme (No.CO6E1). The funding bodies did not play a role in the design of the study, collection, analysis and interpretation of the data, or writing of the manuscript.

References

1. Thurman, D.J., The epidemiology of traumatic brain injury in children and youths: a review of research since 1990. *Journal of Child Neurology,* 2016. 31(1):20-27.
2. Anderson, V. and C. Catroppa, Recovery of executive skills following paediatric traumatic brain injury (TBI): A 2 year follow-up. *Brain Injury,* 2005. 19(6):459-470.
3. Babikian, T. and R. Asarnow, Neurocognitive outcomes and recovery after pediatric TBI: meta-analytic review of the literature. *Neuropsychology,* 2009, 23(3):283-296.
4. Catroppa, C. and V. Anderson, Neurodevelopmental outcomes of pediatric traumatic brain injury. *Future Neurology,* 2009. 4(6):811-821.
5. Mangeot, S., et al., Long-term executive function deficits in children with traumatic brain injuries: Assessment using the Behavior Rating Inventory of Executive Function (BRIEF). *Child Neuropsychology,* 2002. 8(4):271-284.
6. Sesma, H.W., et al., Executive functioning in the first year after pediatric traumatic brain injury. *Pediatrics,* 2008. 121(6):e1686-e1695.
7. van Heugten, C., et al., Long-term neuropsychological performance in a cohort of children and adolescents after severe paediatric traumatic brain injury. *Brain Injury,* 2006. 20(9):895-903.
8. Anderson, P., Assessment and development of executive function (EF) during childhood. *Child Neuropsychology,* 2002. 8(2):71-82.
9. Diamond, A. and K. Lee, Interventions shown to aid executive function development in children 4 to 12 years old*. Science,* 2011. 333(6045):959-964.
10. Borella, E., B. Carretti, and S. Pelegrina, The specific role of inhibition in reading comprehension in good and poor comprehenders. *Journal of Learning Disabilities,* 2010. 43(6):541-552.
11. Diamond, A., Executive functions. *Annual Review of Psychology,* 2013. 64:135-168.
12. Gathercole, S.E., et al., Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology,* 2004. 18(1):1-16.
13. Galvin, J., E.H. Froude, and J. McAleer, Children's participation in home, school and community life after acquired brain injury. *Australian Occupational Therapy Journal,* 2010. 57(2):118-126.
14. Levin, H.S., G. Hanten, and X. Li, The relation of cognitive control to social outcome after paediatric TBI: Implications for intervention. *Developmental Neurorehabilitation*, 2009. 12(5):320-329.
15. Levin, H.S., et al., Concept formation and problem-solving following closed head injury in children. *Journal of the International Neuropsychological Society*, 1997. 3(06):598-607.
16. Rosema, S., L. Crowe, and V. Anderson, Social function in children and adolescents after traumatic brain injury: A systematic review 1989–2011. *Journal of Neurotrauma*, 2012. 29(7):1277-1291.
17. Ylvisaker, M. and T. Feeney, Executive functions, self-regulation, and learned optimism in paediatric rehabilitation: a review and implications for intervention. *Pediatric Rehabilitation*, 2002. 5(2):51-70.
18. Huizinga, M., C.V. Dolan, and M.W. van der Molen, Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia,* 2006. 44(11):2017-2036.
19. Miyake, A., et al., The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology,* 2000. 41(1): 49-100.
20. Baddeley, A.D. and G. Hitch, *Working memory. Psychology of learning and Motivation*, 1974. 8: 47-89.
21. Bayliss, D.M., et al., Mapping the developmental constraints on working memory span performance. *Developmental Psychology*, 2005. 41(4):579.
22. Colorado Medical Society. *Report of the sports medicine committee: Guidelines for the management of concussion in sports.* 1991, Colorado Medical Society: Denver.
23. Anderson, V., et al., Does early age at brain insult predict worse outcome? Neuropsychological implications. *Journal of Pediatric Psychology,* 2009:jsp100.
24. Woodward, H., et al., Prediction of neurobehavioral outcome 1–5 years post pediatric traumatic head injury. *The Journal of Head Trauma Rehabilitation*, 1999. 14(4):351-359.

25. Anderson, V., et al., Functional plasticity or vulnerability after early brain injury? *Pediatrics*, 2005. 116(6): 1374-1382.
26. Anderson, V., et al., Predictors of cognitive function and recovery 10 years after traumatic brain injury in young children. *Pediatrics,* 2012. 129(2):e254-e261.
27. Anderson, V., M. Spencer-Smith, and A. Wood, Do children really recover better? Neurobehavioural plasticity after early brain insult. *Brain,* 2011. 134(8):2197-2221.
28. Crowe, L.M., et al., Timing of traumatic brain injury in childhood and intellectual outcome. *Journal of Pediatric Psychology,* 2012. 37(7):745-754.
29. Dennis, M., et al., Functional plasticity in childhood brain disorders: When, what, how, and whom to assess. *Neuropsychology Review,* 2014. 24(4):389.
30. Casey, B., J.N. Giedd, and K.M. Thomas, Structural and functional brain development and its relation to cognitive development. *Biological Psychology,* 2000. 54(1):241-257.
31. De Luca, C.R., et al., Normative data from the CANTAB. I: development of executive function over the lifespan. *Journal of Clinical and Experimental Neuropsychology,* 2003. 25(2):242-254.
32. Romine, C.B. and C.R. Reynolds, A model of the development of frontal lobe functioning: Findings from a meta-analysis. *Applied Neuropsychology,* 2005. 12(4):190-201.
33. Best, J.R., P.H. Miller, and L.L. Jones, Executive functions after age 5: Changes and correlates. *Developmental Review*, 2009. 29(3):180-200.
34. Jurado, M.B. and M. Rosselli, The elusive nature of executive functions: a review of our current understanding. *Neuropsychology Review,* 2007. 17(3):213-233.
35. Anderson, V., et al., Children's executive functions: are they poorer after very early brain insult. *Neuropsychologia*, 2010. 48(7):2041-2050.
36. Giedd, J.N., et al., Brain development during childhood and adolescence: a longitudinal MRI study. *Nature Neuroscience,* 1999. 2(10):861-863.
37. Gogtay, N., et al., Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National academy of Sciences of the United States of America,* 2004. 101(21):8174-8179.
38. Blakemore, S.J. and S. Choudhury, Development of the adolescent brain: implications for executive function and social cognition. *Journal of child psychology and psychiatry,* 2006. 47(3-4):296-312.
39. Blakemore, S.-J. and T.W. Robbins, Decision-making in the adolescent brain. *Nature Neuroscience*, 2012. 15(9):1184.
40. Sawyer, S.M., et al., Adolescence: a foundation for future health. *The Lancet,* 2012. 379(9826):1630-1640.
41. Krasny-Pacini, A., et al., Executive function after severe childhood traumatic brain injury–Age-at-injury vulnerability periods: The TGE prospective longitudinal study. *Annals of Physical and Rehabilitation Medicine*, 2017. 60(2):74-82.
42. Lewis, S.J., et al., Striatal contributions to working memory: a functional magnetic resonance imaging study in humans. *European Journal of Neuroscience,* 2004. 19(3):755-760.
43. Monchi, O., et al., Functional role of the basal ganglia in the planning and execution of actions. *Annals of Neurology*, 2006. 59(2):257-264.
44. Nowrangi, M.A., et al., Systematic review of neuroimaging correlates of executive functioning: converging evidence from different clinical populations. *The Journal of Neuropsychiatry and Clinical Neurosciences,* 2014. 26(2):114-125.
45. Power, T., et al., Do lesion site and severity predict deficits in attentional control after preschool traumatic brain injury (TBI)? *Brain Injury,* 2007. 21(3):279-292.
46. Haacke, E.M., et al., Susceptibility-weighted imaging (SWI). *Magnetic Resonance in Medicine,* 2004. 52(3):612-618.
47. Tong, K.A., et al., Hemorrhagic shearing lesions in children and adolescents with posttraumatic diffuse axonal injury: improved detection and initial results 1. *Radiology*, 2003. 227(2): 32-339.

48. Spitz, G., et al., Detecting lesions after traumatic brain injury using susceptibility weighted imaging: a comparison with fluid-attenuated inversion recovery and correlation with clinical outcome. *Journal of Neurotrauma*, 2013. 30(24):2038-2050.

49. Beauchamp, M.H., et al., Detecting traumatic brain lesions in children: CT versus MRI versus susceptibility weighted imaging (SWI). *Journal of Neurotrauma*, 2011. 28(6):915-27.

50. Babikian, T., et al., Susceptibility weighted imaging: neuropsychologic outcome and pediatric head injury. *Pediatric Neurology*, 2005. 33(3):184-194.

51. Beauchamp, M., et al., Hippocampus, amygdala and global brain changes 10 years after childhood traumatic brain injury. *International Journal of Developmental Neuroscience,* 2011. 29(2):137-143.

52. Anderson, V., et al., Social Competence at Two Years after Child Traumatic Brain Injury. *Journal of Neurotrauma,* 2017.

53. Ryan, N.P., et al., Relationships between acute imaging biomarkers and theory of mind impairment in post-acute pediatric traumatic brain injury: a prospective analysis using susceptibility weighted imaging (SWI). *Neuropsychologia,* 2015. 66:32-38.

54. Giza, C.C. and M.L. Prins, Is being plastic fantastic? Mechanisms of altered plasticity after developmental traumatic brain injury. *Developmental Neuroscience,* 2006. 28(4-5):364-379.

55. Kolb, B., S. Pellis, and T.E. Robinson, Plasticity and functions of the orbital frontal cortex. *Brain and Cognition,* 2004. 55(1): 04-115.

56. Van Praag, H., G. Kempermann, and F.H. Gage, Neural consequences of enviromental enrichment. *Nature Reviews Neuroscience,* 2000. 1(3):191-198.

57. Anderson, V., et al., Childhood brain insult: can age at insult help us predict outcome? *Brain,* 2009. 132(1):45-56.

58. McMillan, J., A. Beavis, and F.L. Jones, The AUSEI06: A new socioeconomic index for Australia. *Journal of Sociology*, 2009. 45(2): 23-149.

59. Manly, T., et al., *The Test of Everyday Attention (TEA-CH).* Bury St. Edmunds: Thames Valley Test Company, 1994.

60. Wechsler, D., *Wechsler Intelligence Scale for Children–Fourth Edition (WISC-IV).* San Antonio, TX: The Psychological Corporation, 2003.

61. Gioia, G.A., et al., *Behavior Rating Inventory of Executive Function: BRIEF.* 2000: Psychological Assessment Resources Odessa, FL.

62. Coffey, C. and G. Figiel, Neuropsychiatric significance of subcortical encephalomalacia. *Psychopathology and the Brain,* 1991. 3(11):243-264.

63. Yushkevich, P.A., et al., User-guided 3D active contour segmentation of anatomical structures: significantly improved efficiency and reliability. *Neuroimage,* 2006. 31(3): p. 1116-1128.

64. Kraus, M.F., et al., White matter integrity and cognition in chronic traumatic brain injury: a diffusion tensor imaging study. *Brain,* 2007. 130(10):2508-2519.

65. Ryan, N.P., et al., The emergence of age-dependent social cognitive deficits after generalized insult to the developing brain: A longitudinal prospective analysis using susceptibility-weighted imaging. *Human Brain Mapping,* 2015. 36(5): 1677-1691.

66. Vickers, A.J. and D.G. Altman, Analysing controlled trials with baseline and follow up measurements. *BMJ,* 2001. 323(7321):1123-1124.

67. Cohen, J., *Statistical power analysis for the behavioral sciences.* Hilsdale. NJ: Lawrence Earlbaum Associates, 1988. 2.

68. Cohen, J., et al., *Applied multiple regression/correlation analysis for the behavioral sciences.* 2013: Routledge.

69. Teasdale, G. and B. Jennett, Assessment of coma and impaired consciousness: a practical scale. *The Lancet,* 1974. 304(7872):81-84.

70. Middleton, J.A., Psychological sequelae of head injury in children and adolescents. *The Journal of Child Psychology and Psychiatry and Allied Disciplines,* 2001. 42(2):165-180.

71. Beauchamp, M.H., et al., Susceptibility weighted imaging and its relationship to outcome after pediatric traumatic brain injury. *Cortex,* 2013. 49(2):591-8.

72. Anderson, V.A., et al., Understanding predictors of functional recovery and outcome 30 months following early childhood head injury. *Neuropsychology,* 2006. 20(1):42.

73. Chapman, L.A., et al., Clinically significant behavior problems during the initial 18 months following early childhood traumatic brain injury. *Rehabilitation Psychology,* 2010. 55(1):48.

74. Maillard-Wermelinger, A., et al., Mild traumatic brain injury and executive functions in school-aged children. *Developmental Neurorehabilitation,* 2009. 12(5):330-341.

75. Vriezen, E.R. and S.E. Pigott, The relationship between parental report on the BRIEF and performance-based measures of executive function in children with moderate to severe traumatic brain injury. *Child Neuropsychology,* 2002. 8(4):296-303.

5

Supplemental material 1. EF performance tests

Inhibitory control. Due to negative skewness, test scores on the Walk/Don't Walk subtest were reversed square root transformed for both assessments. At the 6-month assessment, there was no age by TBI interaction, $F(3, 135) = 0.101$, $p = 0.959$, $\eta_p^2 = 0.002$, or main effect of TBI, $F(1, 135) = 0.057$, $p = 0.811$, $\eta_p^2 < 0.001$. At the 2-year assessment, a significant age by TBI interaction emerged, $F(3, 112) = 3.701$, $p = 0.014$, $\eta_p^2 = 0.090$. Simple effects analyses showed a significant effect of TBI in the early childhood group, $F(1, 18) = 4.920$, $p = 0.040$, $\eta_p^2 = 0.215$, but not in the middle childhood, $F(1, 25) = 1.009$, $p = 0.325$, $\eta_p^2 = 0.030$, late childhood, $F(1, 44) = 1.447$, $p = 0.235$, $\eta_p^2 = 0.032$, or adolescence group, $F(1, 19) = 1.928$, $p = 0.181$, $\eta_p^2 = 0.092$.

Working memory. Data from the Digit Span Backward task 6-month as well as the 2-year assessment were square root transformed. For the 6-month assessment, analysis revealed no age by TBI interaction, $F(3, 136) = 1.679$, $p = 0.175$, $\eta_p^2 = 0.036$, or main effect of TBI, $F(1, 136) = 2.305$, $p = 0.131$, $\eta_p^2 = 0.017$. Similarly, at the 2-year assessment, there was no age by TBI interaction, $F(3, 113) = 0.891$, $p = 0.448$, $\eta_p^2 = 0.023$, or main effect of TBI, $F(1, 113) = 0.006$, $p = 0.938$, $\eta_p^2 = 0.000$.

Cognitive flexibility. For the TEA-Ch Creature Counting score at the 6-month assessment, the assumption of homogeneity of variance was strongly violated. Therefore, negative binomial regression was used. No interaction between age and TBI, $\chi^2(3) = 7.141$, $p = 0.068$, or main effect of TBI, $\chi^2(1) = 1.320$, $p = 0.251$, was found. At the 2-year assessment, TEA-Ch Creature Counting score was reverse log transformed. There was no age by TBI interaction, $F(3, 112) = 2.034$, $p = 0.113$, $\eta_p^2 = 0.052$, or main effect of TBI, $F(1, 112) = 1.203$, $p = 0.275$, $\eta_p^2 = 0.011$.

The timing score of the Creature Counting test measuring cognitive flexibility could not be computed for 18 children (12 TBI: 7 early childhood, 1 middle childhood, 4 late childhood; 6 TD: 4 early childhood, 2 middle childhood), at the 6-month assessment and for 2 children (1 TBI: late childhood; 1 TD: early childhood) at the 2-year assessment. Given that this significantly reduced the number of available scores for children in the early childhood group at 6-month assessment, this age group was left out of the analyses of this variable. Data were log-transformed to meet test-assumptions. No age group by TBI, $F(3, 86) = 0.598$, $p = 0.552$, $\eta_p^2 = 0.014$, or main effect of TBI, $F(1, 86) = 0.614$, $p = 0.436$, $\eta_p^2 = 0.007$, was found. At the 2-year assessment, again, there was no age by TBI interaction, $F(3, 94) = 0.322$, $p = 0.809$, $\eta_p^2 = 0.010$, or main effect of TBI, $F(1, 94) = 0.894$, $p = 0.347$, $\eta_p^2 = 0.009$.

Global EF performance score. No age by TBI interaction, $F(3, 135) = 0.822$, $p = 0.484$, $\eta_p^2 = 0.018$, or main effect of TBI, $F(1, 135) = 0.909$, $p = 0.342$, $\eta_p^2 = 0.007$, was found at the 6-month assessment. Data from the 2-year assessment was reversed square root transformed. There was a significant interaction between age and TBI, $F(3, 111) = 3.669$, $p = 0.014$, $\eta_p^2 = 0.090$. Simple effects analyses revealed trends towards an effect of TBI in the early childhood group, $F(1, 18) = 3.386$, $p = 0.082$, $\eta_p^2 = 0.158$, and in the adolescence group, $F(1, 19) = 3.777$, $p = 0.067$, $\eta_p^2 = 0.166$. No effect of TBI was found in the middle childhood group, $F(1, 25) = 1.454$, $p = 0.239$, $\eta_p^2 = 0.055$, and in the late childhood group, $F(1, 43) = 1.407$, $p = 0.242$, $\eta_p^2 = 0.032$.

Supplemental material 2. Parent-report on everyday EF

Inhibitory Control. Data from the 6-month assessment were analysed using negative binomial regression analysis due to violation of the assumption of homogeneity of variance. No interaction between age and TBI, χ^2 (3) = 0.065, p = 0.996, or main effect of TBI, χ^2 (1) = 0.030, p = 0.863, was found. Data from the 2-year assessment was transformed using a reciprocal transformation. No age by TBI, F(3, 108) = 0.802, p = 0.495, η_p^2 = 0.022, was found. There was a main effect of TBI, F(1, 108) = 4.778, p = 0.031, η_p^2 = 0.042, with the scores suggesting that children with TBI have higher scores on this scale, indicative of more problems, than TD children.

Working Memory. At the 6-month assessment, no age by TBI interaction was found, F(3, 128) = 1.660, p = 0.179, η_p^2 = 0.037. There was no main effect of TBI, F(1, 128) = 1.665, p = 0.199, η_p^2 = 0.013. Data from the 2-year assessment were transformed with a reciprocal transformation. No interaction between age and TBI, F(3, 107) = 1.011, p = 0.998, η_p^2 < 0.001, or main effect of TBI, F(1, 107) = 1.010, p = 0.317, η_p^2 = 0.009, was found.

Shifting/Flexibility. A reciprocal transformation was used to normalize the distribution of the Shift/Flexibility scale at both time points. At the 6-month assessment, no age by TBI interaction was found, F(3, 128) = 0.373, p = 0.772, η_p^2 = 0.009. There was no main effect of TBI, F(1, 128) = 0.783, p = 0.378, η_p^2 = 0.006. Similarly, there was no age by TBI interaction, F(3, 107) = 1.759, p = 0.159, η_p^2 = 0.047, or main effect of TBI, F(1, 107) = 1.999, p = 0.160, η_p^2 = 0.018, at the 2-year assessment.

Global Executive Component (GEC). The GEC scale was reciprocally transformed for the 6-month assessment. There was no age by TBI interaction, F(3, 125) = 0.871, p = 0.458, η_p^2 = 0.020, or a main effect of TBI, F(1, 125) = 0.014, p = 0.906, η_p^2 < 0.001. Due to violation of the assumption of homogeneity of variances, the data from the 2-year assessment were analysed using negative binomial regression. No interaction between age and TBI, χ^2 (3) = 0.088, p = 0.993, or main effect of TBI, χ^2 (1) = 0.022, p = 0.881, was found.

Supplemental material 3

Correlations between EF outcomes and SWI variables

			EF performance					Everyday EF (BRIEF)			
			Inhibitory control	Working memory	Cognitive flexibility (Creature Counting Correct)	Cognitive flexibility (Creature Counting Timing score)	Global EF score	Inhibitory control	Working memory	Shift/ flexibility	GEC
Early childhood	6-month assessment	Extent	-.024	.000	**-.343**	**-.346**	-.139	.102	**.366**	**.336**	.052
		Number	-.091	-.073	**-.399**	**-.346**	-.200	.078	**.372**	**.385**	.074
		Volume	.153	.256	**-.316**	**-.346**	.000	.057	.227	.117	.000
	2-year assessment	Extent	-.153	-.245	-.166	-.224	-.224	-.234	-.149	-.115	.000
		Number	-.250	-.228	-.194	-.104	-.243	-.218	-.104	.000	.036
		Volume	-.101	-.179	-.073	-.196	-.131	-.239	-.196	-.235	-.067
Middle childhood	6-month assessment	Extent	.112	.337	.010	.066	.213	.236	-.083	.026	.082
		Number	.125	**.376***	.000	-.058	.234	.215	-.083	-.012	.071
		Volume	.073	.277	.000	-.014	.182	.177	-.106	-.024	.070
	2-year assessment	Extent	-.235	.000	**-.332**	.042	-.331	.205	.068	.017	.138
		Number	-.195	-.051	**-.377**	-.039	**-.411***	.199	.088	-.008	.152
		Volume	-.161	.100	**-.345**	.023	-.266	.197	.071	.024	.198
Late childhood	6-month assessment	Extent	-.014	-.004	-.163	-.004	-.060	-.005	-.043	.174	-0.49
		Number	.025	-.064	-.143	-.035	-.052	.027	-.026	.178	-0.15
		Volume	.003	-.075	-.174	-.027	-.079	.013	-.043	.157	-0.38
	2-year assessment	Extent	-.095	.207	-.068	-.041	.092	-.020	.103	-0.23	.076
		Number	-.105	.179	-.070	-.047	.085	.026	.088	.007	.096
		Volume	-.119	.181	-.089	-.056	.081	.026	.071	.002	.063
Adolescence	6-month assessment	Extent	-.162	-.101	-.227	-.220	-.220	.417	**.537***	**.472***	**.540***
		Number	-.162	-.101	-.227	-.220	-.220	.417	**.537***	**.472***	**.540***
		Volume	-.176	-.067	-.202	-.264	-.171	.396	**.481***	**.515***	**.487***
	2-year assessment	Extent	-.145	-.332	.200	-.145	.177	.150	**.499**	.150	**.405**
		Number	-.145	-.332	.200	-.145	.177	.150	**.499**	.150	**.405**
		Volume	-.145	-.332	.200	-.145	.177	.150	**.499**	.150	**.405**

Note. Medium to large correlation coefficients are presented as bold text. * p < .05, BRIEF = Behavioral Rating Inventory of Executive Function, EF = executive function, GEC = General Executive Component.

5

Chapter 6

Searching for effective components of cognitive rehabilitation for children and adolescents with acquired brain injury: A systematic review

Resch, C., Rosema, S., Hurks, P., de Kloet, A., & van Heugten, C. (2018).
Brain Injury, 32(6), 679-692.

Abstract

Cognitive rehabilitation is of interest after paediatric acquired brain injury (ABI). The present systematic review examined studies investigating cognitive rehabilitation interventions for children with ABI, while focusing on identifying effective components. Components were categorized as (1) metacognition and/or strategy use, (2) (computerized) drill-based exercises, and (3) external aids. The databases PubMed (including MEDLINE), PsycInfo, and CINAHL were searched until June 22nd, 2017. Additionally, studies were identified through cross-referencing and by consulting experts in the field. Twenty articles describing 19 studies were included. Metacognition/strategy use trainings (five studies) mainly improved psychosocial functioning. Drill-based interventions (six studies) improved performance on tasks similar to training tasks. Interventions combining these two components (six studies) benefited cognitive and psychosocial functioning. External aids (two studies) improved everyday memory. No studies combined external aids with drill-based interventions or all three components. Available evidence suggests that multi-component rehabilitation, e.g. combining metacognition/strategy use and drill-based training is most promising, as it can lead to improvements in both cognitive and psychosocial functioning of children with ABI. Intervention setting and duration may play a role. Conclusions remain tentative due to small sample sizes of included studies heterogeneity regarding outcome measures, intervention and therapist variables, and patient characteristics.

Introduction

Acquired brain injury (ABI) is damage to the brain that occurred after birth, but is not related to congenital diseases or neurodegenerative disorders [1]. Aetiologies include traumatic brain injury (TBI), infections (e.g. encephalitis or meningitis), brain tumours, stroke, and hypoxia [2]. In the Netherlands, each year approximately 19 000 children and adolescents are diagnosed with ABI [3]. Incidence rates in other countries such as Australia and the United Kingdom seem to be even higher [4, 5]. Children and adolescents who are diagnosed with ABI frequently report post-injury (i.e. directly after injury as well as several months to years later) problems with cognitive functions, such as attention, memory, and executive functions [6-9]. In turn, these cognitive difficulties may negatively impact a patient's psychosocial functioning including social participation, family functioning, and quality of life [10-13]. Improving cognitive functioning after paediatric ABI is therefore believed to be essential for neurocognitive as well as psychosocial rehabilitation and recovery.

Over the last decade, multiple reviews have contributed to collecting and describing available effect studies into cognitive rehabilitation after paediatric ABI [2, 14-18]. Cognitive rehabilitation is defined as a systematic intervention directed at restoring impaired cognitive abilities or compensating for the impact of present difficulties [19]. The most recent review into this topic searched for articles published before May 2013 [17]. Since then, the literature in this rapidly evolving field of investigation, especially in training with computer games, has been growing, and an update of the literature is warranted. Therefore, the present review aimed to provide an up-to-date overview of studies into the effectiveness of cognitive rehabilitation for children with ABI.

In previous reviews it has been pointed out that there is a need for explicit identification of the active components in effective cognitive rehabilitation interventions [2, 15, 16, 18]. Categorizing cognitive rehabilitation interventions based on their different components might advance our knowledge on what intervention components are most effective in improving cognitive functioning of children and adolescents with ABI. Furthermore, it enables researchers and clinicians to compare different interventions and to select the most appropriate intervention for the cognitive problems at hand. In the present systematic review, we explicitly focus on intervention components when examining the available literature on intervention effectiveness in improving cognitive functions in children and adolescents with ABI. More specifically, we aimed to delineate the effects of different types of interventions to identify their effective components.

For the purpose of this review, three main intervention components are distinguished: 1) metacognition and/or strategy use, 2) (computerized) drill-based exercises, and 3) external aids. Metacognition training is directed at teaching participants to 'think about their thinking' and provides general instructions, for example "What is the best way to approach a (i.e. any) task?". Strategy use can be defined as instructions to approach a specific task, for example, “How can you best remember this list of words?”. Drill-based training is based on repeated practice of simple exercises, either on the computer or on paper, mostly targeting one particular cognitive function, such as working memory. Sometimes these exercises are placed in a game-like context, like adventurous journeys and treasure hunts. Lastly, external aids, such as diaries and pagers provide children and adolescents with ABI with external support (e.g. notes and reminders) to compensate for cognitive difficulties and to aid daily life functioning. The different intervention components are used either alone or combined, for example, an intervention may consist only of drill-based exercises or can be a combined drill-based practice with metacognitive training.

The present systematic review focused on interventions targeting cognitive functioning (e.g. attention, memory, and/or executive functions), either on the level of functions or on the level of activities. For example, memory on the level of functions can refer to the ability to remember certain stimuli in a memory task, while memory on the level of activities can mean the ability to remember important daily tasks. Furthermore, possible generalizable effects to other areas of functioning (e.g. social participation, family functioning and quality of life) were investigated. We included studies with a wide range of clinical trial designs (i.e. not only randomized controlled trials), since high quality non-randomized controlled studies have previously been found to produce similar treatment effect sizes as randomized controlled trials [20, 21]. Quality of all included studies and their risk of bias will be explicitly evaluated in the following sections.

Method

A systematic review was designed and reported in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement [22, 23]. No review protocol was published.

Eligibility criteria

Studies were included when they met the following criteria: (1) a non-pharmacological intervention directed at improving cognitive functioning (i.e. attention, executive functions, information processing, language, memory, and/or perception) was investigated.; (2) cognitive functioning was assessed on the level of functions (e.g. with cognitive tests) and/or on the level of activities (e.g. with questionnaires or interviews about daily life cognitive functioning); (3) participants were diagnosed with ABI (i.e. TBI, brain tumour, brain infections, stroke or hypoxia). If the study included patients with other diseases than ABI that affect the central nervous system (CNS) and/or cognitive functioning (e.g. acute lymphoblastic leukaemia), data for children and adolescents with ABI and data for children with other diseases had to be presented separately or at least 50% of the participants had to be diagnosed with ABI, to be included; (4) the sample consisted of children and adolescents (i.e. age < 19 years). If the sample also included adults, the study was only included if data for children and adolescents and data for adults were presented separately or at least 50% of the participants were children or adolescents; (5) results were statistically analysed whereby outcomes of the intervention group were compared either to outcomes of another intervention group or to pre-intervention functioning (i.e. no case studies or single-case designs); (6) the study was an empirical study; (7) the study was published in a peer-reviewed journal article.

Information sources

The search was conducted in PubMed including MEDLINE (1966 – present), PsycInfo (1967 – present), and CINAHL (1982 – present) electronic databases to identify studies published in English, Dutch, or German. The initial search was carried out on May 28th, 2015. For all three databases, the authors performing the search (CR and SR) created e-mail alerts to be kept up to date if a new article that met the search criteria was added to the database. Therefore, the current systematic review encompasses articles that were included in the above described databases before June 22nd, 2017. In addition to the database search, the reference lists of the included full-text articles and of relevant review articles and meta-analyses known to the authors were examined, and the expert network of the authors was consulted for articles relevant for the present review.

Search

Search terms were formulated according to three categories: acquired brain injury, intervention, and cognition. With the aim to investigate effectiveness of cognitive rehabilitation in a paediatric ABI population, terms within a category were combined with OR, while the three categories were combined with AND (i.e. brain injury OR head injury [...] AND intervention OR training [...] AND cognition OR cognitive [...]). For the search, all individual keywords were separately entered in the MeSH or Thesaurus databases to find the appropriate index terms used in the electronic databases. Supplemental material 1 displays the search terms as well as the full electronic search for the PubMed database including all MeSH terms. The searches were employed without date restriction. Results were limited to (controlled) clinical trials and empirical studies with a paediatric population.

Study selection

Two of the authors (CR and SR) independently reviewed the articles at each stage of the literature search (i.e. screening titles, screening abstracts, reading full-texts) to determine inclusion eligibility. In case of doubt, two other authors (PH and CH) were consulted.

Data collection process and data items

Data were extracted by one author (CR). The following information was collected whenever available: (1) study characteristics, i.e. authors and design; (2) patient characteristics, i.e. sample size, diagnosis, time post-injury, age, baseline level of cognitive functioning; (3) intervention characteristics, i.e. type of intervention, setting, duration and frequency; and (4) outcome measures, i.e. cognitive outcomes on the level of functions (i.e. with cognitive testing), cognitive outcomes on the level of activities (i.e. questionnaires or interviews about daily life cognitive functioning, goal setting regarding cognition), and other outcomes (e.g. psychosocial or academic).

Risk of bias within and across studies

Risk bias within the included studies was assessed by two authors (CR and SR) with the Quality Assessment Tool for Quantitative Studies (Effective Public Health Practice Project) [24]. This is one of the methods for risk bias assessment recommended by the Consolidated Standards of Reporting Trials (CONSORT) [25]. The method includes ratings of eight different domains (i.e. selection bias, study design, confounders, blinding, data collection methods, withdrawals and drop-outs, intervention integrity, and analyses) to judge the extent of the presence of bias. A study can be assessed as 'strong', 'moderate', or 'weak', where a 'strong' rating equals a low risk of bias. The tool is applicable to randomized trials as well as non-randomized studies and quasi-experimental designs. Furthermore, it has shown excellent inter-rater agreement for the final rating and fair agreement for individual domains [24] and was previously found to be one of the best quality assessment tools and useful in systematic reviews [26].

Risk of bias across studies was considered, but could not be addressed statistically, due to the large variation in study designs and outcome measures of the included studies. The authors of the present review considered it unlikely that there were many studies unpublished due to non-significant results since investigations into cognitive rehabilitation after paediatric ABI are still rare and the present review demonstrated that many of the published studies also showed non-significant effects.

Results

Study selection

Details concerning the study selection are illustrated in a flow diagram in Figure 1. A total of 1911 articles were identified during the first search of the electronic databases on May 28th, 2015. After duplicates were removed, titles of 1812 articles were screened. Based on the titles, 1668 articles were excluded. Reviewing abstracts of the remaining 144 articles left 67 full texts to be examined in more detail. Eleven examined full texts met all eligibility criteria.

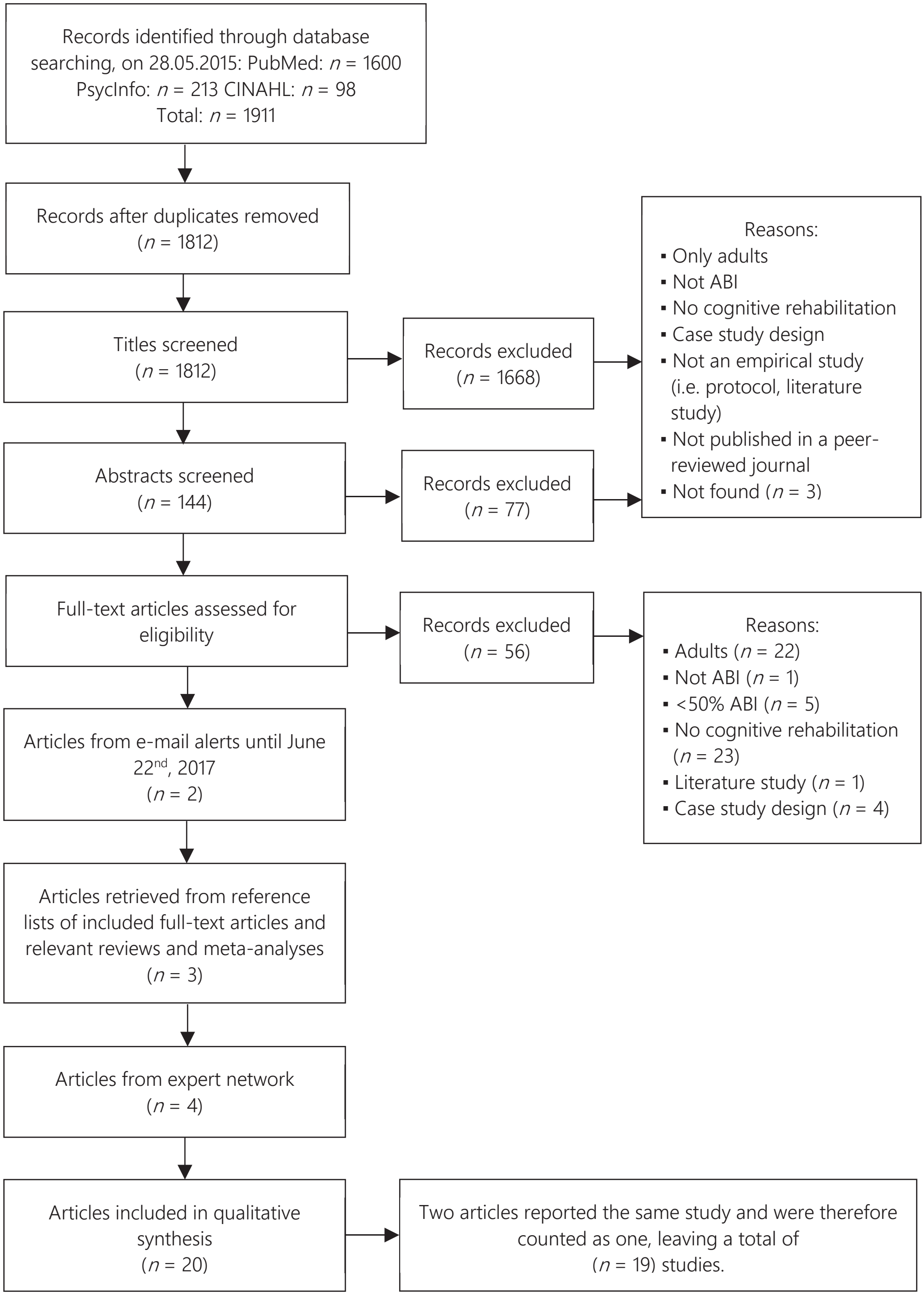

Figure 1. Flowchart for the literature search and the study selection. Adapted from "Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement", by D. Moher, A. Liberati, J. Tetzlaff, D.G. Altman, and The PRISMA Group [23]. Copyright by the Public Library of Science.

The authors specifically want to remark on the exclusion of studies into family-centred interventions (see for example [27-31]) and on a peer-supported metacognition intervention [32]. While these studies examine cognitive functioning as one of their primary outcome measures, the interventions themselves were mainly focused on finding the best intervention context (i.e. family-centred or clinician delivered) [27], or were directed at family problem-solving and communication [28-31] or cooperative learning and social mediation [32]. While these studies give a good indication that family and/or peer involvement can be beneficial for rehabilitation after paediatric ABI, it would not be clear whether an effect of the intervention was the result of the intervention itself or of the system involved. Therefore, the authors decided to exclude these studies from the present review.

E-mail alerts from the searched database until June 22nd, 2017 revealed two additional articles [33, 34]. An inquiry in the expert network of the authors yielded four more articles that met inclusion criteria [35-38]. Finally, another three articles [39-41] that met the eligibility criteria were found in reference lists of the previously included articles. In total, 20 articles were included. Two of these articles were combined in further description, since one of them [42] reported follow-up data from the study described in the other one [43], making a total of 19 included studies.

Risk of bias within studies

Five of the included 19 studies were randomized controlled trials, of which one was analysed as a pre-/post-test trial. Five of the other studies used a (non-randomized) control group, the other nine studies were uncontrolled trials. Results based on studies not designed as randomized controlled trials should be interpreted with caution: the absence of a control group makes it impossible to disentangle intervention effects from confounding due to time or retesting effects and regression to the mean. Furthermore, the absence of a thorough randomization procedure might lead to selection bias over the groups. Ratings of risk bias are displayed in Tables 1 to 4.

Syntheses of results

Below, we will describe the main findings for each of the intervention types and combination of types that we have encountered in the included studies (i.e. metacognition and/or strategy use, drill-based exercises, metacognition/strategy use combined with drill-based exercises, external aids, and metacognition/strategy use combined with external aids). No investigated intervention combined drill-based exercises with external aids, or made use of a combination of all three interventions components. An overview per study is presented in Tables 1 to 4. All results will be described while considering the great heterogeneity across studies in terms of age of participants, types and severity of brain injury, time post-injury, treatment setting, and intervention duration and frequency.

When synthesizing the results, it was noted that occasionally, the same outcome measure was categorized as measuring different aspects of cognitive and/or psychosocial functioning by different authors. For example, the Digit Span task consists of two parts: recalling a string of digits in the same order as presented (Digit Span Forward) and recalling these digits in the reversed order (Digit Span Backward). Moreover, these two task parts are often grouped together in a Digit Span Total Score or a larger composite score. This Digit Span Total Score [44, 45] and/or composite scores including this test were used as a measure of working memory by some studies [34, 35, 46], while others used them as indicators for attention [41, 47] or memory [41-43]. To be consistent in reporting the results for different outcome domains, the outcome measures used in the original articles were occasionally re-grouped. For example, in line with the assumption that the Digit Span Backward measures working memory and not solely attention or memory [48], the score on this test or any composite score including this test was categorized as a measure of working memory.

Metacognition and/or strategy use. Six cognitive rehabilitation interventions, examined in five different studies, were based on metacognition and/or strategy use. One study was a randomized controlled trial and one was a controlled clinical trial, both using an active control group. The other three studies were quasi-experimental pre-/post-test designs, of which one [40] used a passive control group (i.e. a control group that received no alternative treatment). Samples ranged from n = 6 to n = 32, including patients with mild to severe TBI, brain tumours, and other forms of cancer not located in but still affecting the brain. Interventions were provided in a 1:1 patient-therapist setting, except for one small-group (i.e. five to six children per two therapists) metacognition training. Intervention duration ranged from 6 to 42 hours over 7 weeks to 10 months.

Metacognition and/or strategy use seemed especially powerful in improving areas of functioning other than cognition. Three of five studies investigated this and found improvements in social behaviour and adaptive communication behaviour. Neither cognitive functioning on the level of functions nor cognitive functioning on the level of activities were found to change consistently, although it seems that the intervention that took place in small groups and lasted 42 hours (stretched over 7 weeks) yielded more positive changes in these areas than shorter 1:1 interventions in these areas. Since only one, although high quality, study investigated this long (in terms of duration) group-based intervention, it is not clear whether the duration, the setting or the intervention itself (i.e. problem-solving training based on metacognition), underlie the positive effects. Only one study investigated long-term (i.e. 4-month) effectiveness of the intervention in 6 children with TBI and found sustained improvements in functional task performance and in performance satisfaction.

Table 1. Overview of studies into interventions based on metacognition/strategy use

Study characteristics		Patient characteristics	Intervention characteristics		Main findings [2]
Authors, quality	Design and measures		Intervention	Setting, duration and frequency [1]	I: Cognition on level of functions II: Cognition on level of activities III: Psychosocial and academic outcomes
Chan & Fong, 2011 [49] Strong	Quasi-experimental, matched pairs controlled pre-/post-test design. Pre - Post	*n*=32 (E:16, C:16) *Injury:* 21 moderate to severe TBI, 6 BT, 5 AVM, > 3y post-injury *Age:* 7–16y ▪ Objectified problem-solving difficulties.	Problem-solving skills training with metacognitive principles; pen and paper exercises, group games and discussions, role play, self-evaluation. *Control intervention:* Attending school.	5–6 children, 2 therapists. Parents receive strategy instruction. *Duration/frequency:* *Scheduled:* 7w, 2 sessions/w, 3h/session	I: + Metacognition, intellectual functioning and social problem-solving. II: + Parent-reported executive functioning III: + Child- and parent-reported goal-directed functional behaviour
Cook et al., 2014 [35] Moderate	Single-blind (pseudo)randomized controlled pilot design. Pre - Post	*n*=20 (E1:10, E2:10) *Injury:* Mild to severe TBI, 0.6–13.1y post-injury *Age:*12–20y ▪ Objectified gist reasoning difficulties.	E1 = SMART: top-down gist reasoning training, strategy-based pen and paper tasks and individual exercises with personal examples. E2 = Fact-based memory training: Bottom-up training with pen and paper tasks and school work tasks.	1:1 with speech-language clinician at home, at the school library or at the community centre. *Duration/frequency:* *Scheduled:* 1m, 8 sessions, 45min/session	I: = intellectual functioning; + only SMART group: abstracting meaning from complex information (some parameters), verbal working memory, inhibition II: + only fact-based memory training group: parent-reported everyday executive functioning III: NA
Light et al., 1987 [40] Weak	Quasi-experimental controlled pre-/post-test design Pre - Post	*n*= 21(E:15, C:6) *Injury:* TBI, ±2.5-3.5y post-injury' *Age:*4–10y .	NEP: Program for attention, memory, behavioural/self-control and problem solving. Pen and paper exercises, cognitive strategies, and counselling for problems at home. *Control group:* Passive.	*Setting:* 1:1 tutoring at school and at home by volunteer *Duration/frequency:* *Scheduled:* 6m, 2 sessions/w at school + 1 session/w at home *Actual:* 3–7m (M: 21w), 19–68 hours (M: 39.7, SD 14.2)	I: = intellectual functioning, spatial memory, picture memory, attention, receptive and expressive vocabulary, verbal fluency, visual motor integration II: NA III: + adaptive behaviour in area of communication; = Academic achievement tests, parent reports of child behaviour, daily living skills, socialization, maladaptive behaviour

Table 1. *Continued*

Study characteristics		Patient characteristics	Intervention characteristics		Main findings [2]
Authors, quality	Design and measures		Intervention	Setting, duration and frequency [1]	I: Cognition on level of functions II: Cognition on level of activities III: Psychosocial and academic outcomes
Missiuna et al., 2011 [50] Weak	Quasi-experimental pre-/post-test design Pre - Post - 4m	*n*=6 *Injury:* mild to moderate TBI, 6–19m post-injury *Age:* 6–15y ▪ Unable to fully participate in all school settings.	CO-OP: problem-solving training based on the Goal-Plan-Do-Check strategy, linked to daily life situations.	*Setting:* 1:1 with occupational therapist. *Duration/frequency:* *Scheduled:* 10w, 1session/w, 1h/session	I: NA II: + individually selected functional task performance, performance satisfaction III: + adaptive behaviour in communication, daily living skills, social skills (All improvements maintained to 4m follow-up)
Patel et al., 2009 [47] Moderate	Quasi-experimental pre-/post-test design Pre - Post	*n*=12 *Injury:* 9 BT, 2 Leukaemia, 1 CNS Histiocytosis, 2–12y, post-injury; *Age:* 7–19y ▪ Objectified attention and memory problems.	Five-components: 1) problem-solving, 2) study skills and metacognition, 3) information processing strategies, 4) compensatory techniques for academic performance, 5) collaborate with parent to reinforce strategy use at home.	*Setting:* 1:1 with therapist. *Duration/frequency:* *Scheduled:*3m, 15 w, 1 session/w, 60–90min/session *Actual:* 6m, 7–15 sessions	I: + quality of writing; = attention, verbal working memory, verbal learning skills, writing comprehension II: = attention behaviour III: + social behaviour with respect to cooperation, assertion, empathy and self-control; = externalizing and internalizing behaviours

Note. [1] Whenever possible, scheduled as well as actual training duration and frequency are displayed. [2] +: improvement, = : no change, –: deterioration, NA: 'not assessed'. *Abbreviations:* E = experimental group, C = control group, y = year(s), m = month(s), w = week(s), h = hour(s), min = minutes, M = mean, SD = standard deviation. *Abbreviations injury:* AVM = Arteriovenous malformation, BT = brain tumour, CNS = central nervous system, TBI = traumatic brain injury. *Abbreviations interventions:* CO-OP = Cognitive Orientation to Daily Occupational Performance, NEP = Neuro-Cognitive Education Project, SMART = Strategic Memory Advanced Reasoning Training.

Table 2. Overview of studies into interventions based on (computerized) drill-based exercises

Study characteristics		Patient characteristics	Intervention characteristics		Main findings [2]
Authors, quality	Design and measures		Intervention	Setting, duration and frequency [1]	I: Cognition on level of functions II: Cognition on level of activities III: Psychosocial and academic outcomes
de Kloet et al., 2012, [51] Moderate	Multicentre quasi-experimental pre-/post-test design Pre - Post	*n*=50 *Injury:* 27 TBI, 23 nTBI, 0–2y post-injury *Age:* 6–29y	Nintendo Wii ™: a selection of computerized games directed at information processing, fine and gross motor skills, communication, self-confidence, social participation and/or daily physical activity.	*Setting:* At home training, two initial 1h training sessions with a clinician at participating centre. *Duration/frequency: Scheduled:*12w, 2days/w, 20min/day	I: + alertness, attentional flexibility, visuospatial working memory, motor tracking improved (all on some parameters) II: NA III: + time spent on physical activities, goal achievement rating, parent-reported quality of life regarding school, participation in terms of recreational diversity and physical frequency
Eve et al., 2016 [34] Moderate	Quasi-experimental pre-/post-test design Pre - Post - 12m	*n*=7 *Injury:* Arterial ischemic stroke, 4-10y post-injury *Age:* 10-16y ▪ Average to below-average working memory skills.	Cogmed™: computerized tasks targeting verbal and visuospatial working memory.	*Setting:* Individual home training, parental supervision. Weekly phone calls with coach to promote training adherence and motivation. Reward after post-test. *Duration/frequency: Scheduled.actual:* 5-7w, 25 sessions, 5 sessions/w, 30-40min/session	I: + verbal working memory (not maintained to follow-up); = visual-spatial working memory, attention, inhibition II: NA III: = academic performance.
Hardy et al., 2011 [46] Moderate	Quasi-experimental pre-/post-test pilot design Pre - Post - 3m	*n*=9 *Injury:* 6 BT, 3 ALL, 1–10y post-treatment *Age:* 10–17y ▪ Objectified attention and/or working memory deficits.	Captain's Log: computer training consisting of game-like exercises for attention, memory, listening skills, processing speed and self-control.	*Setting:* Home-based training, weekly phone calls to address problems. Earn gift cards in week 4, 8 and 12 to enhance compliance. *Duration/frequency: Scheduled:* 12w, ≥50min/w *Actual:* 9-53 sessions (M: 28.4), 3.7-20.8h (M: 11.4).	I: + three of the five verbal working memory indices (two of which remained improved at a three- month follow-up) II: + parent reported attention between pre-test and follow-up (but not between pre-test and post-test) III: NA.

Table 2. *Continued*

Study characteristics		Patient characteristics	Intervention characteristics		Main findings [2] I: Cognition on level of functions II: Cognition on level of activities III: Psychosocial and academic outcomes
Authors, quality	Design and measures		Intervention	Setting, duration and frequency [1]	
Kaldoja et al., 2015 [36] Weak	Quasi-experimental pre-/post-test design Pre – Post - 1.63y	*n*=8 *Injury:* 5 mild TBI, 3 Partial Epilepsy, ± 3.79y post-injury *Age:* 9-12y ▪ Mild to moderate attention impairment.	FORAMEN Rehab®: Cognitive rehabilitation software training focused, sustained, and complex, and tracking.	*Setting:* 1:1 sessions with therapist at outpatient children's clinic. *Duration/frequency:* *Scheduled:* 6w, 2 sessions/w, 30-50min/session	I: + performance on some of the FORAMENRehab program tasks (some maintained to follow-up) II: NA III: NA
Phillips et al., 2016 [37] Moderate	Randomized controlled design Pre - Post - 3m	*n*=23 (E: 10, C: 13) *Injury:* moderate to severe TBI, >12m post-inury *Age:* 8–15y	Cogmed™: see Eve et al., 2016 *Control intervention*: non-adaptive Cogmed training (i.e. working memory span was continuously kept at a level of 3).	*Setting:* See Eve et al., 2016 *Additions:* Reminder e-mails. Reward for participants after every 5 sessions. *Duration/frequency:* *Scheduled:*5w, 5 sessions/w, 30- 40min/session *Actual:* Training days/w M: 4.49 SD: 0.93. Total time training: M 10.23-14.76h.	I: + visual-spatial working memory (maintained to follow-up); = verbal working memory, attention, inhibition II: NA III: + reading comprehension at post-test, reading accuracy at follow-up; = mathematics
Thomas-Stonell et al., 1994 [52] Weak	Randomized controlled double pre-test design Pre 1 - Pre 2 (4w) - Post	*n*=12 (E: 6, C: 6) *Injury:* TBI, 3m-47 post-injury *Age:* 12–21y ▪ Deficits in cognitive-communication based on assessment.	Computer-based TEACHware™ directed at word retrieval, attention, understanding abstract language, organization, and problem solving. *Control interventions:* School programs (*n*=3), traditional rehabilitation (*n*=3).	1:1 with speech-language pathologist, teacher, or occupational therapist; clinician helps transfer learned skills to daily life. *Duration/frequency:* *Scheduled:* 8w, individualized nr of 1-h-sessions/w (M: 2).	I: + verbal memory, word retrieval, comprehension and problem-solving in language tasks (on some parameters), composite scores of language tests; = organization in language tasks

Note. [1] Whenever possible, scheduled as well as actual training duration and frequency are displayed. [2] +: improvement, = : no change, –: deterioration, NA: 'not assessed'. *Abbreviations*. E = experimental group, C = control group, y = year(s), w = week(s), h = hour(s), min = minutes, M = mean, SD = standard deviation, Md = median. *Abbreviations injury*. ALL = acute lymphoblastic leukaemia, BT = brain tumour, TBI = traumatic brain injury, nTBI = non-TBI.

6

Drill-based exercises. Six studies investigated five different cognitive rehabilitation interventions that consisted of drill-based exercises. All interventions were computerized trainings. Participants were groups of n = 7 to n = 50 patients with TBI, brain tumours, stroke or a not further specified form of non-TBI ABI. Two studies were randomized controlled trials with active control groups. Four of the interventions were home-based and could be used by the child without supervision. The other two were provided in a 1:1 setting. Intervention duration ranged from approximately 6 hours to approximately 24 hours of training overall (i.e. 50 minutes to 3.5 hours per week) over a period of 5 weeks to 3 months.

Improvements after (computerized) drill-based exercises are mostly seen to the extent that performance improved on the trained tasks or on cognitive tasks similar to the trained tasks in the intervention. In children and adolescents with TBI, the improvement(s) seemed to generalize to enhanced reading abilities in one study with 23 children aged eight to 15 and to parent-rated attention on the long term in another with 12 children aged 12 to 21. However, these findings require further research since they were only investigated in one study each.

Metacognition/strategy use combined with drill-based exercises. Four interventions combining metacognition and/or strategy use with drill-based exercises were investigated in six different studies with sample sizes ranging from 7 to 65. One was a randomized controlled trial using an active control group; the others were quasi-experimental designs, two of which used a passive control group. Children and adolescents participating in these studies were diagnosed with TBI or various other forms of ABI (i.e. infection, hypoxia, anoxia, birth trauma, brain tumour or stroke) and were 10 months to 16 years post-injury. The interventions were mostly provided in a 1:1 setting, with a therapist and/or parent practicing with the child. The duration of the interventions ranged from 10 weeks to 6 months with two to seven sessions per week.

Summarizing the results of the six studies, the combination of drill-based exercises with metacognition and/or strategy use training seemed to be effective in enhancing cognitive functioning on the level of functions when examining selective and sustained attention, memory, working memory and inhibition. This was found in all studies except for one investigating a 10-week attention intervention in 24 children with TBI aged nine to 15. Also, on the level of activities, cognitive functioning improved across multiple studies based on increased parent- or trainer-reported executive functioning and individual goal achievement. Results regarding changes in adaptive behaviour were inconsistent across studies: of the three studies investigating this, two found improvements after the intervention: in one study, this improvement was seen 18 weeks after baseline, in the other study, improvement was found 1 year after baseline, both investigating only children with TBI. The third study that investigated adaptive behaviour but found no results was a small study of 10 children with various types of ABI (mainly TBI), investigating an 18-week attention and memory intervention.

External aids. The use of the external aid NeuroPage as a reminder tool was investigated in one study and was found to be beneficial for everyday memory functioning up to 7 weeks after the intervention in a group of 12 children and adolescents with various forms of ABI. However, the quality of this one study was assessed as weak and results should therefore be interpreted with caution.

Metacognition/strategy use combined with external aids. Combining external aids (i.e. diaries) with metacognition/strategy use (i.e. self-instruction training) to target memory functioning of 15 children aged 11 to 17 with TBI seemed to decrease daily memory problems for a short period of time. Cognitive functioning on the level of functions and behavioural functioning improved slightly. The one study that investigated this combination of intervention components was of weak quality.

Discussion

The aim of this systematic review was to provide an up-to-date overview of cognitive rehabilitation for children and adolescents with ABI and to compare the effectiveness of different components (i.e. metacognition, drill-based practice, and external aids). Our search yielded 20 articles discussing 19 studies which in total investigated 17 different cognitive rehabilitation interventions. Seven relevant new studies [33-38, 50] were found which, to the authors' knowledge, have never been included before in reviews on cognitive rehabilitation for children and adolescents with ABI and therefore add important new knowledge to the limited evidence-base presented in previous reviews.

Summary of evidence

Findings of the current review indicate that the types of components making up a cognitive rehabilitation intervention may play a crucial role in the effectiveness of the intervention. It is important to note that all conclusions of the present review are based on still a limited number of studies that were heterogeneous in multiple important aspects other than intervention components, such as intervention durations settings, but also patient and injury characteristics of the samples included. In the following section, we discuss the evidence for the effectiveness of different intervention types in children with ABI. Furthermore, we consider what effective interventions have in common beyond their components, focussing on intervention variables, such as setting, therapist-involvement, and duration and frequency. Future directions are discussed.

Table 3. Overview of studies into interventions combining metacognition/strategy use and (computerized) drill-based exercises

Study characteristics		Patient characteristics	Intervention characteristics		Main findings [2] I: Cognition on level of functions II: Cognition on level of activities III: Psychosocial and academic outcomes
Authors, quality	Design and measures		Intervention	Setting, duration and frequency [1]	
Brett & Laatsch, 1998 [39] Moderate	Quasi-experimental pre-/post- test design Pre - Post	*n*=10 *Injury:*: 9 TBI, 1 Infection, 1–16y post-injury *Age:* 14.4–18.7y	Computerized exercises and interactive tasks with metacognition targeting 1) alertness, attention, concentration, 2) perception and memory, 3) problem-solving.	*Setting:* 1:1 or 1:2 treatment from specialized teacher (*n*=6) or group treatment (*n*=4). *Duration/frequency:* *Scheduled:* 20w, 2 sessions/w, 40min/session *Actual:* 18-42 sessions (md: 33.5)	I: + memory; = intellectual functioning, problem-solving abilities II: NA III: = self-esteem
Catroppa et al., 2015 [33] Moderate	Quasi-experimental pre-/post-test design *Measures:* Pre - Post - 6m	*n*=10 *Injury:* 8 TBI, 1 Hypoxia, 1 Birth trauma, 1.6–12.7y post-injury *Age:* 8.4–13.6y, ▪ Objectified attention and/or memory problems.	AMAT-C: Drill-based exercises and attention and memory techniques.	*Setting:* 30 minutes per day homework with parent, 1 hour per week with therapist in clinic *Duration/frequency:* *Scheduled:* 18 w, 30min/d, 6d/w+ 1h/w *Actual:* Homework complete 62-100% (M: 92)	I: + visual memory (up to 6-months follow-up); = attention, verbal memory II: = parent-reported executive functioning III: = (adaptive) behaviour
Galbiati et al, 2009 [53] Weak	Quasi-experimental controlled pre-/post-test design Pre - 1y	*N*=65 (E:40, C:25) *Injury:* Severe TBI, ±6–10m post-injury *Age:* 6–18y ▪ Objectified attention deficits.	Computer training and table-top tasks targeting attention (i.e. selective, focused, sustained, divided, inhibition, shifting) and metacognition. *Control intervention:* Passive	*Setting:* 1:1 with therapist at the institute. *Duration/frequency:* *Scheduled:* 6m, 4 sessions/w, 45min/session. Per session 30min computer, 15min table-top.	I: + selective and sustained attention, impulsiveness; = intellectual functioning II: NA III: + adaptive behaviour in the areas of communication, daily living skills and social skills

Table 3. *Continued*

Study characteristics		Patient characteristics	Intervention characteristics		Main findings [2] I: Cognition on level of functions II: Cognition on level of activities III: Psychosocial and academic outcomes
Authors, quality	Design and measures		Intervention	Setting, duration and frequency [1]	
Sjö et al., 2009 [41] Moderate	Quasi-experimental pre-/post-test pilot design Pre - Post	*N*=7 *Injury:* 3 TBI, 2 BT, 2 Stroke, 10m–8y post-injury *Age:* 11.3–15.8y ▪ Attention and/or memory problems.	AMAT-C (see Catroppa et al., 2015) integrated in school.	*Setting:* 1:1 with child's regular teacher. *Duration/frequency:* *Scheduled:*18–20w, 5 sessions/w, 30-45min/session *Actual:* 18–20w over 6–9m	I: + verbal and visual memory, cognitive flexibility (some parameters); = working memory, selective/sustained/divided attention, process speed, strategy use II: + trainer-reported emotional control, – parent-reported initiation, planning/organizing III: NA
Treble-Barna et al., 2015 [38] Weak	Quasi-experimental matched controlled pre-/post-test design Pre - Post (18w after pre)	*N*=24 (E:13, C:11) *Injury:* mild complicated to severe TBI, 1.1–9.1y post-injury *Age:* 9–15y ▪ Reported attention deficits based on parent rating scale.	AIM: Computerized exercises for attention combined with metacognitive strategies. *Control intervention:* Healthy controls, no intervention.	*Setting:* 1:1 meetings with clinician, home practice. Rewards for completing home training sessions. *Duration/frequency:* *Scheduled:* 10w, 1 therapist session/w (60-90min) + 2-4 home sessions/w (20-40min). *Actual:* 10-13 therapist sessions, 8-44 home sess.	I: + sustained attention (some parameters); = selective attention, inhibition, cognitive flexibility, planning II: + parent-reported executive functioning; = child-reported executive functioning III: + goal attainment
Van 't Hooft et al., 2005 /2007 [42, 43] Strong	Randomized controlled design Pre - Post - 6m	*n*=38 (E:18, C:20) *Injury:* 21 mild to severe TBI, 14 BT , 2 Infection, 1 Anoxia, 1–5y post-injury *Age:* 9–16y ▪ Objectified attention and/or memory problems.	AMAT-C (see Catroppa et al., 2015). Modifications: shorter (17w), individualized difficulty, rewards, program overview for children *Control intervention:* Chosen interactive activity with coach.	*Setting:* 1:1 with parent or teacher as coach at home or at school, 1 meeting per week with clinician, child and coach at hospital for feedback. *Duration/frequency:* *Scheduled:* 17w, 6 sessions/w, 30min/session.	I: + visual memory, verbal memory, everyday memory, cognitive flexibility, processing speed (all maintained up to follow-up); + sustained and selective attention (some parameters); + verbal working memory, (not up to follow-up); full scale IQ and verbal inhibition (from pre-test to follow-up) II/III: NA

Note. [1] Whenever possible, scheduled as well as actual training duration and frequency are displayed. [2] +: improvement, = : no change, –: deterioration, NA: 'not assessed'. *Abbreviations*: E = experimental group, C = control group, y = year(s), m = month(s), w = week(s), h = hour(s), min = minutes, M = mean, SD = standard deviation. *Abbreviations injury:* ABI = acquired brain injury, BT = brain tumour, TBI = traumatic brain injury. *Abbreviations interventions:* AIM = Attention Improvement and Management, AMAT-C = Amsterdam Memory and Attention Training for Children.

Table 4. Overview of studies into interventions based on external aids, and the combination of external aids and metacognition/strategy use

Study characteristics		Patient characteristics	Intervention characteristics		Main findings [2]
Authors, quality	Design and measures		Intervention	Setting, duration and frequency [1]	I: Cognition on level of functions II: Cognition on level of activities III: Psychosocial and academic outcomes
Ho et al., 2011 [54] Weak	Quasi-experimental pre-/post-test design Pre - Post - 3m	*n*=15 *Injury:* mild to severe TBI, 1.42–12.25y post-injury *Age:* 11–17.42y ▪ Difficulties in everyday memory.	Self-instruction training combined with diary training and case examples.	*Setting:* 1:1, 1:2 or 1:3 sessions with instructor, homework assignments regarding diary use and application of skills in daily life. *Duration/frequency:* *Scheduled:* 6w, 1 session/ w, 1.5h/session + regular use of diary + use learned strategies in daily life.	I: + cognitive flexibility accuracy, selective attention speed; = verbal memory, sustained attention, sustained divided attention, cognitive flexibility speed, selective attention accuracy II: + parent- and child-reported everyday memory difficulties (not persistent to follow-up), III: + child-reported internalizing behaviour; = parent-reported internalizing behaviour, parent- and child-reported externalizing behaviour
Wilson et al., 2009 [55] Weak	Randomized controlled cross-over design – only within-subjects analyses *Measures:* Pre-Post-5-7w	*n*=12 (E: 4, C: 8) *Injury:* 5 TBI, 1 Anoxia, 4 Develop-mental problems, 1 Cerebral palsy, 1 Birth injury, 2–3y post TBI, 15y post birth injury/anoxia *Age:* 8–17y ▪ Reported memory and/or planning difficulties.	NeuroPage: reminder messages for individual target behaviours. Diaries were kept regarding (completion of) target behaviours. *Control intervention:* Keeping diaries regarding target behaviours for measurement purposes	*Setting:* Daily life, no therapist contact. Determining target behaviours together with a relative and a researcher at baseline. *Duration/frequency:* *Scheduled:* 7w with pager, individual number of reminders/day (M: 5-23), completing diaries in w6–7 *Actual:* As scheduled	I: NA II: + number of achieved targets (e.g. doing homework) (maintained up to a 5- to 7-week follow-up) III: NA

Note. [1] Whenever possible, scheduled as well as actual training duration and frequency are displayed. [2] +: improvement, = : no change, –: deterioration, NA: 'not assessed'. *Abbreviations general*: E = experimental group, C = control group, y = year(s), w = week(s), h = hour(s), M = mean, SD = standard deviation. *Abbreviations injury*: TBI = traumatic brain injury.

Metacognition/strategy use and the influence of intervention settings. Interventions based on metacognition and/or strategy use seem to have benefits for adaptive behaviour, but less so for cognitive functions, such as memory and executive functions. This is in accordance with previous suggestions that metacognitive skills are essential for promoting behavioural and social functioning of children with ABI [56]. While the studies investigating this type of intervention varied greatly regarding study designs and participant characteristics, five of six studies included individual patient-therapist contact. Interestingly, the one intervention that took place in groups yielded even more positive changes (i.e. on more outcome measures) than the individual interventions. Note that in the present review, this effect might be confounded since the group intervention was also the most intensive, providing multiple 3-hour long sessions over a relatively short period of time. Influence of intervention duration and frequency will be discussed below.

The scarcity of studies into group-treatments included in the present review made it impossible to directly compare their effects to that of 1:1 interventions. However, previous studies have shown that group interventions might provide patients with age-appropriate social experience as well as a relief from social isolation, thereby enhancing the effectiveness of and motivation for the intervention. For example, metacognitive training focused on cooperative learning and social mediation for adolescents with ABI was found to be more effective when provided in a peer-supported context than in a family-based context [32]. This is also in line with studies in other populations, indicating for example that a group intervention for adolescents with epilepsy has a positive influence on psychosocial functioning [57, 58]. For children with ABI, more improvement in cognitive and motor outcomes can be achieved when they receive the intervention in the family context, supported by their parents, than when the intervention was provided directly by a therapist [27]. Future studies should investigate further whether family-centred or peer-supported interventions are also feasible in cognitive rehabilitation after paediatric ABI, and whether they have additional benefits compared to 1:1 interventions.

Drill-based/computerized interventions and the effect of intervention duration. Interventions using (computerized) drill-based exercises seem to improve cognitive functions on the level of functions (e.g. verbal working memory in three of the studies, visual spatial working memory in two of the studies and attentional abilities in two of the studies) of children and adolescents with ABI, but only when outcome measures are similar to the training tasks. Improvements in other areas of functioning, such as executive function behaviour or adaptive behaviour, did not consistently occur. These findings are in line with previous studies in other populations such as children with ADHD and typically developing children [59] and adults with ABI [60], where training of specific functions did not transfer to other function and/or skills. Moreover, in the broader field of cognitive rehabilitation, it has previously been suggested that, to achieve wide-ranging effects with an intervention, mere repetitive practice is insufficient and complementary treatments should be employed [61, 62].

In the present review, interventions that were based on (computerized) drill-based exercises did not seem to lead to wide-ranging results, but were also the interventions that took place over a relatively short period of time (i.e. 5 weeks to 3 months) with a moderate total training time (i.e. a mean of approximately 11 training hours). In contrast, other interventions such as metacognition training and combinations of metacognition and drill-based exercises seem to take longer in general (7 weeks to 10 months and 10 weeks to 6 months respectively) and seem to have a higher total intervention time. The optimal duration, frequency and total intervention time for any of the intervention types is still unknown: to our knowledge, there is for example no direct comparison between long and short interventions with low or high session frequency. It has previously been suggested that more intensive trainings (i.e. incorporating a large amount of intervention time) will lead to better results in children with ABI [18]. In the current review, that suggestion could not be objectively confirmed, because again, heterogeneity in other domains such as patient and injury characteristics made this difficult to investigate. In any regard, these intervention characteristics are important since they may influence selection of a treatment for children with ABI. More specifically, since the effectiveness of cognitive rehabilitation is still not completely clear, treatment choice may be based on costs and time investment (of therapists, but also patients and other persons involved) and thereby indirectly on session duration and frequency.

Metacognition/strategy use combined with drill-based training and target patients. In contrast to the single-component interventions discussed above, multi-component interventions combining metacognition/strategy use training with drill-based training may lead to improvements in a broad range of cognitive functions and psychosocial areas. The results regarding the effectiveness of this combination of interventions are in line with previous literature on the effectiveness of cognitive rehabilitation in other populations. For example, authors of a large scale review of adult cognitive rehabilitation recommended to combine drill-based attention training with metacognitive training to enhance attention as well as generalization to daily functioning in adults with ABI [61]. Similarly, another systematic review indicated that Goal Management Training, a form of metacognitive intervention, in adults with ABI is most efficient when embedded in larger, more holistic programs [63]

In children with ADHD, a multi-component memory intervention combining memory strategies with memory exercises was found to lead to improvements in memory, attention, and working memory but also parent-rated ADHD behaviour [64]. For children and adolescents with ABI, the effects on daily functioning still need to be determined in future research. A recently proposed model specific to the development of intervention for children with ABI also highlights the potential of multi-component interventions, especially if they are sequentially introduced in the intervention, from lower-level process/drill-based training to higher-level strategy training [65]. This model also emphasizes the importance of developmental stage a patient is in. For example, metacognitive trainings may not always be appropriate for young children, since they may not have developed sufficient self-awareness yet to successfully implement the strategies [66]. Certain interventions may thus be less effective for children compared to adolescent. This is also highlighted in reviews concerning cognitive interventions for other paediatric patient groups, for example children with ADHD [67]. Next to age, many other patient characteristics might influence intervention effectiveness. For example: are interventions more effective for children and adolescents with ABI who have greater impairments in baseline cognitive functioning? Does injury severity or type of injury play a role? The diversity in study designs, samples and outcome measures of the included studies made it, again, impossible to address these questions in the current review. Of importance for all types of cognitive rehabilitation are also family and environmental factors, such as socio-economic status and family functioning, which have been shown to significantly influence (long-term) outcomes after ABI [28, 68]. Of the studies included in the present review, only two reported on these factors, making it impossible to further examine their influence on intervention effectiveness across studies. Therefore, further research is required to determine what interventions are optimal for which patients, focusing on type, severity and time post injury as well as age of the patients and family environmental factors.

External aids with and without metacognition/strategy use. External aids seemed mainly useful when the treatment goal is to improve specific daily life cognitive functions, such as everyday memory [55]. External aids in combination with metacognition/strategy use have additional positive effects on some cognitive functions and limited areas of psychosocial functioning [54], again supporting the use of multi-component interventions. Given that only two studies investigated external aids either alone or in a multi-component intervention, results remain preliminary.

Limitations of the included studies

Many of the available studies have limitations that can affect study results. For one, studies often do not include a control group and randomized controlled trials are rare. Basing conclusions about intervention effectiveness on differences between pre-test and post-test performance without comparison to a control group is prone to biasing influences, such as natural changes in performance over time. Secondly, sample sizes of the included studies are mostly small, potentially leaving them underpowered to detect all but large or very large effects. Thirdly, there is a great variety in outcome measures in the available studies, making a meaningful comparison of results across studies difficult. To make studies more comparable in this regard, a set of common outcome measures should be used, for example recommended by the inter-agency Pediatric TBI Outcomes Workgroup [69].

Most studies included in the present review were rated to be of moderate quality. However, when assessing study quality, the authors of the present review noted that multiple studies failed to report important information, for example the number of patients approached versus the number of included participants. When this information was not described, the score given for this item was ‘moderate’, based on the criteria of the quality rating tool [24]. Study quality might therefore be under- or over-estimated, due to the lack of information provided in some of the studies. The authors of the present review are aware that performing high-quality randomized controlled trials in children with ABI has many challenges, one of which being the necessity to include large samples of participants, due to their heterogeneity with respect to a the great number of factors that could influence intervention effectiveness. Researchers could therefore consider other study designs, such as high-quality single-case experimental designs (SCED) [70-72]. Considering SCEDs in the preliminary phase of evidence, as is currently the case with cognitive rehabilitation after paediatric ABI, can help develop randomized controlled trials for promising interventions and even provide some evidence themselves [70-72]. Furthermore, SCEDs may also give an indication which factors other than the intervention itself have an influence on the intervention effectiveness. For example, a study investigating metacognitive Goal Management Training in a series of four children with severe ABI found that prospective memory could be improved, but that involvement of parents and teachers is necessary to enhance the intervention effect and achieve generalization to daily life [73].

Limitations of the present review

First, the number of included studies in the present review increased compared to previous reviews [2, 15, 16, 18]. Nevertheless, a meta-analysis of the data was not carried out, given that the increase in number of included studies was paralleled by an increase in heterogeneity of outcome measures, patients in terms of age, type and severity of injury, and investigated interventions differing substantially in aim, duration and frequency. This large variety in outcomes, patients and interventions across a relatively small number of studies prevented a meaningful interpretation of meta-analytic statistics. Inconsistent findings in this systematic review might be due to this large variation in patient and intervention characteristics as well as in outcome measures. It is recommended for future studies to further consider these potentially influential factors. Moreover, the problem of large variety in patients and interventions can only be overcome when the amount of studies in this field is increased, enabling better pooling of data.

Second, during the study selection for the present review, four studies were excluded whose sample consisted of children with ABI but also more than 50% children with central-nervous system involving cancer (see inclusion criteria in Methods section and Figure 1). Even though cognitive interventions may be relevant for children with cognitive problems regardless of their diagnosis, previous studies have found that effectiveness is not always the same across different patient groups. For example, the effect of cognitive interventions was found to be larger in children with ABI and neurological disorders than in children with neurodevelopmental disorders such as ADHD [17]. Of the excluded studies, two investigated two different computerized drill-based interventions [74, 75], while the other two examined the same intervention combining metacognition/strategy use with drill-based attention training [76, 77]. In line with the conclusions of the present review, effectiveness of the two drill-based intervention mentioned above pertained mainly to cognitive tasks that were similar to the training tasks, except for a short-term improvement (not maintained over 3 months) in parent-reported learning problems [74]. The two studies investigating the multi-component intervention found improvements in the area of attention as well as on academic achievement measures [76, 77]; this again is in line with the conclusions of the present review, indicated the potential of multi-component interventions to improve different areas of functioning. Contrarily, in the present review, five studies were included that investigated not only children with ABI (more than 50% of the sample) but also children with other disorders that affected their cognitive functioning, such as central-nervous system involving cancer and epilepsy. Excluding these five studies would weaken our review to the extent that the conclusions would be based on a smaller number of studies, but the conclusions itself would not change. Including the four studies that did not meet the criterion would, similarly, not change the conclusions of the present review. Moreover, rather than strengthening the conclusions because of the increased number of studies, including these studies would have introduced equivocality of the results regarding effectiveness of cognitive interventions for children with ABI, given the high number of children who did not suffer from ABI.

Third, four of the articles found in the database search did not have an abstract and/or full text available online. These articles (published between 1972 and 1989) were also not described in any of the previous reviews investigating cognitive rehabilitation for children and adolescents with ABI, and they were all published in national (i.e. German and South African) journals.

Lastly, of the 20 articles included in the present review, only 13 were derived from the database search and e-mail alerts following that search. This suggests that not all articles are consistently based on the same system, emphasizing the importance also of expert selection of relevant studies. Thanks to the large expert network and the thorough search of reference lists of included articles and previous reviews, we are confident that all relevant articles meeting inclusion criteria for the present review were recovered.

Conclusions

The present review was the first to specifically focus on components of cognitive rehabilitation when investigating their effectiveness in improving cognitive functions (e.g. attention, memory and executive functions) in children and adolescents with ABI. In the current review, 17 different cognitive rehabilitation interventions were examined. Results suggest that multi-component interventions combining for example metacognition/strategy use with (computerized) drill-based exercises seems to have potential to improve cognitive functioning on the level of functions and activities, as well as daily life functioning of children and adolescents with ABI. Although intervention, patient and outcome heterogeneity in the present review make definite conclusions difficult, findings from previous studies suggest that, in addition to being of a multi-component nature, cognitive (rehabilitation) interventions are most promising when they are intensive, appropriate for the developmental stage of the child, and provided in a family- or peer supported context.

Acknowledgements

The research was partly funded by Johanna KinderFonds, Cornelia-Stichting and Stichting Rotterdams Kinderrevalidatie Fonds Adriaanstichting. The authors report no conflicts of interest.

References

1. Spreij LA, Visser-Meily J, van Heugten CM, Nijboer TC. Novel insights into the rehabilitation of memory post acquired brain injury: a systematic review. *Frontiers in Human Neuroscience.* 2014;8:993.
2. Slomine B, Locascio G. Cognitive rehabilitation for children with acquired brain injury. *Developmental Disabilities Research Reviews.* 2009;15(2):133-43.
3. de Kloet A, Hilberink S, Roebroeck M, Catsman-Berrevoets C, Peeters E, Lambregts S, et al. Youth with acquired brain injury in The Netherlands: A multi-centre study. *Brain Injury.* 2013;27(7-8):843-9.
4. Crowe L, Babl F, Anderson V, Catroppa C. The epidemiology of paediatric head injuries: data from a referral centre in Victoria, Australia. *Journal of Paediatrics and Child Health.* 2009;45(6):346-50.
5. Hawley CA, Ward AB, Long J, Owen DW, Magnay AR. Prevalence of traumatic brain injury amongst children admitted to hospital in one health district: a population-based study. *Injury.* 2003;34(4):256-60.
6. Anderson VA, Catroppa C, Dudgeon P, Morse SA, Haritou F, Rosenfeld JV. Understanding predictors of functional recovery and outcome 30 months following early childhood head injury. *Neuropsychology.* 2006;20(1):42.
7. Babikian T, Asarnow R. Neurocognitive outcomes and recovery after pediatric TBI: meta-analytic review of the literature. *Neuropsychology.* 2009;23(3):283.
8. Keenan HT, Hooper SR, Wetherington CE, Nocera M, Runyan DK. Neurodevelopmental consequences of early traumatic brain injury in 3-year-old children. *Pediatrics.* 2007;119(3):e616-e23.
9. van Heugten C, Hendriksen J, Rasquin S, Dijcks B, Jaeken D, Vles J. Long-term neuropsychological performance in a cohort of children and adolescents after severe paediatric traumatic brain injury. *Brain Injury.* 2006;20(9):895-903.
10. Galvin J, Froude EH, McAleer J. Children's participation in home, school and community life after acquired brain injury. *Australian Occupational Therapy Journal.* 2010;57(2):118-26.
11. Levin HS, Hanten G, Li X. The relation of cognitive control to social outcome after paediatric TBI: Implications for intervention. *Developmental Neurorehabilitation*. 2009;12(5):320-9.
12. Rosema S, Crowe L, Anderson V. Social function in children and adolescents after traumatic brain injury: A systematic review 1989–2011. *Journal of Neurotrauma.* 2012;29(7):1277-91.
13. van Tol E, Gorter JW, DeMatteo C, Meester-Delver A. Participation outcomes for children with acquired brain injury: A narrative review. *Brain Injury.* 2011;25(13-14):1279-87.
14. Backeljauw B, Kurowski BG. Interventions for attention problems after pediatric traumatic brain injury: what is the evidence? *PM&R.* 2014;6(9):814-24.
15. Laatsch L, Harrington D, Hotz G, Marcantuono J, Mozzoni MP, Walsh V, et al. An evidence-based review of cognitive and behavioral rehabilitation treatment studies in children with acquired brain injury. The *Journal of Head Trauma Rehabilitation.* 2007;22(4):248-56.
16. Limond J, Leeke R. Practitioner review: cognitive rehabilitation for children with acquired brain injury. *Journal of Child Psychology and Psychiatry*. 2005;46(4):339-52.
17. Robinson KE, Kaizar E, Catroppa C, Godfrey C, Yeates KO. Systematic review and meta-analysis of cognitive interventions for children with central nervous system disorders and neurodevelopmental disorders. *Journal of Pediatric Psychology.* 2014;39(8):846-65.
18. Ross KA, Dorris L, McMillan T. A systematic review of psychological interventions to alleviate cognitive and psychosocial problems in children with acquired brain injury. *Developmental Medicine & Child Neurology.* 2011;53(8):692-701.
19. Ylvisaker M. *Traumatic brain injury rehabilitation: Children and adolescents:* Butterworth-Heinemann; 1998.
20. Concato J, Shah N, Horwitz RI. Randomized, controlled trials, observational studies, and the hierarchy of research designs. *New England Journal of Medicine.* 2000;342(25):1887-92.
21. Ferriter M, Huband N. Does the non-randomized controlled study have a place in the systematic review? A pilot study. *Criminal Behaviour and Mental Health.* 2005;15(2):111-20.
22. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Annals of Internal Medicine.* 2009;151(4):W-65-W-94.

23. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of Internal Medicine.* 2009;151(4):264-9.
24. Thomas B, Ciliska D, Dobbins M, Micucci S. A process for systematically reviewing the literature: providing the research evidence for public health nursing interventions. *Worldviews on Evidence-Based Nursing*. 2004;1(3):176-84.
25. Moher D, Hopewell S, Schulz KF, Montori V, Gøtzsche PC, Devereaux P, et al. CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. *Journal of Clinical Epidemiology.* 2010;63(8):e1-e37.
26. Deeks J, Dinnes J, D'amico R, Sowden A, Sakarovitch C, Song F, et al. Evaluating non-randomised intervention studies. *Health Technology Assessment* (Winchester, England). 2003;7(27):iii-x, 1-173.
27. Braga LW, da Paz AC, Ylvisaker M. Direct clinician-delivered versus indirect family-supported rehabilitation of children with traumatic brain injury: a randomized controlled trial. *Brain Injury.* 2005;19(10):819-31.
28. Kurowski BG, Wade SL, Kirkwood MW, Brown TM, Stancin T, Taylor HG. Long-term benefits of an early online problem-solving intervention for executive dysfunction after traumatic brain injury in children: a randomized clinical trial. *JAMA Pediatrics.* 2014;168(6):523-31.
29. Wade SL, Kurowski BG, Kirkwood MW, Zhang N, Cassedy A, Brown TM, et al. Online problem-solving therapy after traumatic brain injury: a randomized controlled trial. *Pediatrics.* 2015;135(2):e487-e95.
30. Wade SL, Stancin T, Kirkwood M, Brown TM. Counselor-Assisted Problem Solving (CAPS) improves behavioral outcomes in older adolescents with complicated mild to severe TBI. *The Journal of Head Trauma Rehabilitation.* 2014;29(3):198.
31. Wade SL, Walz NC, Carey J, Williams KM, Cass J, Herren L, et al. A randomized trial of teen online problem solving for improving executive function deficits following pediatric traumatic brain injury. *The Journal of Head Trauma Rehabilitation.* 2010;25(6):409-15.
32. Braga LW, Rossi L, Moretto ALL, da Silva JM, Cole M. Empowering preadolescents with ABI through metacognition: Preliminary results of a randomized clinical trial. *NeuroRehabilitation.* 2012;30(3):205-12.
33. Catroppa C, Stone K, Hearps SJ, Soo C, Anderson V, Rosema S. Evaluation of an attention and memory intervention post-childhood acquired brain injury: Preliminary efficacy, immediate and 6 months post-intervention. *Brain Injury.* 2015;29(11):1317-24.
34. Eve M, O'Keeffe F, Jhuty S, Ganesan V, Brown G, Murphy T. Computerized Working-Memory Training for Children Following Arterial Ischemic Stroke: A Pilot Study With Long-Term Follow-Up. *Applied Neuropsychology: Child.* 2016:1-10.
35. Cook LG, Chapman SB, Elliott AC, Evenson NN, Vinton K. Cognitive gains from gist reasoning training in adolescents with chronic-stage traumatic brain injury. *Frontiers in Neurology.* 2014;5.
36. Kaldoja M-L, Saard M, Lange K, Raud T, Teeveer O-K, Kolk A. Neuropsychological benefits of computer-assisted cognitive rehabilitation (using FORAMENRehab program) in children with mild traumatic brain injury or partial epilepsy: A pilot study. *Journal of Pediatric Rehabilitation Medicine.* 2015;8(4):271-83.
37. Phillips NL, Mandalis A, Benson S, Parry L, Epps A, Morrow A, et al. Computerized working memory training for children with moderate to severe traumatic brain injury: a double-blind, randomized, placebo-controlled trial. *Journal of Neurotrauma.* 2016.
38. Treble-Barna A, Sohlberg M, Harn BE, Wade SL. Cognitive Intervention for Attention and Executive Function Impairments in Children With Traumatic Brain Injury: A Pilot Study. *The Journal of Head Trauma Rehabilitation.* 2015.
39. Brett AW, Laatsch L. Cognitive rehabilitation therapy of brain-injured students in a public high school setting. *Pediatric Rehabilitation.* 1998;2(1):27-31.
40. Light R, Neumann E, Oberg CM, Lewis R, Asarnow R, Satz P. An evaluation of a neuropsychologically based reeducation project for the head-injured child. *The Journal of Head Trauma Rehabilitation.* 1987;2(1):11-25.
41. Sjö NM, Spellerberg S, Weidner S, Kihlgren M. Training of attention and memory deficits in children with acquired brain injury. *Acta Paediatrica*. 2010;99(2):230-6.
42. van 't Hooft I, Andersson K, Bergman B, Sejersen T, von Wendt L, Bartfai A. Sustained favorable effects of cognitive training in children with acquired brain injuries. *NeuroRehabilitation.* 2007;22(2):109-16.

43. van 't Hooft I, Andersson K, Bergman B, Sejersen T, Von Wendt L, Bartfai A. Beneficial effect from a cognitive training programme on children with acquired brain injuries demonstrated in a controlled study. *Brain Injury*. 2005;19(7):511-8.
44. Wechsler D. *Wechsler Intelligence Scale for Children-WISC-IV:* Psychological Corporation; 2003.
45. Wechsler D. *Wechsler Adult Intelligence Scale–Fourth Edition (WAIS–IV)*. 2014.
46. Hardy KK, Willard VW, Bonner MJ. Computerized cognitive training in survivors of childhood cancer a pilot study. *Journal of Pediatric Oncology Nursing.* 2011;28(1):27-33.
47. Patel SK, Katz ER, Richardson R, Rimmer M, Kilian S. Cognitive and problem solving training in children with cancer: a pilot project. *Journal of Pediatric Hematology/Oncology.* 2009;31(9):670-7.
48. Dehn MJ. *Working memory and academic learning: Assessment and Intervention*: John Wiley & Sons; 2011.
49. Chan D, Fong K. The effects of problem-solving skills training based on metacognitive principles for children with acquired brain injury attending mainstream schools: a controlled clinical trial. *Disability and Rehabilitation.* 2011;33(21-22):2023-32.
50. Missiuna C, DeMatteo C, Hanna S, Mandich A, Law M, Mahoney W, et al. Exploring the use of cognitive intervention for children with acquired brain injury. *Physical & Occupational Therapy in Pediatrics.* 2010;30(3):205-19.
51. de Kloet A, Berger M, Verhoeven I, van Stein Callenfels K, Vlieland TV. Gaming supports youth with acquired brain injury? A pilot study. *Brain Injury.* 2012;26(7-8):1021-9.
52. Thomas-Stonell N, Johnson P, Schuller R, Jutai J. Evaluation of a computer-based program for remediation of cognitive-communication skills. *The Journal of Head Trauma Rehabilitation*. 1994;9(4):25-37.
53. Galbiati S, Recla M, Pastore V, Liscio M, Bardoni A, Castelli E, et al. Attention remediation following traumatic brain injury in childhood and adolescence. *Neuropsychology.* 2009;23(1):40.
54. Ho J, Epps A, Parry L, Poole M, Lah S. Rehabilitation of everyday memory deficits in paediatric brain injury: self-instruction and diary training. *Neuropsychological Rehabilitation*. 2011;21(2):183-207.
55. Wilson BA, Emslie H, Evans JJ, Quirk K, Watson P, Fish J. The NeuroPage system for children and adolescents with neurological deficits. *Developmental Neurorehabilitation.* 2009;12(6):421-6.
56. Ylvisaker M, Feeney T. Executive functions, self-regulation, and learned optimism in paediatric rehabilitation: a review and implications for intervention. *Pediatric Rehabilitation.* 2002;5(2):51-70.
57. Dorris L, Broome H, Wilson M, Grant C, Young D, Baker G, et al. A randomized controlled trial of a manual-based psychosocial group intervention for young people with epilepsy [PIE]. *Epilepsy & Behavior*. 2017;72:89-98.
58. Suurmeijer TP, Reuvekamp MF, Aldenkamp BP. Social functioning, psychological functioning, and quality of life in epilepsy. *Epilepsia.* 2001;42(9):1160-8.
59. Melby-Lervåg M, Hulme C. Is working memory training effective? A meta-analytic review. *Developmental Psychology.* 2013;49(2):270.
60. van de Ven RM, Murre JM, Veltman DJ, Schmand BA. Computer-Based Cognitive Training for Executive Functions after Stroke: A Systematic Review. *Frontiers in Human Neuroscience*. 2016;10.
61. Cicerone KD, Langenbahn DM, Braden C, Malec JF, Kalmar K, Fraas M, et al. Evidence-based cognitive rehabilitation: updated review of the literature from 2003 through 2008. *Archives of Physical Medicine and Rehabilitation.* 2011;92(4):519-30.
62. Sohlberg MM, Mateer CA. *Cognitive Rehabilitation: An Integrative Neuropsychological Approach*: Guilford Press; 2001.
63. Krasny-Pacini A, Chevignard M, Evans J. Goal Management Training for rehabilitation of executive functions: a systematic review of effectivness in patients with acquired brain injury. *Disability and Rehabilitation.* 2014;36(2):105-16.
64. Jonkman LM, Hurks PP, Schleepen TM. Effects of memory strategy training on performance and event-related brain potentials of children with ADHD in an episodic memory task. *Neuropsychological Rehabilitation.* 2016;26(5-6):910-41.
65. Limond J, Adlam A, Cormack M. A model for pediatric neurocognitive interventions: Considering the role of development and maturation in rehabilitation planning. *The Clinical Neuropsychologist.* 2014;28(2):181-98.

66. Krasny-Pacini A, Limond J, Evans J, Hiebel J, Bendjelida K, Chevignard M. Self-awareness assessment during cognitive rehabilitation in children with acquired brain injury: a feasibility study and proposed model of child anosognosia. *Disability and Rehabilitation*. 2015;37(22):2092-106.

67. Toplak ME, Connors L, Shuster J, Knezevic B, Parks S. Review of cognitive, cognitive-behavioral, and neural-based interventions for Attention-Deficit/Hyperactivity Disorder (ADHD). *Clinical Psychology Review.* 2008;28(5):801-23.

68. Catroppa C, Anderson V, Godfrey C, Rosenfeld JV. Attentional skills 10 years post-paediatric traumatic brain injury (TBI). *Brain Injury.* 2011;25(9):858-69.

69. McCauley SR, Wilde EA, Anderson VA, Bedell G, Beers SR, Campbell TF, et al. Recommendations for the use of common outcome measures in pediatric traumatic brain injury research. *Journal of Neurotrauma.* 2012;29(4):678-705.

70. Tate RL, Perdices M, McDonald S, Togher L, Rosenkoetter U. The design, conduct and report of single-case research: Resources to improve the quality of the neurorehabilitation literature. *Neuropsychological Rehabilitation.* 2014;24(3-4):315-31.

71. Tate RL, Perdices M, Rosenkoetter U, Shadish W, Vohra S, Barlow DH, et al. The single-case reporting guideline In BEhavioural interventions (SCRIBE) 2016 statement. *Evidence-based Communication Assessment and Intervention.* 2016;10(1):44-58.

72. Tate RL, Perdices M, Rosenkoetter U, Wakim D, Godbee K, Togher L, et al. Revision of a method quality rating scale for single-case experimental designs and n-of-1 trials: The 15-item Risk of Bias in N-of-1 Trials (RoBiNT) Scale. *Neuropsychological Rehabilitation.* 2013;23(5):619-38.

73. Krasny-Pacini A, Limond J, Evans J, Hiebel J, Bendjelida K, Chevignard M. Context-sensitive goal management training for everyday executive dysfunction in children after severe traumatic brain injury. *The Journal of Head Trauma Rehabilitation.* 2014;29(5):E49-E64.

74. Hardy KK, Willard VW, Allen TM, Bonner MJ. Working memory training in survivors of pediatric cancer: A randomized pilot study. *Psycho-Oncology.* 2013;22(8):1856-65.

75. Kesler SR, Lacayo NJ, Jo B. A pilot study of an online cognitive rehabilitation program for executive function skills in children with cancer-related brain injury. *Brain Injury.* 2011;25(1):101-12.

76. Butler RW, Copeland DR. Attentional processes and their remediation in children treated for cancer: A literature review and the development of a therapeutic approach. *Journal of the International Neuropsychological Society.* 2002;8(1):115-24.

77. Butler RW, Copeland DR, Fairclough DL, Mulhern RK, Katz ER, Kazak AE, et al. A multicenter, randomized clinical trial of a cognitive remediation program for childhood survivors of a pediatric malignancy. *Journal of Consulting and Clinical Psychology.* 2008;76(3):367.

Supplemental material 1. Search terms per category and full electronic search strategy for the PubMed electronic database.

Category	Search terms
Acquired brain injury	brain injury / head injury / brain damage / stroke / brain tumor / encephalitis / meningitis / hypoxia
Intervention	intervention / rehabilitation / training / retraining / therapy / treatment / remediation / program
Cognition	cognition / cognitive / attention / attentional / concentration / information processing / executive / planning / organization / memory / perception / perceptual / problem solving / reasoning / neurocognition / neurocognitive / neuropsychological / neuropsychology / language

Search ((“Contrecoup Injury”[Mesh] OR “Hypoxia-Ischemia, Brain”[Mesh] OR “Diffuse Axonal Injury”[Mesh] OR “Meningitis, Escherichia coli”[Mesh] OR “Stroke”[Mesh] OR “Brain Infarction”[Mesh] OR “Intracranial Hemorrhages”[Mesh] OR “Brain Stem Neoplasms”[Mesh] OR “Cerebrovascular Trauma”[Mesh] OR “Brain Injury, Chronic”[Mesh] OR “Brain Stem Hemorrhage, Traumatic”[Mesh] OR “Brain Hemorrhage, Traumatic”[Mesh] OR “Head Injuries, Penetrating”[Mesh] OR “Meningitis, Fungal”[Mesh] OR “Meningitis, Bacterial”[Mesh] OR “Meningitis, Cryptococcal”[Mesh] OR “Head Injuries, Closed”[Mesh] OR “Tuberculosis, Meningeal”[Mesh] OR “Meningitis, Viral”[Mesh] OR “Meningitis, Pneumococcal”[Mesh] OR “Meningitis, Meningococcal”[Mesh] OR “Meningitis, Listeria”[Mesh] OR “Meningitis, Haemophilus”[Mesh] OR “Meningitis, Aseptic”[Mesh] OR “Meningitis”[Mesh] OR “Craniocerebral Trauma”[Mesh] OR “Encephalitis”[Mesh] OR “Cerebrovascular Disorders”[Mesh] OR “Cerebral Ventricle Neoplasms”[Mesh] OR “Brain Ischemia”[Mesh] OR “Hypoxia, Brain”[Mesh] OR “Brain Neoplasms”[Mesh] OR “Brain Injuries”[Mesh] OR “Brain Diseases”[Mesh] OR “Brain Concussion”[Mesh] OR “Brain Abscess”[Mesh] OR “Brain Damage, Chronic”[Mesh] OR “Brain Diseases, Metabolic”[Mesh])

AND

(“Early Intervention (Education)”[Mesh] OR “Treatment Outcome”[Mesh] OR “Intervention Studies”[Mesh] OR “Program Evaluation”[Mesh] OR “Remedial Teaching”[Mesh] OR “Teaching”[Mesh] OR “Therapeutics”[Mesh] OR “Transfer (Psychology)”[Mesh] OR “Rehabilitation”[Mesh] OR “Intervention” OR “Therapy” OR “Treatment” OR “Program”)

AND

(“Cognition”[Mesh] OR “Mild Cognitive Impairment”[Mesh] OR “Attention”[Mesh] OR “Mental Processes”[Mesh] OR “Executive Function”[Mesh] OR “Planning Techniques”[Mesh] OR “Memory”[Mesh] OR “Memory, Short-Term”[Mesh] OR “ Memory, Long-Term “[Mesh] OR “ Memory, Episodic “[Mesh] OR “ Spatial Memory “[Mesh] OR “ Perception “[Mesh] OR “ Problem Solving “[Mesh] OR “Neuropsychology”[Mesh] OR “Language”[Mesh] OR “Speech”[Mesh] OR “Concentration” OR “Information Processing” OR “Planning” OR “Organization” OR “Organizational” OR “Reasoning” OR “Neurocognitive” OR “Neuropsychological”))

Filters: Clinical Trial; Randomized Controlled Trial; Dutch; English; German; Child: birth-18 year

Chapter 7

Computer-based cognitive retraining combined with explicit strategy instruction: rationale and description of a new cognitive intervention for children and adolescents with acquired brain injury

Resch, C., Hurks, P., de Kloet, A., & van Heugten, C.

Submitted for publication.

Abstract

Children and adolescents with acquired brain injury (ABI) frequently report problems with cognitive functioning and, consequently, daily life problems with cognition and psychosocial functioning. Currently, there is a lack of interventions to target these cognitive problems. Theoretical models suggest combining repeated practice of cognitive tasks with explicit strategy instruction may yield positive effects on cognitive and daily life functioning of children and adolescents with ABI. In the present article, we present a new intervention combining these elements. Repeated task practice is achieved in a computer-based cognitive retraining (CBCR), targeting a wide range of cognitive functions (i.e. attention, working memory and executive functions) with the use of computerised tasks. For the explicit strategy instruction, we developed a novel protocol to provide and practice function specific and metacognitive strategies. The intervention period is six weeks, during which children and adolescents with ABI train five times per week for 30 minutes per day at home with the CBCR and attend 45 minutes of explicit strategy instruction per week at their rehabilitation centre or specialised school. Effectiveness of the intervention is currently being examined in a multicentre clinical trial in the Netherlands.

Introduction

Each year, approximately 19.000 children and adolescents in the Netherlands are diagnosed with acquired brain injury (ABI) [1]. ABI is defined as damage to the brain that has occurred after birth, but is not related to any congenital disease or neurodegenerative disorder [2]. Aetiologies include traumatic brain injury, infections (e.g. encephalitis, meningitis), brain tumours, stroke, and hypoxia [3]. The negative consequences of ABI are often lifelong for the patient, his or her family, and society, with the patients most frequently reporting problems in a variety of cognitive function domains, such as attention, information processing, working memory, and executive functions (e.g. inhibitory control, cognitive flexibility) [4-6]. In turn, these cognitive difficulties negatively impact the patient's psychosocial functioning (i.e. participation, family functioning, and quality of life) [7-10].

Cognitive problems associated with ABI are mostly targeted with cognitive rehabilitation. Cognitive rehabilitation is a systematic intervention directed at improving patients' daily functioning by means of relearning previous abilities or compensating for the impact of present difficulties [11, 12]. A method that is popular in cognitive rehabilitation is computer-based cognitive retraining (CBCR). CBCR is a non-invasive training approach in which patients play specific computer games that have been specifically developed to improve cognitive functioning. Most CBCR underlie the assumption that by solely training one specific function repeatedly, performance will improve on a wider range of functions and areas of functioning. This type of intervention has been indicated to be a feasible cognitive rehabilitation intervention for various groups of ABI patients, for example, adult patients with traumatic brain injury [13], children and adolescents with cancer-related brain injuries [14, 15] and adolescents with traumatic brain injury [16]. CBCR knows multiple advantages over non-digital cognitive rehabilitation methods. For one, patients can complete the training with minimal supervision while still receiving immediate feedback on their performance [13-15]. Second, task difficulty can be automatically adapted to the level of performance of the player. Third, the use of computer games is often compatible with interests of children and adolescents and the game-like elements have previously been found to lead to more perseverance and motivation during training [17].

Effects of CBCR can be assessed on near, intermediate, and far transfer outcomes. Near transfer outcomes are assessed with tasks similar to the trained tasks. Intermediate transfer outcomes are measured using tasks relying on the same or similar cognitive functions as trained, but using different tasks. Far transfer outcomes differ substantially from what was trained, for example different cognitive functions or daily life outcomes. Previous studies into the effects of CBCR in children with attention deficit hyperactivity disorder (ADHD) [18-21], children and adolescents with learning disabilities [22, 23], and adults with ABI [24, 25] have revealed mainly near transfer effects after CBCR. More specifically, studies showed improvements in performance on tasks tapping into the same cognitive functions as targeted during the training. In the few studies with children and adolescents with ABI, results also seem to indicate preliminary positive near transfer effects of CBCR on tasks of attention, working memory and executive functions [14, 15, 26-28]. Across populations, intermediate or far transfer effects of CBCR do not occur. More specifically, improvement on untrained tasks or on daily life functioning after CBCR is small to non-existent [29-31]. Together, these results suggest that repeated practice alone is not sufficient to reach wide-ranging improvements in (cognitive) functioning.

Rationale for the new intervention

Guidelines for adult cognitive rehabilitation suggest that interventions should contain three important elements to promote generalisation of improvement beyond the trained task and to impact also daily life (i.e. intermediate and far transfer) [11, 32]. For one, they should ensure overlearning of skills by repeated practice (i.e. patients have to perform a certain task over and over again, in line with the assumptions of CBCR). Second, they should incorporate explicit instructions regarding the use of learned strategies in various settings. Strategies can for example include mnemonics to support semantic memory, or higher-level strategies such as metacognition (i.e. the general ability to oversee how various tasks can be approached). Third, they should target a variety of cognitive functions that collaborate to ensure optimal daily life functioning. A recent model of paediatric neurocognitive intervention [33] provides similar suggestions, stating that interventions for children and adolescents may target cognitive functioning on multiple levels, including skill building (e.g. through repeated practice) and strategy use. Both the cognitive rehabilitation guidelines and the propositions of the theoretical model converge with findings of our review of effective components of cognitive rehabilitation for children and adolescents with ABI, providing preliminary indication that multi-component interventions combining repeated practice and explicit strategy instruction are promising to yield intermediate and far transfer effects [30].

Unfortunately, results of our review also indicate that most CBCR do not conform to these suggestions. Rather, they underlie the assumption that by solely training one specific function repeatedly and intensely, performance will improve on a wider range of functions and areas of functioning. Supplementing the training with therapeutic guidance to incorporate explicit strategy instruction of how to apply the learned skills in various settings may help improve the effectiveness of the training [11]. A previous study on five children with ABI using non-digital cognitive training has already suggested that explicit training (i.e. non-digital cognitive training combined with strategy instruction) has potential to not only increase performance on the trained tasks but also improve cognitive and behavioural functioning in daily life [34]. However, there is currently no intervention available for children and adolescents with ABI (or any other paediatric population) combining modern, motivating CBCR and explicit strategy instruction for a wide range of cognitive functions.

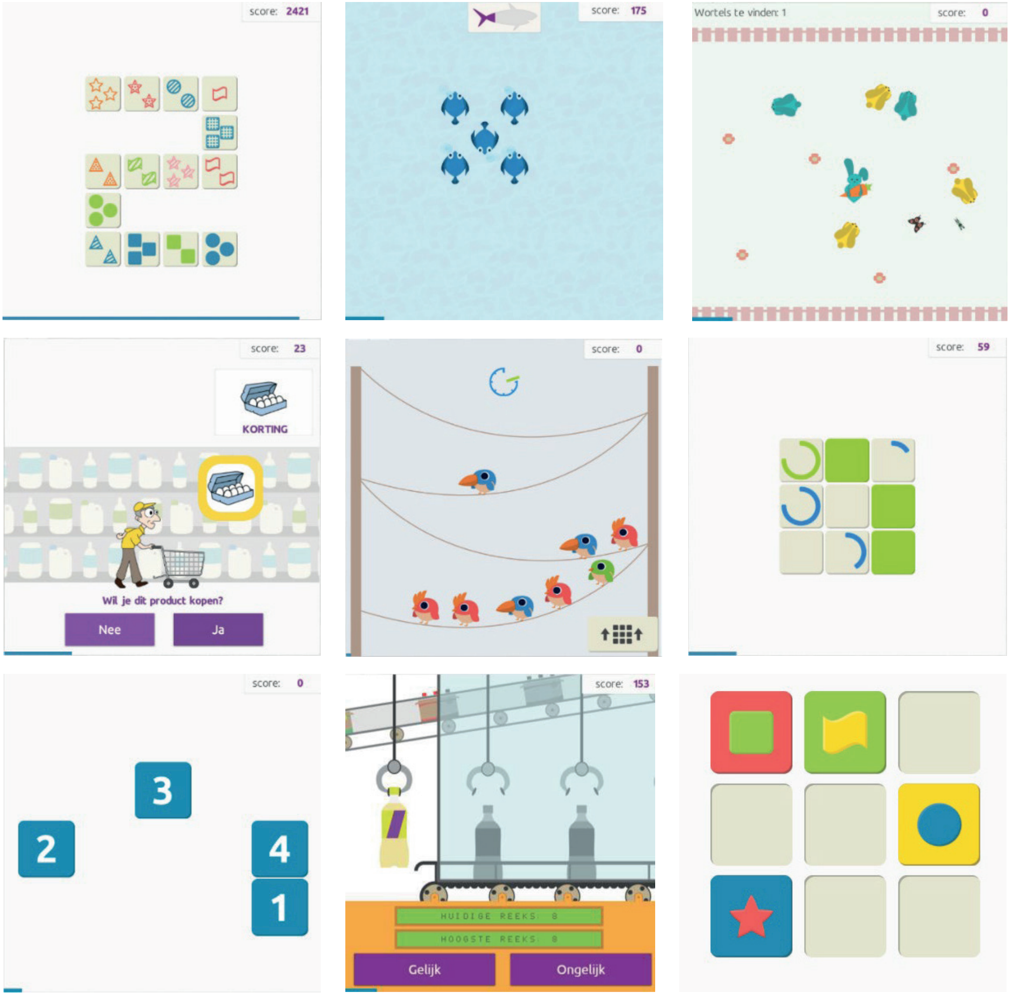

Figure 1. Screenshots of the BrainGymmer games. From top to bottom, left to right: Out of Order, Bait, Tracker, ShopShift, Birds of a Feather, Pay Attention, Digit, N-back, and Multi Memory. *Reproduced with permission from BrainGymmer.*

Description of the new intervention

Aligning with theoretical models and guidelines of cognitive rehabilitation [11, 30, 32, 33], we developed a new intervention for children and adolescents with ABI. The intervention consists of CBCR targeting a wide range of cognitive functions combined with explicit strategy instruction on how to improve these cognitive functions, both when training with the CBCR as well as in daily life situations. Cognitive functions targeted are attention (i.e. selective attention, divided attention and sustained attention), working memory, and executive functions (i.e. inhibitory control, cognitive flexibility, and planning). The aim of the intervention is to improve these cognitive functions and, consequently, daily life functioning of children and adolescents (age 8 – 18 years) with ABI who experience difficulties with one (or more) of these cognitive function(s). The CBCR provides the opportunity to first explain the strategies in a game-like context before linking them to daily life situations. Moreover, repeated task practice is thought to facilitate repetition and thereby consolidation of these strategies. It is proposed that the explicit strategy instruction can promote the use of strategies on cognitive tasks as well as the generalisation of the improved cognitive functioning by explicitly relating the newly acquired strategies to relevant daily life areas.

Computer-based cognitive retraining (CBCR). For the CBCR, existing cognitive games are used, provided by the training software BrainGymmer. BrainGymmer is an online available so-called ‘brain-training’ program developed to improve a variety of cognitive functions with the use of game-like cognitive training tasks. This program has previously been used as an intervention for adult ABI patients [35]. A separate training environment was developed, tailored to the aims and needs of the new intervention. A selection of nine games was made that are appropriate to target the cognitive functions mentioned above (see Figure 1). The selection of games could be extended to incorporate an even more diverse or more extensive array of games. A detailed description of the selected games is presented in Table 1.

Each participant receives a personal BrainGymmer account, which can be accessed via the internet. This account keeps track of the participants’ performance, and difficulty level is automatically adapted depending on the performance of the participant. Adaptivity of a CBCR to an individual’s level of performance is essential to keep the training stimulating and challenging while keeping the balance with the level of frustration (i.e. the task should not be too difficult) [23, 36]. Participants receive feedback on their performance throughout the game (e.g. a green check mark is shown for correct responses). Moreover, before the start of each game, a participant is shown his/her average score over previous game sessions and his/her high score for that particular game. Players can start one training session per day, which provides them with a predetermined selection of the games in a predetermined order, which was the same for all participants. Once a player has played the required games of the day, the program cannot be accessed again until the next day. Thereby, we ensure that the intervention is sufficiently spaced over the intended period of time (i.e. 6 weeks, see below).

Table 1. Detailed description of the selected games

Name of the game; target function [a]	Game objective and rules	Adaptive mechanisms
Out of Order; planning	The player has to place the cards in a way that each card shares at least one characteristic with the card(s) next to it. Characteristics are shape, number, colour and fill pattern of the objects displayed on the cards. Players can only move one card at a time.	- The number of cards to be put in order increases. - The minimal number of steps needed to put the cards in order increase.
Bait; inhibitory control	The player has to indicate in which direction the fish in the middle is swimming. The player has to do so before the shark eats the fish.	- The number of distractor fish increases. - The time until the shark has arrived decreases.
Tracker; sustained attention	The player sees a couple of rabbits. One or more of them have a carrot. The rabbits hide their carrot and then slowly move crisscross across the field. When they stop walking, the player has to click on the one(s) with the carrot.	- The number of distractors (i.e. rabbits without carrots, butterflies, flowers) increases. - The number of rabbits with a carrot increases.
ShopShift; cognitive flexibility	A man is doing groceries. The player has to indicate whether to buy a certain item or not. In the upper right corner, the player sees what item is next on the shopping list. This item changes frequently. Moreover, the player has to switch between buying a specific item and buying all items in a certain colour category.	- The walking speed of the man increases. - The rates of switching of items on the shopping list increases.
Birds of a Feather; selective attention	The player sees a 'target' bird. Next, the player sees a larger group of birds and has to count/guess how many of the target birds are in that group. This is easier if the player selectively attends to the target birds, identifying characteristics such as colour, tail or beak.	- The number of birds in the larger group increases. - The target bird and the birds in the larger group become more similar (e.g. requiring the player to pay attention to multiple characteristics of the target bird).
Pay Attention; divided attention	Circles start to appear in a matrix at different rates. The player has to click on the circles ones they have been completed.	- The number of circles appearing on the matrix increases. - The size of the matrix increases.

Table 1. *Continued*

Name of the game; target function [a]	Game objective and rules	Adaptive mechanisms
Digit; visual-spatial working memory	Tiles with digits appear one by one on a matrix. After a while, the tiles are turned around. The player has to click on the tiles in the correct order, starting with the tile with '1'.	- The size of the matrix increases. - Simultaneously, the number of the to be remembered tiles increases.
N-back; updating/visual working memory	Bottles with different patterns are manufactured. One by one, the bottles disappear behind a screen. The player has to indicate whether the bottle currently presented has the same pattern as the bottle on the far right behind the screen.	- The number of bottles that need to be remembered increases (i.e. from 1-back to 2-back to 3-back etc.).
Multi Memory; visual-spatial working memory	Tiles have been placed on a matrix. The tiles have different colours and display various shapes of different colours. The player has to remember the location of the tiles. Once the player has memorised the location, the tiles move across the matrix. The player has to move the tiles back to their previous location.	- The size of the matrix increases. - Simultaneously, the number of the to be remembered tiles increases.

Note. [a] Performance on each BrainGymmer games relies on a variety of cognitive functions. Here, we indicate the main cognitive function proposed to be targeted by each game.

Explicit strategy instruction. In addition to the CBCR, participants attend explicit strategy instruction. During the explicit strategy instruction, children are provided strategies that they can use to improve their performance on the games of the CBCR. Moreover, it is discussed in which daily life situation these strategies are also relevant, and how they can be applied there. A detailed protocol for the explicit strategy instruction was designed, and the clinicians were trained and instructed accordingly. The protocol describes the content of six strategy instruction sessions. Each session contains three key elements: (1) discussing one or two games of the CBCR, as determined in the protocol; (2) discussing function specific (i.e. attention, working memory or executive functions) cognitive strategies to improve performance on the games; (3) explicitly relating these strategies to other tasks and daily life situations (such as completing school work). All strategies are embedded in a larger context focussing on handing children and adolescents additional metacognitive strategies (e.g. 'before beginning with a task, first make sure you understand the instructions completely') directed at improving their ability to select an appropriate cognitive strategy and/or behave in a situational appropriate manner. The metacognitive strategies are based on a 'stop – think – do – check' self-instruction method [37] (see Figure 2).

Both function specific and metacognitive strategies are related to a child's or adolescent's individual goal that they formulate before the first explicit strategy instruction session. Thereby, we aim to enhance motivation and training perseverance and to achieve improvements in the child's or adolescent's meaningful life areas. Across strategy instruction sessions, strategies are rehearsed multiple times and repeatedly linked to daily life situations. For each strategy, the protocol provides various examples of life situations to which the strategy can be linked. However, both children and adolescents as well as their treating specialist are encouraged to come up with their own examples, connecting the strategies directly to what is important to them. Moreover, children and adolescents will be provided with a workbook with exercises to explicitly apply the learned strategies in their daily living activities. As an example, the outline of three of the six strategy instruction sessions are presented in Table 2.

Figure 2. The 'stop-think-do-check' method as used in the new intervention.

Table 2. Outline of three strategy instruction sessions

Session 1	Session 2	Session 3
Welcome	Welcome	Welcome
Discuss personal goal		
Review the first days of practice with the computer games	Review the previous session and the homework (i.e. computer games, workbook, use of strategies in daily life)	Review of the previous session and the homework (i.e. computer games, workbook, use of strategies in daily life)
Discuss the stop-think-do-check method	Review the stop-think-do-check method	Review the stop-think-do-check method
Practice the stop-think-do-check method using the Out of Order game	Practice an inhibitory control strategy using the Bait game	Practice a cognitive flexibility strategy using the ShopShift game
Link the stop-think-do-check strategy to daily life situations	Link the inhibitory control strategy to daily life situations	Link the cognitive flexibility strategy to daily life situations
	Practice a sustained attention strategy using the Tracker game	Repeat the strategies learned in sessions 1 to 3 and link them to (other) daily life situations
	Link the sustained attention strategy to daily life situations	
Review the session: shortly summarise what you practiced and discussed	Review the session: shortly summarise what you practiced and discussed	Review the session: shortly summarise what you practiced and discussed
Discuss the homework for the upcoming week (i.e. computer games, workbook, use of strategies in daily life)	Discuss the homework for the upcoming week (i.e. computer games, workbook, use of strategies in daily life)	Discuss the homework for the upcoming week (i.e. computer games, workbook, use of strategies in daily life)
Closing	Closing	Closing

Duration and intensity

The intervention period is six weeks. During this time, children train (i.e. play the BrainGymmer games) five times a week (i.e. 30 times in total) for approximately 30 minutes per day. The duration of each of the nine games was set to five minutes per game. When all training sessions have been completed, all games will have been played 20 times (i.e. 100 minutes per game). Total training time is 900 minutes. If participants have not completed the 900 minutes of training after six weeks, the training period will be extended to a maximum of seven weeks. The explicit strategy instruction is conducted in six weekly, 45-minute sessions. Optimal duration of cognitive rehabilitation training for children and adolescents with ABI has yet to be determined, since there is considerable variation in the training periods of previous studies [15]. For typically developing children, it has previously been found that sufficient spacing within an intervention (i.e. over at least 20 days) yields the best results in terms of improved cognitive functioning [38]. With the chosen duration and training intensity of the present intervention, we aim to find a balance between the amount of training necessary to elicit changes in cognitive performance as well as psychosocial functioning, and the feasibility to keep participants motivated and compliant with the training schedule. Duration and intensity are comparable to previous studies in children and adolescents with ABI and other populations such as children with ADHD and cancer-related cognitive difficulties [15, 19, 39]. In case future research shows that optimal training duration and intensity is shorter or longer than offered in the present intervention, the intervention protocol can easily be adapted based on these emerging insights.

Target population

The intervention was developed for children and adolescents with cognitive complaints after ABI. However, during the intervention, no emphasis is put on the origin of the cognitive complaints (e.g. ABI). The intervention may therefore also be suitable for other paediatric populations who report cognitive difficulties, for example children with ADHD or learning disabilities. Both the CBCR and the strategy instruction protocol have been developed to be suitable for children and adolescents aged 8 to 18 years. From at least age 8 years onwards, children have been shown to be able to benefit from explicit strategy instruction (including function specific and metacognitive strategies) in terms of improved strategy use and application of those strategies to relevant situations [40, 41]. The intervention is only suitable for children and adolescents who are sufficiently able to understand the instructions on the games and the strategies. Treating clinicians can determine this on an individual basis. It is advised not to use the intervention for children or adolescents who present with extreme sensibility for visual stimuli. Moreover, children and adolescents have to be able to control the arrow keys of a keyboard and/or to use a computer mouse. They have to be able to perceive a complete screen and to adequately process the stimuli of the computer games. Finally, sufficient understanding of the Dutch language is required to be able to benefit from the strategy instruction sessions.

Intervention setting

Children and adolescents play the computer games at home. It is advised to play the games on a personal computer or laptop. Alternatively, the games can be played on a tablet computer. Due to the small screen size, they are discouraged to play the games on a smartphone. The games can be played without supervision of an adult. The explicit strategy instruction is provided by a selected specialist, in other words, a person with experience in cognitive rehabilitation. Strategy instruction sessions take place at the rehabilitation centre or the specialised school the child with ABI is attending.

Investigating effectiveness of the intervention

The effectiveness of the new intervention is currently being investigated in a multicentre clinical trial (Protocol IDs: NTR5639, NL54523.068.15). Participants are children and adolescents with ABI who are prescribed cognitive rehabilitation at one of eight participation rehabilitation centres or specialized schools in the Netherlands (Adelante Zorggroep, Valkenburg; Basalt Revalidatie, Den Haag; Brein Support, Arnhem; Heliomare, Heemskerk; De Hoogstraat Revalidatie, Utrecht; Libra Revalidatie & Audiologie, Eindhoven; Merem Medische Revalidatie, Hilversum; Revant, Breda). The recruitment takes place over a period of approximately 3 years, from November 2016 to December 2019.

Acknowledgements

The development of the intervention was funded by Johanna Kinderfonds (Project ID: 2014/0039-1552), Cornelia-Stichting (Project ID: 2014/0039-1552) and Stichting Rotterdams Kinderrevalidatie Fonds Adriaanstichting (Project ID: 14.09.30-2014/0039).

References

1. de Kloet A, Hilberink S, Roebroeck M, Catsman-Berrevoets C, Peeters E, Lambregts S, et al. Youth with acquired brain injury in The Netherlands: A multi-centre study. *Brain Injury.* 2013;27(7-8):843-9.
2. Spreij LA, Visser-Meily J, van Heugten CM, Nijboer TC. Novel insights into the rehabilitation of memory post acquired brain injury: a systematic review. *Frontiers in Human Neuroscience.* 2014;8:993.
3. Slomine B, Locascio G. Cognitive rehabilitation for children with acquired brain injury. *Developmental Disabilities Research Reviews.* 2009;15(2):133-43.
4. Anderson VA, Catroppa C, Dudgeon P, Morse SA, Haritou F, Rosenfeld JV. Understanding predictors of functional recovery and outcome 30 months following early childhood head injury. *Neuropsychology.* 2006;20(1):42.
5. Keenan HT, Hooper SR, Wetherington CE, Nocera M, Runyan DK. Neurodevelopmental consequences of early traumatic brain injury in 3-year-old children. *Pediatrics.* 2007;119(3):e616-e23.
6. van Heugten C, Hendriksen J, Rasquin S, Dijcks B, Jaeken D, Vles J. Long-term neuropsychological performance in a cohort of children and adolescents after severe paediatric traumatic brain injury. *Brain Injury.* 2006;20(9):895-903.
7. Galvin J, Froude EH, McAleer J. Children's participation in home, school and community life after acquired brain injury. *Australian Occupational Therapy Journal.* 2010;57(2):118-26.
8. Levin HS, Hanten G, Li X. The relation of cognitive control to social outcome after paediatric TBI: Implications for intervention. *Developmental Neurorehabilitation.* 2009;12(5):320-9.
9. Mangeot S, Armstrong K, Colvin AN, Yeates KO, Taylor HG. Long-term executive function deficits in children with traumatic brain injuries: Assessment using the Behavior Rating Inventory of Executive Function (BRIEF). *Child Neuropsychology.* 2002;8(4):271-84.
10. van Tol E, Gorter JW, DeMatteo C, Meester-Delver A. Participation outcomes for children with acquired brain injury: A narrative review. *Brain Injury.* 2011;25(13-14):1279-87.
11. Cicerone KD, Langenbahn DM, Braden C, Malec JF, Kalmar K, Fraas M, et al. Evidence-based cognitive rehabilitation: updated review of the literature from 2003 through 2008. *Archives of Physical Medicine and Rehabilitation.* 2011;92(4):519-30.
12. Ylvisaker M. *Traumatic brain injury rehabilitation: Children and adolescents:* Butterworth-Heinemann; 1998.
13. Lebowitz MS, Dams-O'Connor K, Cantor JB. Feasibility of computerized brain plasticity-based cognitive training after traumatic brain injury. *Journal of Rehabilitation Research & Development.* 2012;49(10).
14. Hardy KK, Willard VW, Allen TM, Bonner MJ. Working memory training in survivors of pediatric cancer: A randomized pilot study. *Psycho-Oncology.* 2013;22(8):1856-65.
15. Kesler SR, Lacayo NJ, Jo B. A pilot study of an online cognitive rehabilitation program for executive function skills in children with cancer-related brain injury. *Brain Injury.* 2011;25(1):101-12.
16. Verhelst H, Vander Linden C, Vingerhoets G, Caeyenberghs K. How to train an injured brain? A pilot feasibility study of home-based computerized cognitive training. *Games for Health Journal.* 2017;6(1):28-38.
17. Prins PJ, Dovis S, Ponsioen A, Ten Brink E, Van Der Oord S. Does computerized working memory training with game elements enhance motivation and training efficacy in children with ADHD? *Cyberpsychology, Behavior, and Social Networking.* 2011;14(3):115-22.
18. Chacko A, Bedard A, Marks D, Feirsen N, Uderman J, Chimiklis A, et al. A randomized clinical trial of Cogmed working memory training in school-age children with ADHD: A replication in a diverse sample using a control condition. *Journal of Child Psychology and Psychiatry.* 2014;55(3):247-55.
19. Klingberg T, Fernell E, Olesen PJ, Johnson M, Gustafsson P, Dahlström K, et al. Computerized Training of Working Memory in Children With ADHD-A Randomized, Controlled Trial. *Journal of the American Academy of Child & Adolescent Psychiatry.* 2005;44(2):177-86.
20. Shalev L, Tsal Y, Mevorach C. Computerized progressive attentional training (CPAT) program: effective direct intervention for children with ADHD. *Child Neuropsychology*. 2007;13(4):382-8.
21. van der Oord S, Ponsioen AJGB, Geurts HM, Brink ELT, Prins PJM. A Pilot Study of the Efficacy of a Computerized Executive Functioning Remediation Training With Game Elements for Children With ADHD in an Outpatient Setting: Outcome on Parent- and Teacher-Rated Executive Functioning and ADHD Behavior. *Journal of Attention Disorders.* 2012;18(8):699-712.

22. Gray S, Chaban P, Martinussen R, Goldberg R, Gotlieb H, Kronitz R, et al. Effects of a computerized working memory training program on working memory, attention, and academics in adolescents with severe LD and comorbid ADHD: a randomized controlled trial. *Journal of Child Psychology and Psychiatry.* 2012;53(12):1277-84.
23. Peijnenborgh JC, Hurks PM, Aldenkamp AP, Vles JS, Hendriksen JG. Efficacy of working memory training in children and adolescents with learning disabilities: A review study and meta-analysis. *Neuropsychological Rehabilitation.* 2016;26(5-6):645-72.
24. Johansson B, Tornmalm M. Working memory training for patients with acquired brain injury: effects in daily life. *Scandinavian Journal of Occupational Therapy.* 2012;19(2):176-83.
25. Lundqvist A, Grundström K, Samuelsson K, Rönnberg J. Computerized training of working memory in a group of patients suffering from acquired brain injury. *Brain Injury.* 2010;24(10):1173-83.
26. Bangirana P, Allebeck P, Boivin MJ, John CC, Page C, Ehnvall A, et al. Cognition, behaviour and academic skills after cognitive rehabilitation in Ugandan children surviving severe malaria: a randomised trial. *BMC Neurology.* 2011;11(1):96.
27. Verhelst H, Linden CV, Vingerhoets G, Caeyenberghs K. How to train an injured brain? A pilot feasibility study of home-based computerized cognitive training. *Games for Health.* 2017;6(1):28-38.
28. Sohlberg MM, Harn B, MacPherson H, Wade SL. A pilot study evaluating attention and strategy training following pediatric traumatic brain injury. *Clinical Practice in Pediatric Psychology.* 2014;2(3):263.
29. Melby-Lervåg M, Redick TS, Hulme C. Working memory training does not improve performance on measures of intelligence or other measures of "far transfer" evidence from a meta-analytic review. *Perspectives on Psychological Science.* 2016;11(4):512-34.
30. Resch C, Rosema S, Hurks P, de Kloet A, van Heugten C. Searching for effective components of cognitive rehabilitation for children and adolescents with acquired brain injury: A systematic review. *Brain Injury.* 2018;32(6):679-92.
31. Melby-Lervåg M, Hulme C. Is working memory training effective? A meta-analytic review. *Developmental Psychology.* 2013;49(2):270.
32. Sohlberg MM, Mateer CA. *Cognitive Rehabilitation: An Integrative Neuropsychological Approach:* Guilford Press; 2001.
33. Limond J, Adlam AR, Cormack M. A model for pediatric neurocognitive interventions: Considering the role of development and maturation in rehabilitation planning. *The Clinical Neuropsychologist*. 2014;28(2):181-98.
34. Suzman KB, Morris RD, Morris MK, Milan MA. Cognitive-behavioral remediation of problem solving deficits in children with acquired brain injury. *Journal of Behavior Therapy and Experimental Psychiatry.* 1997;28(3):203-12.
35. Van De Ven RM, Buitenweg JI, Schmand B, Veltman DJ, Aaronson JA, Nijboer TC, et al. Brain training improves recovery after stroke but waiting list improves equally: A multicenter randomized controlled trial of a computer-based cognitive flexibility training. *PloS One.* 2017;12(3):e0172993.
36. Diamond A, Ling DS. Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience.* 2016;18:34-48.
37. Meichenbaum DH, Goodman J. Training impulsive children to talk to themselves: a means of developing self-control. *Journal of Abnormal Psychology.* 1971;77(2):115.
38. Wang Z, Zhou R, Shah P. Spaced cognitive training promotes training transfer. *Frontiers in Human Neuroscience.* 2014;8(217).
39. Hardy KK, Willard VW, Bonner MJ. Computerized cognitive training in survivors of childhood cancer a pilot study. *Journal of Pediatric Oncology Nursing.* 2011;28(1):27-33.
40. Bosson MS, Hessels MG, Hessels-Schlatter C, Berger J-L, Kipfer NM, Büchel FP. Strategy acquisition by children with general learning difficulties through metacognitive training. *Australian Journal of Learning Difficulties.* 2010;15(1):13-34.
41. Hessels-Schlatter C, Hessels MG, Godin H, Spillmann-Rojas H. Fostering self-regulated learning: From clinical to whole class interventions. *Educational and Child Psychology.* 2017;34(1):110-25.

Chapter 8

A systematic review of instruments to assess participation of children with acquired brain injury and cerebral palsy: Alignment with the family of Participation-Related Constructs and an overview of measurement properties

Resch, C., van Kruijsbergen, M., Ketelaar, M., Hurks, P., Adair, B., Imms, C., de Kloet, A., Piskur, B., & van Heugten, C.

Submitted for publication.

Abstract

The aim of the present review was (1) to examine which instruments used to assess participation of children with acquired brain injury (ABI) or cerebral palsy (CP) align with attendance and/or involvement constructs of participation; and (2) to systematically review measurement properties of these instruments in children with ABI or CP, to guide instrument selection. Five databases were searched. Instruments that quantified 'attendance' and/or 'involvement' aspects of participation according to the family of Participation-Related Constructs were selected. Data on measurement properties were extracted and methodological quality of the studies assessed. Thirty-seven instruments were used to assess participation in children with ABI or CP. Of those, 12 measured attendance and/or involvement. Reliability, validity and responsiveness of eight of these instruments were examined in 14 studies with children with ABI or CP. Sufficient measurement properties were reported for most of the measures, but no instrument had been assessed on all relevant properties. Moreover, most psychometric studies have marked methodological limitations. Instruments to assess participation of children with ABI or CP should be selected carefully, since many available measures do not align with attendance and/or involvement. Evidence for measurement properties is limited, mainly caused by low methodological study quality. Future studies should follow recommended methodological guidelines.

Introduction

Acquired brain injury (ABI) and cerebral palsy (CP) are two of the most frequently occurring neurological conditions in pediatric rehabilitation, and are the leading causes of disability in children worldwide [1, 2]. Common negative consequences of pediatric ABI and CP include motor, cognitive and behavioral problems that impact children's activity performance. In addition, children with ABI and CP experience restricted participation across home, community and school settings [3-9].

Over the last two decades, participation has received increasing attention as the ultimate outcome of rehabilitation. Participation is a key component of the International Classification of Functioning, Disability and Health (ICF) [10, 11]. According to the ICF, participation represents the societal perspective of functioning and is defined as "involvement in a life situation". However, within the ICF, a uniform operationalization of the term participation has not been provided [12, 13].

To improve collective agreement of what participation is and how it can be defined, the family of Participation-Related Constructs (fPRC) was developed [13, 14]. Within this framework, participation is defined as comprising two essential elements: attendance and involvement. Attendance is defined as 'being there' (in the participatory context) and can be quantified by measuring the frequency or the diversity of activities in which a child takes part [13]. Involvement is the subjective experience of participation in the moment and includes affect, motivation, persistence and perhaps social connection [13]. Results of previous systematic reviews have indicated that instruments used to assess participation in children with a broad range of disabilities sometimes do not measure attendance and/or involvement, but rather assess participation-related constructs such as activity competence, sense of self, preferences or environmental context [13, 15]. For instruments specifically used to assess participation of children with ABI or CP, alignment with the fPRC attendance and involvement constructs remains to be investigated. Being clear about the construct of interest is essential to facilitate understanding and comparability of outcomes.

In addition to the conceptualization of participation, measurement properties are important to consider when selecting instruments for use in research and clinical practice. Providing information about prognosis, as well as decision making regarding treatment and evaluation of interventions, requires reliable and valid tools [16, 17]. Measurement properties can differ substantially between populations [18]. Therefore, to assist researchers and clinicians in selecting instruments, their measurement properties should be known in the specific population of interest [18, 19].

Two previous systematic reviews aimed to identify instruments to assess participation specifically of children with ABI (published in 2010) [20] or CP (published in 2007) [21] and to describe their measurement properties. Note that, in both previous reviews, the selection of the instruments did not consider alignment with attendance and/or involvement. For children with ABI, five instruments were identified, but since most of them had only recently been developed, studies into their measurement properties were rare and more extensive evaluations were recommended [20]. For children with CP, seven instruments were identified, three of which had also been used in children with ABI [21]; some evidence was available regarding reliability and validity. However, studies into measurement properties of the included instruments were not systematically searched. Moreover, in both previous reviews, methodological quality of the studies evaluating measurement properties was not assessed. Evaluating the quality of studies is necessary, since inadequate study quality may bias results and lead to an incorrect approximation of the measurement properties of the instrument [22]. Therefore, the aims of this review were twofold: (1) to examine which instruments have been used to assess participation of children with ABI or CP and their alignment with the concepts of attendance and/or involvement; and (2) to examine what is known about the measurement properties of these instruments in children with ABI or CP.

Method

A systematic review was designed and reported in accordance with the Consensus-based Standards for the selection of health Measurement Instruments (COSMIN) guidelines for systematic reviews of patient-reported outcome measures [19, 23].

Information sources

We conducted one literature search to address both our research aims. The initial literature search was conducted on 12 April 2018 and included the following electronic databases: MEDLINE (1966 – present), CINAHL (1982 – present), Embase (1974 – present), and PsycINFO (1967 – present). The search was updated to include articles published before 1 May 2019. In addition to the database searches, reference lists of all articles included in the present review, as well as of relevant reviews and meta-analyses known to the authors, were examined.

Search

The search consisted of a combination of key terms and Medical Subject Headings (MeSH) or Thesaurus terms. The terms specifying the construct (i.e. participation) and the population of interest (i.e. children with ABI or CP) were based on previous systematic reviews of these topics [4, 24-26], COSMIN guidelines [27], suggestions from experts in the field, and search blocks as formulated on https://blocks.bmi-online.nl/. The search was limited to studies of children (aged 0 to 18 years). No date restriction was employed. The full electronic search for the MEDLINE database may be found in the Supplemental material 1.

Eligibility criteria

For our first aim, regarding which instruments have been used to assess participation of children with ABI or CP, the following criteria were set: (1) the instrument (or a subscale or section) was explicitly used according to the study authors to measure participation, attendance or involvement [8, 28, 29]; (2) the instrument used to assess participation was a quantitative measure that was clearly named and/or was accompanied by the original reference; (3) the instrument was used in a study with children diagnosed with ABI or CP; (4) the instrument was used in a study including children (age < 19 years); (5) the instrument was used in an article reporting on an empirical study; (6) the instrument was used in an article that was published in a peer-reviewed journal.

Counts of frequencies of observed participation behaviour were excluded if they did not concern a named/published instrument. If the study included patients with other diagnoses than ABI or CP, or typically developing children, data for children with ABI or CP had to be presented separately, or at least 50% of the participants had to be diagnosed with ABI or CP [27]. If the sample also included adults, data for children and adults had to be presented separately, at least 50% of the participants had to be children or the mean or median age of the sample had to be between 0 and 18 years [27], for the paper to be included.

Table 1. COSMIN definitions of measurement properties (Adapted from Mokkink et al., 2018 [27])

Measurement property	Definition
Instrument development [a]	The initial development of the instrument. Aspects to consider are relevance, comprehensiveness and comprehensibility of the items of the instruments.
Reliability (e.g. test-retest, inter-rater)	The proportion of variance which is due to actual differences between respondents on the construct of interest and is not caused by inconsistencies in the scores provided by the instrument.
Internal consistency	The strength of interrelatedness among the items of the instrument.
Measurement error	Error, either random or systematic, in a respondent's score.
Content validity	How well the content of the instrument reflects the construct (in this case, participation) to be measured.
Construct validity	The degree to which the outcome of the instrument is consistent with predetermined hypotheses, provided that the instrument is a valid measure of the construct of interest. Examples of hypotheses are associations with other outcomes, or differences between relevant subgroups.
Structural validity	How well the scores of an instrument adequately reflect the dimensions of the construct of interest.
Cross-cultural validity	The degree to which the scores on various items on different instrument versions (e.g. language versions, between countries) adequately reflect the scores of the original instrument version.
Responsiveness	The ability of an instrument to detect change in the construct of interest.

Note. [a] Instrument development is not a measurement property per se, but given the valuable information provided in this stage of instrument evaluation, it was considered of interest in the present review.

The same criteria for the first aim were also applied to address the second aim, regarding the measurement properties of the participation instruments in children with ABI or CP, with one additional eligibility criterion: one aim of the study using the instrument was to evaluate at least one measurement property of the participation instrument [27]. Measurement properties of interest in the present review were determined using the COSMIN guidelines, and included initial instrument development, reliability (i.e. internal consistency, reliability, and measurement error), validity (i.e. content validity, structural validity, construct validity and cross-cultural validity) and responsiveness [19, 22, 27]. Definitions of these terms are provided in Table 1.

Instrument and study selection

Two of the authors (CR and MvK) independently screened titles and abstracts of studies based on the eligibility criteria. Full-texts were read by the first author (CR). Screening the articles to determine which instruments had been used to assess participation of children and adolescent with ABI or CP (relating to the first aim of the present review) was mainly directed at the *instrument* and in which population it was used. In contrast, for our second aim of examining measurement properties, the *study* itself was screened.

Alignment with attendance and/or involvement

All instruments that had been used to measure participation of children with ABI or CP were mapped to the fPRC. Some instruments had been previously mapped by two of the authors of the present review (BA and CI) [15]; if this was the case, results of the previous mapping were recorded. Instruments not yet been mapped to the fPRC were evaluated independently by the two authors who contributed to the development of the fPRC and who conducted the previous mapping (BA and CI). To be considered aligned with the attendance and/or involvement constructs, the instrument, or at least one of its subscales or subscores, had to align exclusively with the attendance and/or involvement constructs of the fPRC. More specifically, if an instrument's total scale or a subscale aligned with attendance and/or involvement but also with another construct of the fPRC (e.g. activity competence), this instrument or subscale was excluded from further consideration.

Extraction and synthesis of measurement properties

Measurement properties of participation instruments were extracted from the included studies per the COSMIN guidelines, and evaluated based on the COSMIN criteria for good measurement properties by the first author (CR) [19, 22, 27]. Results were rated sufficient (+), insufficient (-), or indeterminate (?) [27]. It should be noted that, according to the COSMIN standards, content-validity studies, are those that include a new sample, independent from the sample that was included in the study of the initial development of the instrument [27].

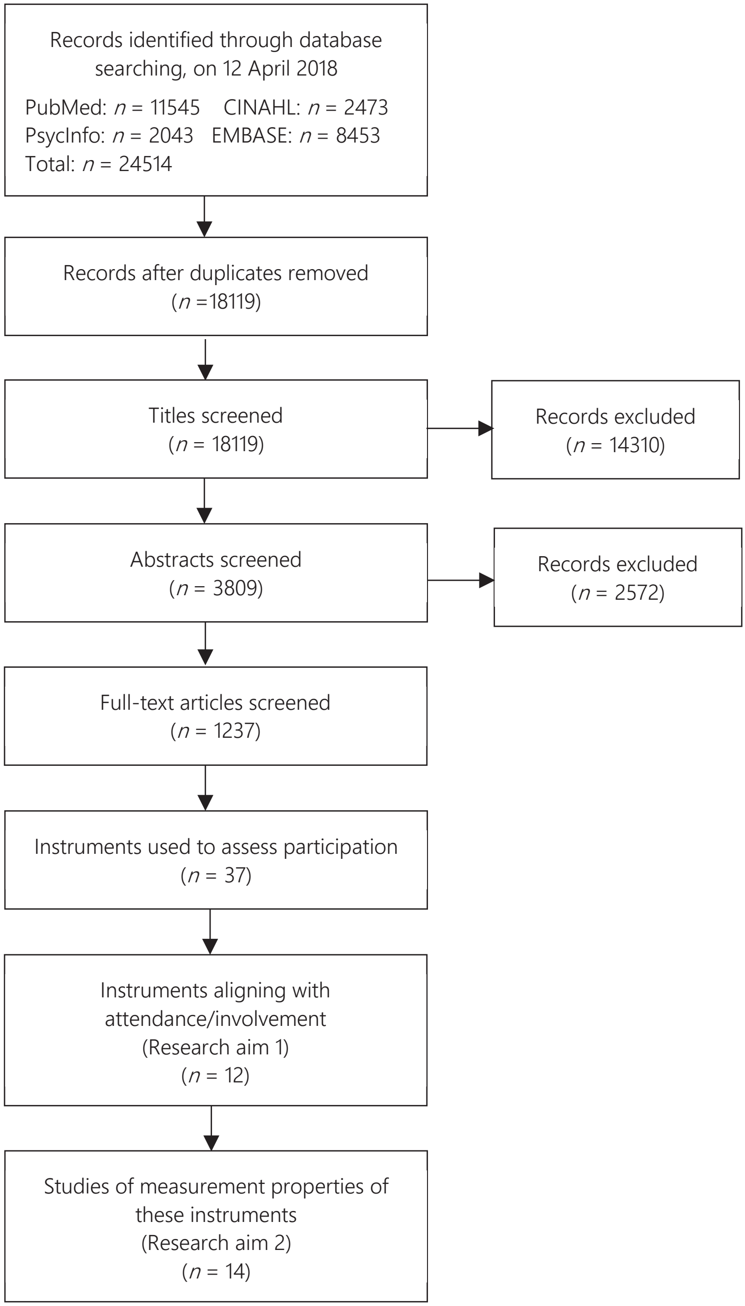

Figure 1. Flowchart for the literature search and the study selection.

Methodological quality of studies into measurement properties

To assess methodological quality of studies examining measurement properties, we used the COSMIN risk of bias checklist. Methodological quality of the study was rated on a 4-point rating scale from 'very good' to 'inadequate' [19]. A previous version of the checklist had good inter-rater reliability and agreement [30]. The new version, as used in the present systematic review, is highly comparable to the previous version [27]. Two authors (CR and PH) determined which of the boxes had to be completed for each included article. Two independent reviewers (pairs including CR plus AdK, BP, CvH, ES or MvK) independently evaluated the methodological quality of the included studies. Disagreement was resolved through discussion or consultation with another author (PH).

Results

Details concerning the instrument and study selection for our two research aims are illustrated in Figure 1. Our search yielded 18119 unique records. Screening of titles (18119), abstracts (*n*=3809) and full-texts (*n*=1237) yielded 37 instruments used to quantify participation in our populations of interest (see Table 2). Of these instruments, 24 had exclusively been used for children with CP. Seven were exclusively used to measure participation of children with ABI. Six instruments had been used both for children with CP and ABI.

Alignment with attendance and/or involvement

Twelve instruments (i.e. the complete instrument or one or more of the subscales) aligned exclusively with the attendance and/or involvement constructs of the fPRC. Detailed characteristics of the instruments are shown in Table 3. For two other instruments (the Canadian Occupational Performance measure [COPM] [31] and the Goal Attainment Scale [GAS] [32]), the content of the items are determined by the individual participant. Therefore, whether the items align with the attendance and/or involvement construct, or something else [15], depends on the goals set by the participant. Three instruments could not be mapped to the fPRC because we were not able to acquire the measure for mapping (the Pediatric Injury Functional Outcome Scale [33], and the Child Health Questionnaire [34]) or because they were only available in Chinese (the Caregiver Questionnaire for Health-Related Quality of Life in children with Cerebral Palsy [35]). Two were excluded because they did not exclusively align with the attendance and/or involvement constructs (the School Function Assessment [36] and the Caregiver Information and Support Link [37]). The resulting scores may therefore not be a clear reflection of attendance and/or involvement.

Table 2. List of instruments used to quantify participation and alignment with the attendance and/or involvement constructs

Instrument	Abbreviation	Alignment with fPRC		Used in children with ABI and/or CP
		Attendance	Involvement	
1 minute walk test [38]		-	-	CP
Assessment of Preschool Children's Participation [39]	APCP	Diversity subscore; Intensity subscore; Total score	-	CP
Activities Scale for Kids [40]	ASK	ASK-p score	-	CP
Children's Assessment of Participation and Enjoyment/Preferences for Activities of Children [41]	CAPE/PAC	Diversity subscore; Intensity subscore	Enjoyment score	ABI, CP
Child and Adolescent Scale of Participation [42]	CASP	Domain scores and the total score align both with attendance and involvement		ABI
Child Engagement in Daily Life Measure [43]	CEDL	Frequency of family and recreational activities	Enjoyment of family and recreational activities	CP
Children Helping Out: Responsibilities, Expectations and Supports [44]	CHORES	Performance score (number of activities completed)	-	CP
Child Health Questionnaire [34]	CHQ	Unknown	Unknown	CP
Caregiver Information and Support Link [37]	CISL [a]	Frequency of participation in specified activities	-	CP
Canadian Occupational Performance Measure [31]	COPM	?	?	ABI, CP
Cerebral Palsy Quality of Life Questionnaire-Child [45]	CP QoL-Child	-	-	CP
Cerebral Palsy Quality of Life Questionnaire-Teen [46]	CP QoL-Teen	-	-	CP
Clinical Performance Measure for Paediatric Brain Injury [47]	CPM-PBI	-	-	ABI
Children Participation Questionnaire [48]	CPQ	Diversity score; Intensity score	Enjoyment score	CP
Caregiver Questionnaire for Health-Related Quality of Life in children with Cerebral Palsy [35]	CQ-HRQL-CP	Unknown	Unknown	CP
Frequency of Participation Questionnaire [49]	FPQ	Activity scores	-	CP
Fulfillment of Social Roles [50]	FSR	-	-	CP
Goal Attainment Scale [32]	GAS	?	?	CP
Gross Motor Function Classification System [51]	GMFCS	-	-	CP
Gross Motor Function Measure [52]	GMFM	-	-	CP
ICF-CY questionnaire [53, 54]		-	-	ABI, CP

8

Table 2. *Continued*

Instrument	Abbreviation	Alignment with fPRC		Used in children with ABI and/or CP
		Attendance	Involvement	
Impact of Childhood Illness Scale [55]	ICIS	-	-	CP
Lifestyle Assessment Questionnaire (general as well as condition-specific for CP) [56]	LAQ	-	-	CP
Assessment of Life Habits [57]	LIFE-H	-	-	ABI, CP
Mayo-Portland Adaptability Inventory-(Paediatric) [58]	MPAI-(P)	-	-	ABI
Physical Activity Questionnaire for Children/Adolescents [59]	PAQ-C/PAQ-A	Frequency of activity in past week; Frequency of high levels of activity; Range of activities	-	ABI
Pediatric Evaluation of Disability Inventory [60, 61]	PEDI(-CAT)	-	-	CP
Participation and Environment Measure for Children and Youth [62]	PEM-CY	Frequency score	Involvement score	ABI, CP
Pediatric Injury Functional Outcome Scale [33]	PIFOS	Unknown	Unknown	ABI
Pediatric Outcomes Data Collection Instrument [63]	PODCI	-	-	CP
Questionnaire of Young Peoples Participation [64]	QYPP	All domain scores	-	CP
Strengths and Difficulties Questionnaire [65]	SDQ	-	-	ABI
School Function Assessment [36]	SFA [a]	Participation score aligns both with attendance and involvement (and activity competence)	ABI, CP	
Sydney Psychosocial Reintegration Scale for children [66]	SPRC-C	-	-	ABI
The Exercise Questionnaire[67]		'How many times' and 'How many minutes each time'	-	CP
Timed Up-and-Go [68]		-	-	CP
Vineland Adaptive Behavior Scales [69]	VABS	-	-	CP

Note. For 19 of these instruments, alignment with the fPRC had been previously determined and published by Adair et al., 2018 [15]. '?' refers to instruments that depend on individual goals as described by a patient, making it impossible to map these instruments. '-' means that the instrument did not align with this construct. Alignment is marked 'unknown' when the instrument was not available for mapping. [a] The total score of these instruments and/or one or more subscales align with the attendance and/or involvement construct, but also with one of the other fPRC constructs. Therefore, studies into measurement properties of these instruments were not included for the second research aim.

Table 3. Characteristics of identified participation instruments

Instrument	Participation construct(s) [a]	Target population	Administration	Recall period	(Sub)scale(s) (number of items)	Scores [Response options]	Completion time
APCP [39]	Attendance	Preschool children aged 2 to 5 years and 11 months	Questionnaire; Parent-report	If the child participates in an activity (diversity score), the parents record how often the child participated over the last 4 months (intensity score)	48 items organized into 4 activity areas: play activities, skill development, active physical recreation, social activities	Diversity [yes or no] Intensity [7-point ordinal scale]	30-40 minutes
ASK [40] [b]	Attendance (performance score)	Children aged 5 to 15 with limitations in physical activity due to musculoskeletal disorders	Questionnaire; Self-report	Participation in activities in the last week	30 items across 7 domains: personal care, dressing, other skills, play, standing skills, and transfers.	Performance score [5-point ordinal scale]	5-9 minutes
CAPE [41] [c]	Attendance (diversity and intensity score), Involvement (enjoyment score)	Children and adolescents between age 6 and 21, with and without disabilities	Questionnaire; Self-report	If the child participates in an activity (diversity score), the parents record how often the child participated over the last 4 months (intensity score)	55 items organized into 5 activity areas: based on skill, active physical, recreation, social, and self-improvement	Diversity [yes or no] Intensity [7-point ordinal scale] With whom [5-point ordinal scale, from alone to with many types of people] Where [6-point ordinal scale, from home to community] Enjoyment [5-point ordinal scale]	30-45 minutes
CASP [42]	Attendance & involvement	Children and youth with ABI aged 3 to 22 years	Questionnaire; Parent-report, self-report	Current participation	20 items assessing participation in 4 areas: home, neighbourhood and community, school, and home and community living activities	Total score and score per area [4-point ordinal scale, from age-expected to unable]	5-10 minutes

8

Table 3. *Continued*

Instrument	Participation construct(s) [a]	Target population	Administration	Recall period	(Sub)scale(s) (number of items)	Scores [Response options]	Completion time
CEDL [43] d	Attendance (part 1: frequency of family and recreational activities), Involvement (part 1: enjoyment of family and recreational activities)	Young children with CP	Questionnaire; Parent-report	Current participation	18 items in two domains: part 1: family and recreational activities, part 2: self-care	Part 1 yields 2 scores: Frequency [5-point ordinal scale] Enjoyment [5-point ordinal scale]	10-15 minutes
CHORES [44] e	Attendance (performance score)	School-aged children	Questionnaire; Parent-report	Current participation	34 items, divided into 2 subscales: self-care and family care	Performance score [yes or no] Assistance score [6-point ordinal scale]	Unknown
CPQ [48] f	Attendance (diversity and intensity score), Involvement (enjoyment score)	Preschool-aged children	Questionnaire; Parent-report	Current participation	44 items organized into 6 subscales: self-care, home participation, play, leisure, social participation, and educational environment	Diversity score [yes or no] Intensity score [5-point ordinal scale] Enjoyment score [6-point ordinal scale] Independence level [6-point ordinal scale] Parent satisfaction [6-point ordinal scale]	Unknown
FPQ [49]	Attendance	Children with and without CP aged 8 to 13 years	Questionnaire; Parent-report	Current participation	14 items concerning 14 different activities	Frequency score per activity	Unknown
PAQ [59]	Attendance	Children (8-14 years) and adolescents (14-20 years); separate versions	Questionnaire; Self-report	Participation in activities in the last week	9 items (children) or 10 items (adolescents) asking about frequency of different activities	Activity summary score [mean of scores on all 5-point ordinal scales]	<20 minutes

Table 3. *Continued*

Instrument	Participation construct(s) [a]	Target population	Administration	Recall period	(Sub)scale(s) (number of items)	Scores [Response options]	Completion time
PEM-CY [62] [g]	Attendance (frequency score) & involvement (involvement score)	Children and youth between age 5-17, with or without disabilities	Questionnaire; Parent-report	The parents record how often the child participated over the last 4 months (frequency score) and how often the child is involved in these activities (involvement score)	25 items assessing participation in 3 areas: home, school, and community	Frequency [8-point ordinal scale] Involvement score [5-point ordinal scale]	20-25 minutes
The Exercise questionnaire [67]	Attendance	Children with CP from age 11 onwards	Questionnaire; Self-report (possibly with help of caregiver)	Participation in activities in the last week	Number of items depending on the activities of the child	Diversity of participation [yes or no] Frequency [open] Duration [open] Intensity [3-point scale]	Unknown
QYPP [64]	Attendance & involvement	Young people with cerebral palsy	Questionnaire; Self-report, proxy-report	Variable (e.g. hours of work per week, activity per month)	45 items covering 7 domains: home life, getting on with other people, school or college life, work, recreation/leisure, autonomy, preparing for future	Total score and score per area [variable ranges of possible answers]	20-30 minutes

Note. [a] The participation construct was determined through mapping to the fPRC by two of the authors of the present review (BA and CI). [b] Only the performance score of this instrument is of interest in the present review, since the competence score does not align with the attendance and/or involvement constructs. [c] Only the diversity, intensity and enjoyment scores of this instrument are of interest in the present review, since the preference score, and the with home and where scores do not align with the attendance and/or involvement constructs. [d] Only part one of this instrument is of interest in the present review, since part two does not align with the attendance/involvement constructs. [e] Only the performance score is of interest in the present review, since the assistance score does not align with the attendance/involvement constructs. [f] Only diversity, intensity and enjoyment scores are of interest in the present review, since the independence level and parent satisfaction do not align with the attendance/involvement constructs. [g] Only the frequency and involvement score are of interest in the present review, since the environmental helpfulness and resources scores do not align with the attendance/involvement constructs. Abbreviations: ABI = Acquired Brain Injury, APCP = Assessment of Preschool Children's Participation, ASK = Activities Scale for Kids, CAPE = Children's Assessment of Participation and Enjoyment, CASP = Child and Adolescent Scale of Participation, CEDL = Child Engagement in Daily Life Measure, CHORES = Children Helping Out: Responsibilities, Expectations and Supports, CP = Cerebral Palsy, CPQ = Children Participation Questionnaire, FPQ = Frequency of Participation Questionnaire, PAQ = Physical Activity Questionnaire, PEM-CY = Participation and Environment Measure for Children and Youth, QYPP = Questionnaire of Young Peoples Participation.

Measurement properties of instruments and methodological quality of their studies
Of the 12 instruments or scales that aligned exclusively with the attendance and/or involvement constructs of the fPRC, eight (in different phases of instrument development and language versions) had undergone testing of measurement properties in children with ABI and/or CP. These instruments are: the Assessment of Preschool Children's Participation (APCP) [39], the Children's Assessment of Participation and Enjoyment (CAPE) [41], the Child and Adolescent Scale of Participation (CASP) [42], the Child Engagement in Daily Life Measure (CEDL) [43], the Children Helping Out: Responsibilities, Expectations and Supports (CHORES) [44], the Children Participation Questionnaire (CPQ) [48], the Frequency of Participation Questionnaire (FPQ) [49], and the Questionnaire of Young Peoples Participation (QYPP) [64]. The CAPE, the CEDL, the CHORES, and the CPQ consist of multiple subscales/scores of which only some align with the attendance and/or involvement constructs, while other scales align with other fPRC components. Only the subscales/scores that align with the attendance and/or involvement constructs were considered for the evaluation of measurement properties.

We identified 14 studies that examined measurement properties of these eight instruments in children with ABI or CP. Characteristics of these studies are reported in Table 4. Measurement properties of participation instruments included from these studies are shown in Table 5. Methodological quality of the included studies is reported in Table 6. Below, we report on the available evidence for each participation instrument both regarding measurement properties and methodological quality of the study examining these properties. Of the studies included in the present review, none examined content validity according to COSMIN criteria. Therefore, no information on the content validity of the instruments could be provided.

Assessment of Preschool Children's Participation (APCP). The APCP was examined in its English version in children with CP in two studies: one conducted in Canada [70] and one in Taiwan [71]. Instrument development, internal consistency, measurement error, construct validity and responsiveness were examined. Due to the lack of evidence of cross-cultural validity, it remains to be determined to what extent results from the studies are comparable, given the potential cultural differences between Canada and Taiwan.

During its initial development in Canada, the APCP was shown to include relevant items for children with CP, but comprehensiveness and comprehensibility are indeterminate. Unfortunately, (description of) instrument development was of inadequate methodological quality. To confirm the relevance (and comprehensiveness and comprehensibility) of the items of the APCP, additional content validity studies are needed. Internal consistency was sufficient for all diversity subscales, but only for one of four intensity subscales; however, methodological study quality was doubtful. Methodological quality of the assessment of measurement error was adequate, with results showing that the minimal detectable change was smaller than the minimal clinically important difference for all diversity and intensity scores except for the social subscale. In terms of construct validity, positive associations were found between APCP scores and assessment of daily activities, gross motor functioning and functional independence. In contrast, APCP scores correlated negatively with the number of additional health conditions. Because the APCP and these other measures assess different constructs (i.e. only the APCP measures attendance/involvement), methodological quality of the assessments of construct validity is doubtful. Other evidence for construct validity comes from findings of differences in APCP scores between children of different ages, gender, gross motor functioning level and income level; methodological quality of this evaluation was adequate. Finally, the APCP was found to be responsive to change over time, but methodological quality of the study was inadequate.

Children's Assessment of Participation and Enjoyment (CAPE). The Spanish version of the CAPE had been studied for its measurement properties in children with CP in Spain. Note that for other language versions of the CAPE, no studies into measurement properties had been conducted with samples where data were available specifically for children with ABI or CP. The Spanish CAPE was shown to include relevant items for children with CP in Spain, assessment of comprehensiveness and comprehensibility was not described. Overall, methodological quality of the (description of) the instrument development was inadequate. Methodological quality of the evaluations of reliability, measurement error and construct validity, was adequate. Results of these evaluations indicate that test-retest reliability was sufficient for 4 out of 5 subscales. Smallest detectable change was reported but not compared to the minimally important change, leaving the rating for the measurement error indeterminate. Methodological quality of the assessment of construct validity was adequate when assessing differences between children with and without CP; differences were found, but the size of the differences is unknown. Construct validity assessment with the KIDSCREEN [73] was of doubtful methodological quality due to the difference in construct assessed with the CAPE (participation) and the KIDSCREEN (quality of life); varying correlations were found between different subscales of these measures, leaving the validity indeterminate.

Child and Adolescent Scale of Participation (CASP). The CASP was examined in five studies. One study examined the English CASP in an early phase of the development, after which it went through another round of (minor) adaptations [42]. Items were found to be relevant for children with ABI, but comprehensiveness and comprehensibility are unknown. Moreover, (description) of the development of the instrument was of doubtful methodological quality. Internal consistency and test-retest reliability are sufficient, but both evaluations were of doubtful methodological quality. Structural validity remains indeterminate. Positive correlations were found with daily functioning and negative correlations with medical and environmental restrictions, providing preliminary indications for sufficient construct validity. However, methodological quality of these assessments is doubtful, since all instruments assessed different constructs.

Similar to the results of the phase 2 version, the final version of the CASP [74] shows sufficient internal consistency (although examined in a methodologically doubtful study), but indeterminate structural validity. Negative correlations with medical and environmental restrictions were found, as well as differences in scores between children with different disabilities, but methodological quality of these assessment was inadequate.

Two other studies examined the final version of the CASP, but combined data from the English and the Spanish versions [17, 75]. Given the lack of evidence of cross-cultural validity of the CASP, it remains to be determined to which extent these versions are comparable. Internal consistency was sufficient (and examined in high quality study), structural validity could not be determined. Positive correlations with quality of life and behavioral assessment, as well as subgroup differences in some disability groups indicate preliminary evidence for construct validity, but methodological quality of these assessments was doubtful. The CASP was found to be responsive to changes in some, but not all, disability groups; however, methodological quality was doubtful at best.

Finally, one study developed and examined the Dutch version of the CASP in the Netherlands [76]. Items of the scale were found to be relevant for children with ABI, comprehensiveness and comprehensibility are still to be determined. However, (description of) the development was methodological doubtful. Internal consistency was sufficient, but the evidence is based on a study of doubtful methodological quality. The evaluation of test-retest reliability was of adequate methodological quality, indicating sufficient test-retest reliability. Evidence for construct validity is mixed, with some associations found between medical and environmental restrictions (negative) and quality of life (positive), but no associations with the Dutch version of the CAPE. Methodological quality of evaluations of construct validity was adequate (for associations with the CAPE), but doubtful for the associations with the measures of other constructs.

Child Engagement in Daily Life (CEDL). The CEDL showed sufficient internal consistency, examined in a high-quality study. Evaluation of reliability was adequate, indicating sufficient test-retest reliability. Rating of measurement error remains indeterminate since minimal important change is unknown. Structural validity remains indeterminate. Differences between subgroups (e.g. depending on level of gross motor functioning or age) provide evidence for construct validity, but methodological quality of the evaluations was doubtful. Differences in change over time between subgroups provide preliminary evidence for responsiveness, examined in a study of adequate methodological quality.

Children Helping Out: Responsibilities, Expectations and Supports (CHORES). The Brazilian-Portuguese translation of the CHORES included relevant items but did not capture all relevant activities for children with CP in Brazil. Comprehensibility could not be determined. Methodological quality of the (description of) initial development was doubtful. Methodological quality of reliability was adequate, indicating sufficient test-retest reliability. Other measurement properties were not investigated.

Children Participation Questionnaire (CPQ). The CPQ Persian language version, evaluated in children with CP in Iran, showed sufficient internal consistency for 13 out of 18 subscales, as evaluated in a very good methodological study. Test retest reliability was sufficient. Structural validity was found to be sufficient, but inadequate methodological approaches/reports were used to evaluate this. Inconsistent evidence for construct validity is found due to varying correlations with behavioral assessment. Moreover, methodological quality of the evaluation of construct validity was doubtful, given that the measure used to assess construct validity measured a different construct than the CPQ.

Frequency of Participation Questionnaire (FPQ). For the FPQ, the English, Swedish, French, Danish and Italian versions were used during psychometric analysis in the specific countries. Cross-cultural validity remains indeterminate. The combined results from these different language versions and countries should therefore only cautiously be used as evidence for measurement properties in one of these countries or versions. There was an inadequate description/evaluation of the development, leaving ratings of relevance, comprehensiveness and comprehensibility for children with CP indeterminate. Differences between subgroups of participants were only partly in line with the original study authors' expectations, thus providing mixed results for construct validity, although methodological quality of the study was adequate.

Questionnaire of Young People's Participation (QYPP). Finally, the study into the QYPP combined data from a self-report and a proxy-report version, even though agreement between these two versions is not clear. Relevance of the questionnaires' items for children with CP was sufficient, while comprehensiveness and comprehensibility were indeterminate. However, methodological quality of the (description) of the instrument development was doubtful. Internal consistency was sufficient for 4 of the 7 subscales, but methodological quality of the evaluation was doubtful. Test-retest reliability was sufficient, but the evaluation was of doubtful methodological quality. Structural validity remains indeterminate. Subgroup testing revealed mixed results, and the evaluation was of doubtful quality.

Table 4. Characteristics of the studies investigating measurement properties of eight of the included instruments in children with ABI or CP

Author, year	Country of study	Instrument			Participants			Other instruments and subgroups for hypothesis testing
		Instrument	Language	Administration in study	Sample size [a]	Age range	% males	
Law, 2012 [70]	Canada	APCP	English	Parent-report	120 CP	2-6y	59	PEDI, Number of additional health conditions (correlations); Age, sex, income, GMFCS (subgroup testing)
Chen, 2013 [71]	Taiwan	APCP	English	Parent-report	82 CP	2-5y11m	52	GMFM-66, WeeFIM (correlations)
Longo, 2012 [72]	Spain	CAPE	Spanish	Self-report	199 (50%) CP 199 (50%) TD Data from groups combined in analyses	8-18y	CP: 57 TD: 49	KIDSCREEN [73] (correlations) Disability group (subgroup testing)
Bedell, 2004 [42]	USA	CASP phase 2	English	Parent-report	60 ABI	3-27y (76.6% ≤18y)	48	PEDI, CAFI, CASE (correlations)
Bedell, 2009 [74]	USA	CASP	English	Parent-report	76 (56%) ABI 61 (19%) Developmental disability 52 (17%) No identified disability 24 (8%) Learning/attention/ sensory disability Data from groups combined in analyses	3-22y (84% ≤18y)	55	CAFI, CASE (correlations) Disability group, age, sex (subgroup testing)
Golos, 2016 [75]	USA	CASP	English (92%), Spanish (8%)	Parent-report	729 (79%) TBI 197 (21%) arm injury Data from groups combined in analyses	0-18y	65	PedsQL, ABAS II (correlations)
Golos, 2018 [17]	USA	CASP	English (95%), Spanish (5%)	Parent-report	401 TBI (78%) 114 arm injury (22%) Data from groups combined in analyses	0-18y	70	Disability group (subgroup testing)
de Kloet, 2015 [76]	Netherlands	CASP	Dutch	Parent-report	Cohort 1: 140 ABI Cohort 2: 27 ABI	Cohort 1: 5-22y Cohort 2: 7-22y	Cohort 1: 52 Cohort 2: 33	CAFI, CASE, CAPE, PedsQL, PSOM (correlations)

Table 4. *Continued*

Author, year	Country of study	Instrument			Participants			Other instruments and subgroups for hypothesis testing
		Instrument	Language	Administration in study	Sample size [a]	Age range	% males	
Chiarello, 2014 [43]	USA, Canada	CEDL	English	Parent-report	429 (80%) CP 110 (20%) TD Data from groups combined in analyses	1.5-5y11m	CP: 57 TD: 54	GMFCS, age, disability group (subgroup testing)
Palisano, 2015 [77]	USA, Canada	CEDL	English	Parent-report	387 CP	1.5-5y	56	GMFCS (subgroup testing)
Amaral, 2012 [78]	Brazil	CHORES	Brazilian-Portuguese	Parent-report	25 (50%) CP 25 (50%) TD Data from groups combined in analyses	6-14y	54	–
Amini, 2017 [79]	Iran	CPQ	Persian	Parent-report	120 CP	4-6y	57	VABS (correlations)
Michelsen 2009 [49]	England, Sweden, Ireland, France, Denmark, Italy	FPQ	English, Swedish, French, Danish, Italian	Parent-report	818 CP 2939 TD Data from TD used for subgroup testing	CP: 7-13y TD: 7-14y	CP: 59 TD: 50	GMFCS, age, gender, IQ, type and level of impairment, pain, socio-economic and demographic variables, region (subgroup testing)
Tuffrey, 2013 [64]	UK	QYPP	English	Self-report (64%) & proxy-report (36%)	107 CP 540 TD Data from TD used for subgroup testing	13-21y	60%	Disability group (i.e. based on impairment questionnaire and CP/TD) (subgroup testing)

Note. [a] The sample size of the analyses corresponding to most of the measurement properties (i.e. internal consistency, measurement error, structural validity, construct validity, cross-cultural validity, and responsiveness) is presented. Sample sizes during the development of the instrument and for the assessment of test-retest reliability are most often much smaller. This will be included in the rating of the quality of evidence. Abbreviations: ABAS = Adaptive Behavior Assessment System [80], ABI = Acquired Brain Injury, APCP = Assessment of Preschool Children's Participation, CAPE = Children's Assessment of Participation and Enjoyment, CAFI = Child and Adolescent Factors Inventory [42], CASE = Child and Adolescent Scale of Environment [42], CASP = Child and Adolescent Scale of Participation, CEDL = Child Engagement in Daily Life Measure, CHORES = Children Helping Out: Responsibilities, Expectations and Supports, CP = Cerebral Palsy, CPQ = Children Participation Questionnaire, FPQ = Frequency of Participation Questionnaire, GMFCS = Gross Motor Function Classification System [81], GMFM = Gross Motor Function Measure [52], PEDI = Pediatric Evaluation of Disability Inventory [60], PedsQL = Pediatric Quality of Life Scale [82], PSOM = Pediatric Stroke Outcome Measure [83], QYPP = Questionnaire of Young Peoples Participation, TBI = Traumatic Brain Injury, TD = Typically Developing, VABS = Vineland Adaptive Behavior Scales [69], WeeFIM = Wee Functional Independence Measure [84].

Table 5. Measurement properties of the eight instruments tested in ABI or CP populations

		Development	Reliability			Validity			Responsiveness
Study	Instrument; language; study country		Internal consistency	Reliability	Measurement error	Structural validity	Construct validity	Cross-cultural validity	
Law, 2012 [70]	APCP; English; Canada	Relevance: + Comprehen-siveness: ? Comprehen-sibility: ?	+/- Diversity: α=0.73–0.85, depending on subscales; Intensity scales: α=0.52– 0.70, depending on subscales (for 1/4 subscales ≥0.70)				+/– Correlations with Number of additional health conditions: r=-0.27 – -0.41; PEDI: r=0.51–0.78 +/? Some subgroup differences depending on age, gender, GMFCS-level and income level		
Chen, 2013 [71]	APCP; English; Taiwan				+/- MDC<MCID for all subscales except Social diversity /intensity		+/– Correlations with GMFM-66: ρ=0.43–0.85; WeeFIM: ρ =0.39–0.73		+ SRM Diversity score=0.8–1.2; Intensity score=1.0–1.3
Longo, 2012 [72]	CAPE; Spanish; Spain	Relevance: + Comprehen-siveness: ? Comprehen-sibility: ?		+/– Test-retest (4w): ICC= 0.54 [95% CI 0.04–0.78] – 0.80 [95% CI 0.69–0.89], depending on subscales (for 4/5 subscales ≥0.70)	? SDC: Diversity (0-55)=9.01, Intensity (0-7)=1.96, Enjoyment (0-5)=2.38		+/- Correlations with KIDSCREEN depending on subscales +/- Subgroup differences between CP and TD in most, but not all, domains, ES not reported		

Table 5. *Continued*

		Development	Reliability			Validity			Responsiveness
Study	Instrument; language; study country		Internal consistency	Reliability	Measurement error	Structural validity	Construct validity	Cross-cultural validity	
Bedell, 2004 [42]	CASP phase 2; English; USA	Relevance: + Comprehen-siveness: ? Comprehen-sibility: ?	+ Total score Cronbach's α=0.95 (when some items were NA) – 0.98 (when all items were completed)	+ Test-retest (interval unknown): ICC=0.94		? Rasch analyses: Infit and outfit=0.56 –2.02	+ Correlations with PEDI: r=0.51–0.72; CASE: r=-0.57; CAFI: r=-0.58		
Bedell, 2009 [74]	CASP; English; USA		+ Total score Cronbach's α=0.96			? Rasch analyses: Infit and outfit=0.68 –1.68	+/? Correlations with CAFI: r=-0.66; CASE: r=-0.43 +/? Subgroup differences in disability groups, no differences between age and sex groups; ES not reported.		
Golos, 2016 [75]	CASP; English & Spanish; USA		+ Cronbach's α Total score α=0.90–0.96; Home participation α=0.73–0.88; Neighborhood and community α=0.83–0.91; School α=0.78–0.91; Home and community α=0.80–0.89, depending on time point (pre-injury, 3-36m post-injury)			? Exploratory factor analyses, only factor loadings reported	+/– Correlations between CASP total and PedsQL subscales: r=0.50–0.60; CASP total and ABAS-II subscales: r=0.49–0.65; CASP subscales and PedsQL/ABAS-II total scores: r=0.24–0.61		

Table 5. *Continued*

		Development	Reliability			Validity			Responsiveness
Study	Instrument; language; study country		Internal consistency	Reliability	Measurement error	Structural validity	Construct validity	Cross-cultural validity	
Golos, 2018 [17]	CASP; English & Spanish; USA						+/– Subgroup differences in some but not all disability groups, ES not reported		+/– Scores change over time for some of the disability groups, ES not reported
de Kloet, 2015 [76]	CASP; Dutch; the Netherlands	Relevance: + Comprehensiveness: ? Comprehensibility: ?	+ Total score Cronbach's α=0.95	+ Test-retest (2w) ICC=0.90 [95% CI 0.79–0.96]			+/– Correlations with CAFI: r=-0.43; CASE r=-0.24; PedsQL: ρ=0.33–0.45, depending on subscales; PSOM: ρ= -0.44 – -0.56, depending on subscales; CAPE diversity: ρ=0.08; CAPE intensity: ρ=0.05		
Chiarello, 2014 [43]	CEDL; English; USA & Canada		+ Frequency Cronbach's α=0.86 Enjoyment Cronbach's α=0.91	+ Test-retest (3-4w) Frequency: ICC=0.70 [95% CI 0.47–0.84] Enjoyment: ICC=0.70 [95% CI 0.47–0.84]		? Frequency (not Enjoyment) Rasch analyses: Infit and outfit 0.69–1.39	+ 1) Subgroup differences in Frequency and Enjoyment depending on GMFCS, CP vs TD, age 2) DIF between GMFCS levels (DIF for 8 of 11 items)		

Table 5. *Continued*

		Development	Reliability			Validity			Responsiveness
Study	Instrument; language; study country		Internal consistency	Reliability	Measurement error	Structural validity	Construct validity	Cross-cultural validity	
Palisano, 2015 [77] a	CEDL; English; USA & Canada				? MDC=13.2 (scores from 11-55)				+ Differential change between GMFCS-level subgroups. ES of change: level I-III = small, level IV-V = no effect
Amaral, 2012 [78]	CHORES; Brazilian-Portuguese; Brazil	Relevance: + Comprehen-siveness: - Comprehen-sibility: ?		+ Test-retest (1-2w): ICC=0.94 [95% CI 0.79–0.98] – 0.96 [95% CI 0.90–0.99], depending on subscales					
Amini, 2017 [79]	CPQ; Persian; Iran		+/– Cronbach's α =0.66–0.99, depending on subscales (for 13/18 subscales ≥0.70)	+ Test-retest(2w): ICC=0.92–0.99, depending on subscales		+ CFA: CFI=0.99 RMSEA=0.04	+/– Correlations with VABS: ρ=0.16–0.52, depending on subscales		

8

Table 5. *Continued*

		Development	Reliability			Validity			Responsiveness
Study	Instrument; language; study country		Internal consistency	Reliability	Measurement error	Structural validity	Construct validity	Cross-cultural validity	
Michelsen, 2009 [49]	FPQ; English, Swedish, Danish, French & Italian; England, Ireland, Sweden, France, Denmark, Italy	Relevance: ? Comprehen-siveness: ? Comprehen-sibility: ?					+/– Differences between subgroups only partly in line with expectations; OR reported	? Regio-nal differ-ences deter-mined with OR.	
Tuffrey, 2013 [64]	QYPP; English; UK	Relevance: + Comprehen-siveness: ? Comprehen-sibility: ?	+/– Cronbach's α = 0.63–0.86, depending on subscales (for 4/7 subscales ≥0.70)	+ Test-retest (2-11w): ICC=0.83 [95% CI 0.67–0.91] – 0.98 [95% CI 0.97–0.99], depending on subscales		? Principal component analyses, no data reported	+/– 1) Correlations with impairment questionnaire ρ= -0.17 – -0.79, depending on subscales 2) Subgroup testing: scores differed between CP and TD; ES not reported		

Note. [a] Only the Frequency (not the Enjoyment) of family and recreational activities was examined in this study. + sufficient, - insufficient, ? indeterminate. Abbreviations: ABAS = Adaptive Behavior Assessment System, APCP = Assessment of Preschool Children's Participation, CAPE = Children's Assessment of Participation and Enjoyment, CAFI = Child and Adolescent Factors Inventory, CASE = Child and Adolescent Scale of Environment, CASP = Child and Adolescent Scale of Participation, CEDL = Child Engagement in Daily Life Measure, CFA = Confirmatory Factor Analysis, CFI = Comparative Fit index, CHORES = Children Helping Out: Responsibilities, Expectations and Supports, CI = Confidence Interval, CP = Cerebral Palsy, CPQ = Children Participation Questionnaire, ES = Effect Size, FPQ = Frequency of Participation Questionnaire, GMFCS = Gross Motor Function Classification System, GMFM = Gross Motor Function Measure, ICC = Intra-Class Correlation, m = months, MCID = Minimal Clinically Important Difference, MDC = Minimal Detectable Change, NA = Not Applicable, OR = Odds Ratios, PEDI = Pediatric Evaluation of Disability Inventory, PedsQL = Pediatric Quality of Life Scale, PSOM = Pediatric Stroke Outcome Measure, QYPP = Questionnaire of Young Peoples Participation, RMSEA = Root Mean Square Error of Approximation, SDC = Smallest Detectable Change, SRM = Standardized Response Mean, TBI = Traumatic Brain Injury, TD = Typically Developing, VABS = Vineland Adaptive Behavior Scales, WeeFIM = Wee Functional Independence Measure.

Table 6. Methodological quality of the studies investigating measurement properties of the instruments tested in ABI or CP samples

		Development	Reliability			Validity			Responsiveness
Study	Instrument		Internal consistency	Reliability	Measurement error	Structural validity	Construct validity	Cross-cultural validity	
Law, 2012 [70]	APCP	Inadequate	Doubtful				Doubtful - Adequate		
Chen, 2013 [71]	APCP				Adequate		Doubtful		Inadequate
Longo, 2012 [72]	CAPE	Inadequate		Adequate	Adequate		Adequate		
Bedell, 2004 [42]	CASP phase 2	Doubtful	Doubtful	Doubtful		Inadequate	Doubtful		
Bedell, 2009 [74]	CASP		Doubtful			Adequate	Inadequate		
Golos, 2016 [75]	CASP		Very good			Adequate	Doubtful		
Golos, 2018 [17]	CASP						Doubtful		Inadequate - Doubtful
de Kloet, 2015 [76]	CASP	Doubtful	Doubtful	Adequate			Doubtful - Adequate		
Chiarello, 2014 [43]	CEDL		Very good	Adequate		Very good	Doubtful		
Palisano, 2015 [77]	CEDL				Inadequate				Adequate
Amaral, 2012 [78]	CHORES	Doubtful		Adequate					
Amini, 2017 [79]	CPQ		Very good	Adequate		Inadequate	Doubtful		
Michelsen, 2009 [49]	FPQ	Inadequate					Adequate	Doubtful	
Tuffrey, 2013 [64]	QYPP	Doubtful	Doubtful	Doubtful		Inadequate	Doubtful		

Note. Abbreviations: ABI = Acquired Brain Injury, APCP = Assessment of Preschool Children's Participation, CAPE = Children's Assessment of Participation and Enjoyment, CASP = Child and Adolescent Scale of Participation, CEDL = Child Engagement in Daily Life Measure, CHORES = Children Helping Out: Responsibilities, Expectations and Supports, CP = Cerebral Palsy, CPQ = Children Participation Questionnaire, FPQ = Frequency of Participation Questionnaire, QYPP = Questionnaire of Young Peoples Participation.

Discussion

In the present review, we investigated instruments that have been used to assess participation in children with ABI or CP, their alignment with the attendance and/or involvement constructs of the fPRC, and what evidence exists for the measurement properties of these instruments in our population of interest.

We identified 37 instruments that had been used to assess participation of children with ABI or CP. When mapped to the fPRC, only 12 of these instruments were found to align with attendance and/or involvement and are therefore thought to assess the essential elements of 'participation' according to the recent fPRC conceptualization [13]. Participation is an evolving concept, and the fPRC framework was not available when most of the studies screened for the present review were conducted. Selection of the instruments to assess participation in many previous studies is therefore likely to have been guided by the understanding of the concept at that time (e.g. by using the ICF [10]). For example, prior to the development of the fPRC, a previous review from 2005 into participation instruments for children with CP recommended the use of the Activities Scale for Kids (ASK) and the condition-specific Lifestyle Assessment Questionnaire for cerebral palsy (LAQ-CP) [85]. According to the fPRC, only a subscale of the ASK quantifies attendance, while the LAQ-CP does not align with either attendance or involvement (see Table 2). Thus, while these two instruments are both categorized as measures of Activities and Participation according to the ICF, they assess different constructs according to the fPRC. When comparing results on participation outcomes across different studies, it is therefore essential to critically examine the instruments used and the underlying constructs assessed by these instruments. Mapping instruments to the fPRC can help clarify which constructs underlie the scores of the instruments, which, in turn, can facilitate comparability of results across studies. Future studies may consider alignment with the fPRC when selecting instruments. The overview of instruments used to assess participation of children with ABI or CP and their alignment with attendance and/or involvement presented in the present review (see Table 2) may provide a useful aid in this regard.

Fourteen studies were identified that assessed measurement properties of eight (out of 12) participation instruments aligning with the attendance and/or involvement constructs. As described previously, we only included studies that examined measurement properties in children with ABI or CP. This is consistent with the recommendation to examine measurement properties of instruments for health-related outcomes, such as participation, in the specific population of interest [18, 19]. Compared to previous reviews investigating measurement properties of participation instruments for children with ABI or CP [20, 21], we identified five additional measures for which information on measurement properties was available (APCP, CEDL, CPQ, FPQ, and QYPP). While this indicates that the evidence has increased, the limited number of studies included still highlights the lack of evidence of measurement properties in the specific population of children with ABI or CP. With the present review, we provide a comprehensive overview of the current evidence of measurement properties of participation instruments in children with ABI or CP, which may provide a useful starting point to determine which measurement properties still need further investigation.

For most instruments, sufficient measurement properties were found for at least one aspect (i.e. reliability, validity or responsiveness). However, no instrument had been investigated for all measurement properties nor demonstrated sufficient properties for all psychometrics. Most noticeable, measurement error and responsiveness have been rarely investigated. Currently, the CEDL is the only instrument that has been shown to have sufficient responsiveness in children with CP, as examined in a study of adequate methodological quality. No instrument has received a sufficient rating for measurement error combined with a study of at least adequate quality. Sufficient measurement error and responsiveness are essential to determine intervention effectiveness, both in research and in clinical settings. Future studies should therefore consider investigating (existing) instruments to confirm these measurement properties.

With the development of the COSMIN guidelines, significant progress was made in establishing standards for instrument development and assessment of measurement properties [22, 27, 86]. According to these guidelines, few studies included in the present review were of good methodological quality. Low methodological study quality does not necessarily indicate that participation instruments themselves are of low quality. Most studies included in the present review were conducted before the development of these guidelines, which made it impossible for the authors to have followed them. With progressive insight and understanding of what is essential in terms of measurement properties and how they should be assessed, measurement properties that have previously been established in low quality studies may need to be confirmed in new, higher quality studies.

There are several reasons why the methodological quality of the included studies was rated low. We present them here and include suggestions for future research on how to improve the methodological quality. For one, indeterminate ratings resulted if a certain measurement property had been examined, but not all information needed for adequate comparison against the quality criteria for good measurement properties was presented. Using the COSMIN guidelines, or a comparable resource, while developing and reporting a study into measurement properties may improve the rating of the studies [19, 22]. Structural validity was frequently not examined using confirmatory factory analysis; when this is missing, rating for the evidence of internal consistency is downgraded, since this requires clarity about the (uni-)dimensionality of the scale. For future studies, it is important to consider statistical guidelines when evaluating measurement properties to increase methodological quality. Construct validity was mostly examined by correlating scores from the participation instrument of interest with another instrument that was not aimed at assessing participation but, for example, quality of life or behavioural functioning. Since participation measures are still emerging and measurement properties of many of these instruments are still unknown, it is understandable that other, valid and reliable, instruments measuring related constructs are chosen as comparison tools. However, as mentioned above, results from correlations with instruments that assess different constructs may not be comparable. To determine construct validity of a participation instrument in relation to another instrument, it is essential that validation occurs also with instruments proposing to assess the same construct (in this case, participation). Future studies could consider computing associations between different participation instruments to assess construct validity, provided that these participation instruments measure the same construct (attendance and/or involvement) in a comparable manner (i.e. comparing frequency and diversity of participation to participation restrictions may yield very different results). Finally, many of the studies included in the present review had small study samples. While we are aware of the challenges of studies into measurement properties in a specific clinical population, it may be essential for future studies to aim to include larger samples to increase the quality of evidence of measurement properties [19].

Five instruments that aligned with the attendance and/or involvement constructs, had not undergone testing of measurement properties in a sample comprising at least 50% of children with ABI or CP: the Activities Scale for Kids (ASK) [40], the Physical Activity Questionnaire for Adolescents (PAQ-A) [59], the Physical Activity Questionnaire for Children (PAQ-C) [59], the Participation and Environment Measure for Children and Youth (PEM-CY) [62], and the Exercise Questionnaire [67]. Future studies are needed to determine validity, reliability and responsiveness of these instruments for children with ABI or CP.

Strengths and limitations of the present review

The present review was aimed at investigating participation instruments and their measurement properties in children with two frequently occurring neurological conditions: ABI and CP. Surprisingly, only a fraction of the instruments discovered had been used to assess participation in both groups. While measurement properties should be examined in the specific population of interest (see below), the instruments themselves may not need to be diagnosis specific. Since participation is an important outcome of interest for both ABI and CP, generic instruments enabling comparison in outcome across these patient groups may be preferred [87, 88]. Future research may want to determine which of the instruments aligning with attendance and/or involvement show good measurement properties for both children with ABI and CP.

In line with our aim to examine measurement properties of participation instruments for children with ABI or CP, we only included studies that investigated measurement properties in this population. This is a strength in the light of recommendations to investigate measurement properties in the specific population of interest [18, 19]. The limited number of studies examining measurement properties of participation instruments in samples of children with ABI or CP may be a surprising finding for many researchers and clinicians. Frequently, information on measurement properties of instruments is combined across multiple populations (e.g. children with various and diverse conditions and disabilities) without analysing subgroups of different diagnostic groups [25]. This can provide a broad overview of available and examined measures. However, it cannot assist researchers or clinicians in selecting instruments with good measurement properties for their specific population of interest. More studies are needed to clarify the measurement properties of instrument to assess participation in children with ABI or CP.

In the present review, we separated different instrument versions to assess their measurement properties. Instruments in different phases of development, different language versions of instruments, and different reporter-versions should be considered separate measures, since measurement properties documented for one of the version may not be transferable to all other versions [19]. Moreover, measurement properties determined simultaneously in multiple countries may be confounded and therefore not necessarily applicable to only one of these countries. However, some studies reported combined data from different instrument versions, making separate assessment impossible. For example, three studies combined data from different language versions of the same instrument, i.e. English and Spanish versions of the CASP [17, 75], and English, Swedish, French, Danish and Italian of the FPQ [49]. One study combined data from a self-report and a proxy-report of the QYPP [64]. Two studies combined data on the measurement properties of the CEDL collected in the USA and Canada [43, 77]. Particularly striking in this context is the lack of evidence of cross-cultural validity for all these measures. When researchers or clinicians want to assess participation, it is essential for them to consider that evidence for measurement properties of an instrument found in different languages or countries are not necessarily transferable to another country or population.

Clinical and research implications

Participation is essential to consider when assessing outcomes ABI or CP. Children should be assessed and monitored using a recommended set of outcome measures which are specific to the life situation in focus, have good measurement properties, and are culturally adapted. To do so, the construct of interest should be clearly defined, and selected instruments should align with these constructs. With the overview of instruments aligning with attendance and/or involvement provided in the present review (Table 2) we aim to facilitate the selection of instruments with a comparable construct for future research and clinical practice.

For valid and reliable assessment of participation, measurement properties of existing or novel instruments need further evaluation. With the present review, we provide a comprehensive overview of the available evidence for measurement properties of eight instruments to assess participation of children with ABI or CP. Since no instrument had sufficient ratings for all measurement properties, researchers and clinicians may consider selecting the instrument based on the aim of the assessment. For example, if a researcher or clinician aims to examine changes in participation of a young child with CP after a certain intervention or treatment, the CEDL may be the instrument of choice, since sufficient responsiveness and test-retest reliability have been determined in studies of adequate methodological quality. For researchers and clinicians working with children with ABI, the CASP may be the instrument of choice since it is the only participation instrument for which preliminary evidence of measurement properties available in this population.

Nevertheless, we cannot yet draw final conclusions about the quality of any of these instruments for use with children with ABI or CP, since the current overall quality of evidence is mostly low. Future studies should consider including the specific population of interest, and, importantly, following the COSMIN guidelines to improve methodological study quality.

Acknowledgements

We would like to thank Eline Scholten (Center of Excellence for Rehabilitation Medicine; University Medical Center Utrecht and De Hoogstraat Rehabilitation, Utrecht, the Netherlands) for her assistance with the COSMIN Risk of bias ratings.

References

1. Oskoui M, Coutinho F, Dykeman J, Jetté N, Pringsheim T. An update on the prevalence of cerebral palsy: a systematic review and meta-analysis. *Developmental Medicine & Child Neurology.* 2013;55(6):509-19.
2. Thurman DJ. The epidemiology of traumatic brain injury in children and youths: a review of research since 1990. *Journal of Child Neurology.* 2016;31(1):20-7.
3. Bedell GM, Dumas HM. Social participation of children and youth with acquired brain injuries discharged from inpatient rehabilitation: a follow-up study. *Brain Injury.* 2004;18(1):65-82.
4. de Kloet AJ, Gijzen R, Braga LW, Meesters JJ, Schoones JW, Vliet Vlieland TP. Determinants of participation of youth with acquired brain injury: a systematic review. *Brain Injury.* 2015;29(10):1135-45.
5. Galvin J, Froude EH, McAleer J. Children's participation in home, school and community life after acquired brain injury. *Australian Occupational Therapy Journal.* 2010;57(2):118-26.
6. Kerr C, McDowell B, McDonough S. The relationship between gross motor function and participation restriction in children with cerebral palsy: an exploratory analysis. *Child: Care, Health and Development.* 2007;33(1):22-7.
7. Rentinck I, Gorter J, Ketelaar M, Lindeman E, Jongmans M. Perceptions of family participation among parents of children with cerebral palsy followed from infancy to toddler hood. *Disability and Rehabilitation.* 2009;31(22):1828-34.
8. van Tol E, Gorter JW, DeMatteo C, Meester-Delver A. Participation outcomes for children with acquired brain injury: A narrative review. *Brain Injury*. 2011;25(13-14):1279-87.
9. Vos RC, Becher JG, Ketelaar M, Smits D-W, Voorman JM, Tan SS, et al. Developmental trajectories of daily activities in children and adolescents with cerebral palsy. *Pediatrics.* 2013;132(4):e915-e23.
10. Organization WH. *International Classification of Functioning, Disability and Health: ICF:* World Health Organization; 2001.
11. Organization WH. *International Classification of Functioning, Disability, and Health: Children & Youth Version: ICF-CY:* World Health Organization; 2007.
12. Coster W, Khetani MA. Measuring participation of children with disabilities: issues and challenges. *Disability and Rehabilitation.* 2008;30(8):639-48.
13. Imms C, Adair B, Keen D, Ullenhag A, Rosenbaum P, Granlund M. 'Participation': a systematic review of language, definitions, and constructs used in intervention research with children with disabilities. *Developmental Medicine & Child Neurology. 2*016;58(1):29-38.
14. Imms C, Granlund M, Wilson PH, Steenbergen B, Rosenbaum PL, Gordon AM. Participation, both a means and an end: a conceptual analysis of processes and outcomes in childhood disability. *Developmental Medicine & Child Neurology.* 2017;59(1):16-25.
15. Adair B, Ullenhag A, Rosenbaum P, Granlund M, Keen D, Imms C. Measures used to quantify participation in childhood disability and their alignment with the family of participation-related constructs: a systematic review. *Developmental Medicine & Child Neurology.* 2018;60(11):1101-16.
16. Bedell G, Coster W. Measuring participation of school-aged children with traumatic brain injuries: Considerations and approaches. *The Journal of Head Trauma Trhabilitation.* 2008;23(4):220-9.
17. Golos A, Bedell G. Responsiveness and discriminant validity of the Child and Adolescent Scale of Participation across three years for children and youth with traumatic brain injury. *Developmental Neurorehabilitation.* 2018;21(7):431-8.
18. Terwee CB, Bot SD, de Boer MR, van der Windt DA, Knol DL, Dekker J, et al. Quality criteria were proposed for measurement properties of health status questionnaires. *Journal of Clinical Epidemiology*. 2007;60(1):34-42.
19. Prinsen CAC, Mokkink LB, Bouter LM, Alonso J, Patrick DL, de Vet HCW, et al. COSMIN guideline for systematic reviews of patient-reported outcome measures. *Quality of Life Research.* 2018.
20. Ziviani J, Desha L, Feeney R, Boyd R. Measures of participation outcomes and environmental considerations for children with acquired brain injury: A systematic review. *Brain Impairment.* 2010;11(2):93-112.
21. Sakzewski L, Boyd R, Ziviani J. Clinimetric properties of participation measures for 5-to 13-year-old children with cerebral palsy: a systematic review. *Developmental Medicine & Child Neurology.* 2007;49(3):232-40.

22. Terwee C, Prinsen C, Garotti MR, Suman A, De Vet H, Mokkink L. The quality of systematic reviews of health-related outcome measurement instruments. *Quality of Life Research.* 2016;25(4):767-79.

23. Mokkink L, de Vet H, Prinsen C, Patrick D, Alonso J, Bouter L, et al. COSMIN Risk of Bias checklist for systematic reviews of Patient-Reported Outcome Measures. *Quality of Life Research.* 2017:1-9.

24. Lami F, Egberts K, Ure A, Conroy R, Williams K. Measurement properties of instruments that assess participation in young people with autism spectrum disorder: a systematic review. *Developmental Medicine & Child Neurology*. 2017.

25. Rainey L, van Nispen R, van der Zee C, van Rens G. Measurement properties of questionnaires assessing participation in children and adolescents with a disability: a systematic review. *Quality of Life Research.* 2014;23(10):2793-808.

26. Resch C, Rosema S, Hurks P, de Kloet A, van Heugten C. Searching for effective components of cognitive rehabilitation for children and adolescents with acquired brain injury: A systematic review. *Brain Injury.* 2018;32(6):679-92.

27. Mokkink LB, Prinsen CA, Patrick DL, Alonso J, Bouter LM, de Vet HC, et al. *COSMIN methodology for systematic reviews of Patient-Reported Outcome Measures (PROMs) – user manual.* 2018.

28. de Kloet AJ, Gijzen R, Braga LW, Meesters JJL, Schoones JW, Vliet Vlieland TPM. Determinants of participation of youth with acquired brain injury: A systematic review. *Brain Injury.* 2015;29(10):1135-45.

29. McCauley SR, Wilde EA, Anderson VA, Bedell G, Beers SR, Campbell TF, et al. Recommendations for the use of common outcome measures in pediatric traumatic brain injury research. *Journal of Neurotrauma.* 2012;29(4):678-705.

30. Mokkink LB, Terwee CB, Gibbons E, Stratford PW, Alonso J, Patrick DL, et al. Inter-rater agreement and reliability of the COSMIN (COnsensus-based Standards for the selection of health status Measurement Instruments) checklist. *BMC Medical Research Methodology.* 2010;10(1):82.

31. Law MC, Baptiste S, Carswell A, McColl MA, Polatajko H, Pollock N. *Canadian Occupational Performance Measure: COPM*: CAOT Publ. ACE; 1998.

32. Kiresuk TJ, Smith A, Cardillo JE. *Goal attainment scaling: Applications, Theory, and Measurement:* Psychology Press; 2014.

33. Ewing-Cobbs L, Bloom DR, Prasad MR, Waugh JK, Cox Jr CS, Swank PR. Assessing recovery and disability after physical trauma: the Pediatric Injury Functional Outcome Scale. *Journal of Pediatric Psychology.* 2014;39(6):653-65.

34. Landgraf J, Abetz L, Ware J. Child Health Questionnaire (CHQ): A user's manual. Boston, MA: The Health Institute, New England Medical Center; 1996. *Journal of Gdansk University of Physical Education and Sport e-ISSN.* 1999:2080-9999.

35. Liu W-Y, Hou Y-J, Liao H-F, Lin Y-H, Chen Y-Y, Wong A. A Preliminary study of the development, validity, and reliability of a caregiver questionnaire for the health-related quality of life in children with cerebral palsy. *Chang Gung Medical Journal* 2010;33(6):646-458.

36. Coster WJ, Mancini MC, Ludlow LH. Factor structure of the school function assessment. *Educational and Psychological Measurement.* 1999;59(4):665-77.

37. Thomas-Stonell N, Johnson P, Rumney P, Wright V, Oddson B. An evaluation of the responsiveness of a comprehensive set of outcome measures for children and adolescents with traumatic brain injuries. *Pediatric Rehabilitation.* 2006;9(1):14-23.

38. McDowell BC, Kerr C, Parkes J, Cosgrove A. Validity of a 1 minute walk test for children with cerebral palsy. *Developmental Medicine and Child Neurology.* 2005;47(11):744-8.

39. King G, Law M, Petrenchik T, Kertoy M. *Assessment of preschool children's participation (APCP).* Hamilton, ON: CanChild Centre for Childhood Disability Research, McMaster University. 2006.

40. Young NL, Williams JI, Yoshida KK, Wright JG. Measurement properties of the activities scale for kids. *Journal of Clinical Epidemiology.* 2000;53(2):125-37.

41. King G, Law M, King S, Hurley P, Hanna S, Kertoy M, et al. C*hildren's Assessment of Participation and Enjoyment (CAPE) and Preferences for Activities of Children (PAC)* San Antonio, TX: Harcourt Assessment. Inc; 2004.

42. Bedell GM. Developing a follow-up survey focused on participation of children and youth with acquired brain injuries after discharge from inpatient rehabilitation. *NeuroRehabilitation.* 2004;19(3):191-205.
43. Chiarello LA, Palisano RJ, McCoy SW, Bartlett DJ, Wood A, Chang H-J, et al. Child engagement in daily life: a measure of participation for young children with cerebral palsy. *Disability and Rehabilitation.* 2014;36(21):1804-16.
44. Dunn L. Validation of the CHORES: a measure of school-aged children's participation in household tasks. *Scandinavian Journal of Occupational Therapy.* 2004;11(4):179-90.
45. Waters E, Maher E, Salmon L, Reddihough D, Boyd R. Development of a condition-specific measure of quality of life for children with cerebral palsy: empirical thematic data reported by parents and children. *Child: Care, Health and Development.* 2005;31(2):127-35.
46. Davis E, Mackinnon A, Davern M, Boyd R, Waters E, Graham HK, et al. Description and psychometric properties of the CP QOL-Teen: a quality of life questionnaire for adolescents with cerebral palsy. *Research in Developmental Disabilities.* 2013;34(1):344-52.
47. Bedell GM, Haley SM, Coster WJ, Smith KW. Developing a responsive measure of change for paediatric brain injury inpatient rehabilitation. *Brain Injury.* 2002;16(8):659-71.
48. Rosenberg L, Jarus T, Bart O. Development and initial validation of the Children Participation Questionnaire (CPQ). *Disability and Rehabilitation.* 2010;32(20):1633-44.
49. Michelsen SI, Flachs EM, Uldall P, Eriksen EL, McManus V, Parkes J, et al. Frequency of participation of 8–12-year-old children with cerebral palsy: A multi-centre cross-sectional European study. *European Journal of Paediatric Neurology.* 2009;13(2):165-77.
50. Kang LJ, Palisano R, King G, Chiarello L, Orlin M, Polansky M. Social participation of youths with cerebral palsy differed based on their self-perceived competence as a friend. *Child: Care, Health and Development.* 2012;38(1):117-27.
51. Rosenbaum PL, Palisano RJ, Bartlett DJ, Galuppi BE, Russell DJ. Development of the gross motor function classification system for cerebral palsy. *Developmental Medicine & Child Neurology.* 2008;50(4):249-53.
52. Russell DJ, Rosenbaum PL, Avery LM, Lane M, Russell DJ. *Gross motor function measure (GMFM-66 & GMFM-88) user's manual:* Mac Keith Press London; 2002.
53. Bonanni P, Gobbo A, Nappi S, Moret O, Nogarol A, Santin M, et al. Functioning and disability in patients with Angelman syndrome: utility of the International Classification of functioning disability and health, children and youth adaptation framework. *Disability and Rehabilitation.* 2009;31(sup1):S121-S7.
54. Trabacca A, Russo L, Losito L, Rinaldis MD, Moro G, Cacudi M, et al. The ICF-CY perspective on the neurorehabilitation of cerebral palsy: a single case study. *Journal of Child Neurology.* 2012;27(2):183-90.
55. Hoare P, Russell M. The quality of life of children with chronic epilepsy and their families: preliminary findings with a new assessment measure. *Developmental Medicine & Child Neurology.* 1995;37(8):689-96.
56. Mackie P, Jessen E, Jarvis S. The lifestyle assessment questionnaire: an instrument to measure the impact of disability on the lives of children with cerebral palsy and their families. *Child: Care, Health and Development.* 1998;24(6):473-86.
57. Noreau L, Lepage C, Boissiere L, Picard R, Fougeyrollas P, Mathieu J, et al. Measuring participation in children with disabilities using the Assessment of Life Habits. *Developmental Medicine & Child Neurology.* 2007;49(9):666-71.
58. Malec JF, Thompson JM. Relationship of the Mayo-Portland Adaptability Inventory to functional outcome and cognitive performance measures. *The Journal of Head Trauma Rehabilitation.* 1994.
59. Kowalski KC, Crocker PR, Donen RM. *The physical activity questionnaire for older children (PAQ-C) and adolescents (PAQ-A) manual.* College of Kinesiology, University of Saskatchewan. 2004;87(1):1-38.
60. Haley SM. *Pediatric Evaluation of Disability Inventory (PEDI): Development, standardization and administration manual:* PEDI Resarch Group; 1992.
61. Haley SM, Coster WJ, Dumas HM, Fragala-Pinkham MA, Kramer J, Ni P, et al. Accuracy and precision of the Pediatric Evaluation of Disability Inventory computer-adaptive tests (PEDI-CAT). *Developmental Medicine & Child Neurology.* 2011;53(12):1100-6.

62. Coster W, Bedell G, Law M, Khetani MA, Teplicky R, Liljenquist K, et al. Psychometric evaluation of the Participation and Environment Measure for Children and Youth. *Developmental Medicine & Child Neurology.* 2011;53(11):1030-7.

63. Lerman JA, Sullivan E, Haynes RJ. The Pediatric Outcomes Data Collection Instrument (PODCI) and functional assessment in patients with adolescent or juvenile idiopathic scoliosis and congenital scoliosis or kyphosis. *Spine.* 2002;27(18):2052-7.

64. Tuffrey C, Bateman B, Colver A. The Q uestionnaire of Y oung P eople's P articipation (QYPP): a new measure of participation frequency for disabled young people. *Child: Care, Health and Development.* 2013;39(4):500-11.

65. Goodman R. The Strengths and Difficulties Questionnaire: A Research Note. *Journal of Child Psychology and Psychiatry.* 1997;38(5):581-6.

66. Soo C, Tate RL, Anderson V, Beauchamp MH, Brookes N, Catroppa C, et al. Assessing psychosocial functioning following childhood acquired brain injury: The Sydney Psychosocial Reintegration Scale for Children. *Developmental Neurorehabilitation.* 2016;19(6):356-64.

67. Brunton LK, Bartlett DJ. Description of exercise participation of adolescents with cerebral palsy across a 4-year period. *Pediatric Physical Therapy.* 2010;22(2):180-7.

68. Williams EN, Carroll SG, Reddihough DS, Phillips BA, Galea MP. Investigation of the timed 'up & go'test in children. *Developmental Medicine and Child Neurology.* 2005;47(8):518-24.

69. Sparrow SS, Cicchetti DV, Balla DA. *Vineland Adaptive Behavior Scales:(VABS):* NCS Pearson; 2005.

70. Law M, King G, Petrenchik T, Kertoy M, Anaby D. The assessment of preschool children's participation: Internal consistency and construct validity. *Physical & Occupational Therapy in Pediatrics.* 2012;32(3):272-87.

71. Chen C-l, Chen C-y, Shen I-h, Liu I-S, Kang L-j, Wu C-y. Clinimetric properties of the Assessment of Preschool Children's Participation in children with cerebral palsy. *Research in Developmental Disabilities*. 2013;34(5):1528-35.

72. Longo E, Badia M, Orgaz B, Verdugo M. Cross-cultural validation of the C hildren's A ssessment of P articipation and E njoyment (CAPE) in S pain. *Child: Care, Health and Development*. 2014;40(2):231-41.

73. Ravens-Sieberer U, Gosch A, Rajmil L, Erhart M, Bruil J, Duer W, et al. KIDSCREEN-52 quality-of-life measure for children and adolescents. *Expert Review of Pharmacoeconomics & Outcomes Research*. 2005;5(3):353-64.

74. Bedell G. Further validation of the Child and Adolescent Scale of Participation (CASP). *Developmental Neurorehabilitation.* 2009;12(5):342-51.

75. Golos A, Bedell G. Psychometric properties of the Child and Adolescent Scale of Participation (CASP) across a 3-year period for children and youth with traumatic brain injury. *NeuroRehabilitation.* 2016;38(4):311-9.

76. de Kloet AJ, Berger MA, Bedell GM, Catsman-Berrevoets CE, van Markus-Doornbosch F, Vliet Vlieland TP. Psychometric evaluation of the Dutch language version of the Child and Family Follow-up Survey. *Developmental Neurorehabilitation.* 2015;18(6):357-64.

77. Palisano RJ, Chiarello LA, McCoy SW, Bartlett D, An M. Use of the child engagement in daily life and ease of caregiving for children to evaluate change in young children with cerebral palsy. *Physical & Occupational Therapy in Pediatrics.* 2015;35(3):280-95.

78. Amaral M, Paula RL, Drummond A, Dunn L, Mancini MC. Translation of the Children Helping Out-Responsibilities, Expectations and Supports (CHORES) questionnaire into Brazilian-Portuguese: semantic, idiomatic, conceptual and experiential equivalences and application in normal children and adolescents and in children with cerebral palsy. *Brazilian Journal of Physical Therapy.* 2012;16(6):515-22.

79. Amini M, Hassani Mehraban A, Rostamzadeh O, Mehdizadeh F. Psychometric Properties of the Iranian-Children Participation Questionnaire (I-CPQ) When Used with Parents of Preschool Children with Cerebral Palsy. *Occupational Therapy in Health Care.* 2017;31(4):341-51.

80. Oakland T, Harrison PL. *Adaptive behavior assessment system-II: Clinical use and interpretation*: Academic Press; 2011.

81. Palisano RJ, Rosenbaum P, Bartlett D, Livingston MH. Content validity of the expanded and revised Gross Motor Function Classification System. *Developmental Medicine & Child Neurology.* 2008;50(10):744-50.

82. Varni JW, Seid M, Kurtin PS. PedsQL™ 4.0: Reliability and validity of the Pediatric Quality of Life Inventory™ Version 4.0 Generic Core Scales in healthy and patient populations. *Medical Care.* 2001;39(8):800-12.

83. Kitchen L, Westmacott R, Friefeld S, MacGregor D, Curtis R, Allen A, et al. The pediatric stroke outcome measure: a validation and reliability study. *Stroke.* 2012;43(6):1602-8.

84. Msall ME, DiGaudio K, Duffy LC, LaForest S, Braun S, Granger CV. WeeFIM: normative sample of an instrument for tracking functional independence in children. *Clinical Pediatrics*. 1994;33(7):431-8.

85. Morris C, Kurinczuk J, Fitzpatrick R. Child or family assessed measures of activity performance and participation for children with cerebral palsy: a structured review. *Child: Care, Health and Development*. 2005;31(4):397-407.

86. Prinsen CA, Vohra S, Rose MR, Boers M, Tugwell P, Clarke M, et al. How to select outcome measurement instruments for outcomes included in a "Core Outcome Set"–a practical guideline. *Trials.* 2016;17(1):449.

87. Coons SJ, Rao S, Keininger DL, Hays RD. A Comparative Review of Generic Quality-of-Life Instruments. *PharmacoEconomics.* 2000;17(1):13-35.

88. Patrick DL, Deyo RA. Generic and disease-specific measures in assessing health status and quality of life. *Medical Care.* 1989:S217-S32.

Supplemental material 1. Full search strategy MEDLINE/PubMed

(Participation [tiab] OR “Social Participation”[Mesh] OR “Community Participation”[Mesh] OR “Interpersonal Relations”[Mesh] OR “Leisure Activities”[Mesh] OR “Self Care”[Mesh] OR “Activities of Daily Living”[Mesh] OR “Communication”[Mesh] OR “Education”[Mesh] OR domestic li* OR mobility OR involvement [tiab] OR engagement [tiab])

AND

((“Brain Injuries”[Mesh] OR brain injur*[tiab] OR brain trauma*[tiab] OR brain lesion*[tiab] OR brain laceration*[tiab] OR brain contusion*[tiab] OR brain damage[tiab] OR concussion*[tiab] OR traumatic brain*[tiab] OR commotio cerebri[tiab] OR cerebral contusion*[tiab] OR cerebral damage[tiab] OR head trauma[tiab] OR post-concussi*[tiab] OR postconcussi*[tiab] OR “Brain Neoplasms”[Mesh] OR brain tumor*[tiab] OR brain tumour*[tiab] OR “Craniocerebral Trauma”[Mesh] OR “Stroke”[Mesh] OR “Cerebrovascular Disorders”[Mesh] OR cva[tiab] OR cvas[tiab] OR stroke[tiab] OR cerebrovascular accident*[tiab] OR “Hypoxia, Brain”[Mesh] OR “Encephalitis”[Mesh] OR encephalitis[tiab] OR “Meningitis”[Mesh] OR meningitis[tiab])
OR
(“Cerebral Palsy”[Mesh] OR cerebral pals*[tiab] OR brain pals*[tiab] OR brain paralys*[tiab] OR central pals*[tiab] OR central paralys*[tiab] OR cerebral paralys*[tiab] OR cerebral pares*[tiab] OR “Muscle Spasticity”[Mesh] OR “Muscle Spasticity”[tiab] OR “CP”[tiab] OR “Spastic*”[tiab] OR “Hemiplegia”[tiab] OR “Diplegi*”[tiab] OR (encephalopathi*[tiab] AND infantil*[tiab]) OR little disease*[tiab] OR little’s disease*[tiab]))

Limits:
Age: 0-18 years

Chapter 9

General discussion

References

1. Anderson P. Assessment and development of executive function (EF) during childhood. *Child Neuropsychology.* 2002;8(2):71-82.
2. Diamond A. Executive functions. *Annual Review of Psychology.* 2013;64:135-68.
3. Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD. The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*. 2000;41(1):49-100.
4. Anderson V, Catroppa C. Recovery of executive skills following paediatric traumatic brain injury (TBI): A 2 year follow-up. *Brain Injury.* 2005;19(6):459-70.
5. Anderson V, Catroppa C, Morse S, Haritou F, Rosenfeld J. Functional plasticity or vulnerability after early brain injury? *Pediatrics.* 2005;116(6):1374-82.
6. Anderson V, Godfrey C, Rosenfeld JV, Catroppa C. Predictors of cognitive function and recovery 10 years after traumatic brain injury in young children. *Pediatrics.* 2012;129(2):e254-e61.
7. Diamond A, Ling DS. Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience.* 2016;18:34-48.
8. Abwender DA, Swan JG, Bowerman JT, Connolly SW. Qualitative analysis of verbal fluency output: Review and comparison of several scoring methods. *Assessment*. 2001;8(3):323-38.
9. Hurks PP. Administering design fluency tests in school-aged children: analyses of design productivity over time, clustering, and switching. *The Clinical Neuropsychologist.* 2013;27(7):1131-49.
10. Hurks PP, Schrans D, Meijs C, Wassenberg R, Feron F, Jolles J. Developmental changes in semantic verbal fluency: Analyses of word productivity as a function of time, clustering, and switching. *Child Neuropsychology.* 2010;16(4):366-87.
11. Kavé G, Kigel S, Kochva R. Switching and clustering in verbal fluency tasks throughout childhood. *Journal of Clinical and Experimental Neuropsychology.* 2008;30(3):349-59.
12. Koren R, Kofman O, Berger A. Analysis of word clustering in verbal fluency of school-aged children. *Archives of Clinical Neuropsychology*. 2005;20(8):1087-104.
13. Hurks P, Vles J, Hendriksen J, Kalff A, Feron F, Kroes M, et al. Semantic category fluency versus initial letter fluency over 60 seconds as a measure of automatic and controlled processing in healthy school-aged children. *Journal of Clinical and Experimental Neuropsychology*. 2006;28(5):684-95.
14. Troyer AK, Moscovitch M, Winocur G. Clustering and switching as two components of verbal fluency: evidence from younger and older healthy adults. *Neuropsychology.* 1997;11(1):138.
15. Hurks PP. Does instruction in semantic clustering and switching enhance verbal fluency in children? *The Clinical Neuropsychologist.* 2012;26(6):1019-37.
16. Siegler RS. Emerging minds: *The process of change in children's thinking:* Oxford University Press; 1998.
17. Miller PH, Seier WL. Strategy utilization deficiencies in children: When, where, and why. In H. W. Reese (Ed.), *Advances in child development and behavior*, Vol. 25, pp. 107-156). San Diego, CA, US: Academic Press. 1994.
18. Mabbott DJ, Bisanz J. Developmental change and individual differences in children's multiplication. *Child Development.* 2003;74(4):1091-107.
19. Osterrieth PA. Le test de copie d'une figure complexe: Contribution a l'etude de la perception et de la memoire [Copying a complex figure: Contributions to the study of perception and memory]. *Archives de Psychologie*. 1944;30:206-356.
20. Rey A. L'examen psychologique dans les cas d'encéphalopathie traumatique [Psychological examination of cases of traumatic encephalopathy]. *Archives de Psychologie*. 1941;28:215-85.
21. Hubley AM. Modification of the Taylor complex figure: A comparable figure to the Rey-Osterrieth figure? *Edgeworth Series in Quantitative Behavioural Science*, Paper No ESQBS-96-71996.
22. Hubley AM. *Scoring system for the Modified Taylor Complex Figure (MTCF).* Unpublished research University of Northern British Columbia, Prince George, BC. 1998.

23. Lezak M, Howieson D, Bigler E, Tranel D. *Neuropsychological Assessment.* 5th ed. New York: Oxford University Press; 2012.
24. Strauss E, Sherman EM, Spreen O. *A compendium of neuropsychological tests: Administration, norms, and commentary.* Oxford, UK: Oxford University Press; 2006.
25. Akshoomoff NA, Stiles J. Developmental trends in visuospatial analysis and planning: II. Memory for a complex figure. *Neuropsychology. 1*995;9(3):378-9.
26. Anderson V, Spencer-Smith M, Wood A. Do children really recover better? Neurobehavioural plasticity after early brain insult. *Brain.* 2011;134(8):2197-221.
27. Crowe LM, Catroppa C, Babl FE, Rosenfeld JV, Anderson V. Timing of traumatic brain injury in childhood and intellectual outcome. *Journal of Pediatric Psychology.* 2012;37(7):745-54.
28. Dennis M, Spiegler BJ, Simic N, Sinopoli KJ, Wilkinson A, Yeates KO, et al. Functional plasticity in childhood brain disorders: When, what, how, and whom to assess. *Neuropsychology Review.* 2014;24(4):389.
29. Romine CB, Reynolds CR. A model of the development of frontal lobe functioning: Findings from a meta-analysis. *Applied Neuropsychology.* 2005;12(4):190-201.
30. Best JR, Miller PH, Jones LL. Executive functions after age 5: Changes and correlates. *Developmental Review*. 2009;29(3):180-200.
31. Jurado MB, Rosselli M. The elusive nature of executive functions: a review of our current understanding. *Neuropsychology Review.* 2007;17(3):213-33.
32. Giedd JN, Blumenthal J, Jeffries NO, Castellanos FX, Liu H, Zijdenbos A, et al. Brain development during childhood and adolescence: a longitudinal MRI study. *Nature Neuroscience*. 1999;2(10):861-3.
33. Gogtay N, Giedd JN, Lusk L, Hayashi KM, Greenstein D, Vaituzis AC, et al. Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National academy of Sciences of the United States of America.* 2004;101(21):8174-9.
34. Organization WH. *International Classification of Functioning,* Disability and Health: ICF: World Health Organization; 2001.
35. Taylor HG, Yeates KO, Wade SL, Drotar D, Stancin T, Burant C. Bidirectional child–family influences on outcomes of traumatic brain injury in children. *Journal of the International Neuropsychological Society.* 2001;7(6):755-67.
36. Catharine VL, Helena V, Eva G, Ellen D, Karen C, Guy V, et al. Is diffuse axonal injury on susceptibility weighted imaging a biomarker for executive functioning in adolescents with traumatic brain injury? *European Journal of Paediatric Neurology.* 2019;23(3):525-36.
37. King D, Ellis K, Seri S, Wood A. A systematic review of cross-sectional differences and longitudinal changes to the morphometry of the brain following paediatric traumatic brain injury. *NeuroImage: Clinical*. 2019:101844.
38. Ryan NP, Reyes J, Crossley L, Beauchamp MH, Catroppa C, Anderson V. Unraveling the association between pediatric traumatic brain injury and social dysfunction: the mediating role of self-regulation. *Journal of Neurotrauma.* 2019(ja).
39. Ryan NP, van Bijnen L, Catroppa C, Beauchamp MH, Crossley L, Hearps S, et al. Longitudinal outcome and recovery of social problems after pediatric traumatic brain injury (TBI): Contribution of brain insult and family environment. *International Journal of Developmental Neuroscience.* 2016;49:23-30.
40. Cnossen MC, Winkler EA, Yue JK, Okonkwo DO, Valadka AB, Steyerberg EW, et al. Development of a prediction model for post-concussive symptoms following mild traumatic brain injury: a TRACK-TBI pilot study. *Journal of Neurotrauma.* 2017;34(16):2396-409.
41. Zemek R, Barrowman N, Freedman SB, Gravel J, Gagnon I, McGahern C, et al. Clinical risk score for persistent postconcussion symptoms among children with acute concussion in the ED. *JAMA.* 2016;315(10):1014-25.
42. Königs M, Pouwels PJ, van Heurn LE, Bakx R, Vermeulen RJ, Goslings JC, et al. Relevance of neuroimaging for neurocognitive and behavioral outcome after pediatric traumatic brain injury. *Brain Imaging and Behavior*. 2018;12(1):29-43.

43. Ryan NP, Catroppa C, Godfrey C, Noble-Haeusslein LJ, Shultz SR, O'Brien TJ, et al. Social dysfunction after pediatric traumatic brain injury: a translational perspective. *Neuroscience & Biobehavioral Reviews*. 2016;64:196-214.

44. Ponsford J. Factors contributing to outcome following traumatic brain injury. *NeuroRehabilitation*. 2013;32(4):803-15.

45. Wolters Gregório G, Ponds RW, Smeets SM, Jonker F, Pouwels CG, Verhey FR, et al. Associations between executive functioning, coping, and psychosocial functioning after acquired brain injury. *British Journal of Clinical Psychology*. 2015;54(3):291-306.

46. Vander Linden C, Verhelst H, Verleysen G, Caeyenberghs K, Deblaere K, Vingerhoets G. Prefrontal and temporal cortical thickness in adolescents with traumatic brain injury. D*evelopmental Medicine & Child Neurology*. 2019;61(6):672-9.

47. Limond J, Adlam AR, Cormack M. A model for pediatric neurocognitive interventions: Considering the role of development and maturation in rehabilitation planning. *The Clinical Neuropsychologist*. 2014;28(2):181-98.

48. Aksayli ND, Sala G, Gobet F. The Cognitive and Academic Benefits of Cogmed: A Meta-Analysis. *Educational Research Review*. 2019.

49. Takacs ZK, Kassai R. The efficacy of different interventions to foster children's executive function skills: A series of meta-analyses. *Psychological Bulletin*. 2019:No Pagination Specified-No Pagination Specified.

50. Bogdanova Y, Yee MK, Ho VT, Cicerone KD. Computerized cognitive rehabilitation of attention and executive function in acquired brain injury: a systematic review. *The Journal of Head Trauma Rehabilitation*. 2016;31(6):419.

51. Cha Y-J, Kim H. Effect of computer-based cognitive rehabilitation (CBCR) for people with stroke: a systematic review and meta-analysis. *NeuroRehabilitation,* 32(2):359-68, 2013.

52. Kassai R, Futo J, Demetrovics Z, Takacs ZK. A meta-analysis of the experimental evidence on the near-and far-transfer effects among children's executive function skills. *Psychological Bulletin*. 2019;145(2):165.

53. Melby-Lervåg M, Hulme C. Is working memory training effective? A meta-analytic review. *Developmental Psychology*. 2013;49(2):270.

54. Melby-Lervåg M, Redick TS, Hulme C. Working memory training does not improve performance on measures of intelligence or other measures of "far transfer" evidence from a meta-analytic review. *Perspectives on Psychological Science*. 2016;11(4):512-34.

55. Peijnenborgh JC, Hurks PM, Aldenkamp AP, Vles JS, Hendriksen JG. Efficacy of working memory training in children and adolescents with learning disabilities: A review study and meta-analysis. *Neuropsychological Rehabilitation*. 2016;26(5-6):645-72.

56. Dunning DL, Holmes J. Does working memory training promote the use of strategies on untrained working memory tasks? *Memory & Cognition*. 2014;42(6):854-62.

57. Klingberg T, Fernell E, Olesen PJ, Johnson M, Gustafsson P, Dahlström K, et al. Computerized Training of Working Memory in Children With ADHD-A Randomized, Controlled Trial. J*ournal of the American Academy of Child & Adolescent Psychiatry*. 2005;44(2):177-86.

58. Limond J, Leeke R. Practitioner review: cognitive rehabilitation for children with acquired brain injury. *Journal of Child Psychology and Psychiatry*. 2005;46(4):339-52.

59. Robinson KE, Kaizar E, Catroppa C, Godfrey C, Yeates KO. Systematic review and meta-analysis of cognitive interventions for children with central nervous system disorders and neurodevelopmental disorders. *Journal of Pediatric Psychology*. 2014;39(8):846-65.

60. Ross KA, Dorris L, McMillan T. A systematic review of psychological interventions to alleviate cognitive and psychosocial problems in children with acquired brain injury. *Developmental Medicine & Child Neurology*. 2011;53(8):692-701.

61. Slomine B, Locascio G. Cognitive rehabilitation for children with acquired brain injury. *Developmental Disabilities Research Reviews*. 2009;15(2):133-43.

62. Imms C, Adair B, Keen D, Ullenhag A, Rosenbaum P, Granlund M. 'Participation': a systematic review of language, definitions, and constructs used in intervention research with children with disabilities. *Developmental Medicine & Child Neurology*. 2016;58(1):29-38.

63. Imms C, Granlund M, Wilson PH, Steenbergen B, Rosenbaum PL, Gordon AM. Participation, both a means and an end: a conceptual analysis of processes and outcomes in childhood disability. *Developmental Medicine & Child Neurology*. 2017;59(1):16-25.

64. McCauley SR, Wilde EA, Anderson VA, Bedell G, Beers SR, Campbell TF, et al. Recommendations for the use of common outcome measures in pediatric traumatic brain injury research. *Journal of Neurotrauma.* 2012;29(4):678-705.

65. Wearne T, Anderson V, Catroppa C, Morgan A, Ponsford J, Tate R, et al. Psychosocial functioning following moderate-to-severe pediatric traumatic brain injury: recommended outcome instruments for research and remediation studies. *Neuropsychological Rehabilitation.* 2018:1-15.

66. Bedell G. Further validation of the Child and Adolescent Scale of Participation (CASP). *Developmental Neurorehabilitation.* 2009;12(5):342-51.

67. Bedell GM. Developing a follow-up survey focused on participation of children and youth with acquired brain injuries after discharge from inpatient rehabilitation. *NeuroRehabilitation.* 2004;19(3):191-205.

68. de Kloet AJ, Berger MA, Bedell GM, Catsman-Berrevoets CE, van Markus-Doornbosch F, Vliet Vlieland TP. Psychometric evaluation of the Dutch language version of the Child and Family Follow-up Survey. *Developmental Neurorehabilitation.* 2015;18(6):357-64.

69. Golos A, Bedell G. Psychometric properties of the Child and Adolescent Scale of Participation (CASP) across a 3-year period for children and youth with traumatic brain injury. *NeuroRehabilitation*. 2016;38(4):311-9.

70. Golos A, Bedell G. Responsiveness and discriminant validity of the Child and Adolescent Scale of Participation across three years for children and youth with traumatic brain injury. *Developmental Neurorehabilitation.* 2018;21(7):431-8.

71. Ardila A, Rosselli M, Matute E, Guajardo S. The influence of the parents' educational level on the development of executive functions. *Developmental Neuropsychology.* 2005;28(1):539-60.

72. Klenberg L, Korkman M, Lahti-Nuuttila P. Differential development of attention and executive functions in 3-to 12-year-old Finnish children. *Developmental Neuropsychology.* 2001;20(1):407-28.

73. Korkman M, Kemp SL, Kirk U. Effects of age on neurocognitive measures of children ages 5 to 12: A cross-sectional study on 800 children from the United States. *Developmental Neuropsychology*. 2001;20(1):331-54.

74. Korkman M, Kirk U, Kemp S. *NEPSY: A Developmental Neuropsychological Assessment*: Psychological Corporation; 1998.

75. Kraemer HC, Yesavage JA, Taylor JL, Kupfer D. How can we learn about developmental processes from cross-sectional studies, or can we? *American Journal of Psychiatry.* 2000;157(2):163-71.

76. Schmiedek F, Lövdén M, von Oertzen T, Lindenberger U. Within-person structures of daily cognitive performance cannot be inferred from between-person structures of cognitive abilities. *PeerJ Preprints*; 2019. Report No.: 2167-9843.

77. Grammer JK, Coffman JL, Ornstein PA, Morrison FJ. Change over time: Conducting longitudinal studies of children's cognitive development. *Journal of Cognition and Development*. 2013;14(4):515-28.

78. Stievano P, Scalisi TG. Unique designs, errors and strategies in the Five-Point Test: The contribution of age, phonemic fluency and visuospatial abilities in Italian children aged 6–11 years. *Child Neuropsychology.* 2016;22(2):197-219.

79. Van Stan JH, Dijkers MP, Whyte J, Hart T, Turkstra LS, Zanca JM, et al. The Rehabilitation Treatment Specification System: implications for improvements in research design, reporting, replication, and synthesis. *Archives of Physical Medicine and Rehabilitation.* 2019;100(1):146-55.

80. Karbach J, Unger K. Executive control training from middle childhood to adolescence. *Frontiers in Psychology.* 2014;5:390.

81. Tate RL, Perdices M, McDonald S, Togher L, Rosenkoetter U. The design, conduct and report of single-case research: Resources to improve the quality of the neurorehabilitation literature. *Neuropsychological Rehabilitation.* 2014;24(3-4):315-31.

82. Tate RL, Perdices M, Rosenkoetter U, Shadish W, Vohra S, Barlow DH, et al. The single-case reporting guideline In BEhavioural interventions (SCRIBE) 2016 statement. *Evidence-based Communication Assessment and Intervention.* 2016;10(1):44-58.

83. Tate RL, Perdices M, Rosenkoetter U, Wakim D, Godbee K, Togher L, et al. Revision of a method quality rating scale for single-case experimental designs and n-of-1 trials: The 15-item Risk of Bias in N-of-1 Trials (RoBiNT) Scale. *Neuropsychological Rehabilitation*. 2013;23(5):619-38.

84. Perdices M, Tate RL. Single-subject designs as a tool for evidence-based clinical practice: Are they unrecognised and undervalued? *Neuropsychological Rehabilitation*. 2009;19(6):904-27.

85. Encarnação P, Alvarez L, Rios A, Maya C, Adams K, Cook A. Using virtual robot-mediated play activities to assess cognitive skills. *Disability and Rehabilitation: Assistive Technology*. 2014;9(3):231-41.

86. Erez N, Weiss PL, Kizony R, Rand D. Comparing performance within a virtual supermarket of children with traumatic brain injury to typically developing children: A pilot study. *OTJR: Occupation, Participation and Health.* 2013;33(4):218-27.

87. van den Heerik MS, Spreij LA, Visser-Meily JMA, Rentinck ICM, Verhoef M, Nijboer TCW. Spelend revalideren: is er toekomst voor virtual reality in de cognitieve kinderrevalidatie? Een literatuuroverzicht. *Neuropraxis.* 2016;20(5):134-46.

88. Tomic W, Klauer KJ. On the effects of training inductive reasoning: How far does it transfer and how long do the effects persist? *European Journal of Psychology of Education.* 1996;11(3):283.

89. Wang Z, Zhou R, Shah P. Spaced cognitive training promotes training transfer. *Frontiers in Human Neuroscience.* 2014;8(217).

90. Chavez-Arana C, Catroppa C, Carranza-Escárcega E, Godfrey C, Yáñez-Téllez G, Prieto-Corona B, et al. A systematic review of interventions for hot and cold executive functions in children and adolescents with acquired brain injury. *Journal of Pediatric Psychology.* 2018;43(8):928-42.

Summary

Samenvatting

Valorisation

Dankwoord

About the author

Publications and presentations

Summary

Executive functions (EF) are a collection of cognitive functions responsible for goal-directed and purposeful behaviour. EF are thought to consist of various unique, but interrelation, functions. There are three core EF (inhibitory control, working memory and cognitive flexibility) which, in turn, underlie more complex, EF such as planning, organising, initiating, monitoring, reasoning, and strategy use. EF are essential for children's and adolescents' daily life functioning, including school functioning, health, participation, and quality of life. Childhood and adolescence are important periods of EF development, marked by cognitive and neural maturation. Current knowledge gaps concern EF processes underlying young children's task performance, the role of age at injury in the impact of acquired brain injury on EF, effective EF interventions for children and adolescents with acquired brain injury, and assessment of participation as ultimate outcome of interventions after acquired brain injury. In **chapter 1,** we discuss the background of these knowledge gaps in more detail.

In **chapter 2**, we report on a cross-sectional study examining age-related differences in performance on a verbal fluency task. A verbal fluency task is a tool to measure a variety of cognitive abilities, such as lexico-semantic knowledge, lexical access, and EF including cognitive flexibility, monitoring and strategy use. To gain insight into the role of EF in performance on a verbal fluency task, we examined so-called 'process measures'. In total, 225 primary school children aged 4 to 6 years participated. We administered a verbal fluency task in which children were instructed to name as many animals as possible within 1 minute. As outcomes of the verbal fluency task, we examined total word productivity, and two process measures: mean cluster size and switching. The mean cluster size is thought to reflect strategy use to improve retrieval of lexico-semantic knowledge. Switching can be considered an indication of cognitive flexibility. Age influenced performance on all verbal fluency outcomes linearly: older children (in the group of 4 to 6-year-olds) produced more words, made larger clusters, and switched more. Findings suggest that already in young children aged 4 to 6, process measures, such as mean cluster size and switching, can provide insight in processes underlying successful performance on a verbal fluency task. Age-extrinsic factors, such as sex and level of parental education, should be taken into account when examining verbal fluency performance, since they were found to affect some outcomes (i.e. total word productivity and switching) in young children.

In **chapter 3,** we present results of a longitudinal study investigating developmental changes in performance on a design fluency task, the non-verbal alternative to a verbal fluency task. Children are asked to create as many different designs as possible within 1 minute by drawing lines between dots in a symmetrically arranged five-dot matrix. Similar to the verbal fluency task, performance on a design fluency task relies on a variety of cognitive functions, amongst which are motor planning, visuospatial abilities, visuo-constructive skills, and the same EF involved in verbal fluency performance (i.e. cognitive flexibility, monitoring and strategy use). To disentangle the various EF involved in design fluency performance, we examined total design productivity, clustering and switching, comparable to the verbal fluency outcomes examined in chapter 2. Children aged 4 to 6 years at inclusion were assessed three times, with each assessment separated from the next by approximately 1 year. Total design productivity increased with age at baseline and across all time points of assessment. Switching increased with age at baseline and up to the second assessment, but not up to the third assessment. In contrast, clustering was only increased at the third assessment. These trends appeared to hold for all children regardless of age at baseline. Findings suggest that children adapt their approach to the design fluency task when performing it multiple times, or that there are individual differences regarding the age at which children adapt their task approach. There was no difference between boys and girls on any of the outcomes. Level of parental education was positively associated with total design productivity, but not with switching or clustering, suggesting that the EF underlying clustering and switching are less dependent on level of parental education than other cognitive functions involved in the task, such as motor skills and visuospatial abilities. The early emergence of clustering during a verbal fluency task (see chapter 2) but not during a design fluency task suggests that assessment of EF processes in young children may be context specific.

In **chapter 4,** we examined whether this context specificity of EF processes also plays a role when targeting process measures with a short instruction on one task to improve children's use of these processes on another task. Specifically, we conducted a randomised controlled trial into the effects of strategy instruction on complex figure tasks. Complex figure tasks require children to first copy and later recall a figure from memory. Task performance relies on visuo-constructional and visual memory skills, and EF such as organising and strategy use. Participants were 98 primary school children aged 9 to 12 years. Children completed the Rey-Osterrieth Complex Figure task (ROCF) as a pretest. Approximately a month later, they were randomised to complete the ROCF again either (1) with strategy instruction or (2) in the standard format. The strategy instruction consisted of sequentially highlighting the elements of the ROCF, starting with the ones that are pivotal for its organisation and finishing with the details. As a posttest, all children copied and recalled the Modified Taylor Complex Figure (MTCF). The main organisational elements of the MTCF are the same as those of the ROCF. Drawings were assessed on their organisation, accuracy and completion time. The group who had received strategy instruction showed better organisation of the recalled MTFC than the group who did not receive strategy instruction. In contrast, neither organisation scores for the copy of the drawing nor accuracy and completion times differed between groups. Process measures can be a useful target to improve EF processes in children in a context with minimal irrelevant stimuli (i.e. during complex figure recall). However, even though children could apply a strategy learned in one context to a different context, improvement in recall organisation was not paralleled by improvement in accuracy. Possibly, children require more explicit instructions, discussing the connection between the new strategy and other relevant contexts. In chapter 6 and 7, we describe how explicit strategy instruction may affect EF in children and adolescents with acquired brain injury.

In **chapter 5** we investigated whether age at injury differentially affects children's and adolescents' EF 6 months and 2 years after traumatic brain injury (TBI; a specific form of acquired brain injury). Three core EF (inhibitory control, working memory and cognitive flexibility) were examined on the level of functions and on the level of activities. Based on previous studies and on proposed timing of cerebral maturational spurts, we categorised 105 children and adolescents with TBI into four age-at-injury groups: early childhood (5 to 6 years), middle childhood (7 to 9 years), late childhood (10 to 12 years) and adolescence (13 to 15 years). Additionally, we included 42 typically developing children matched on age and sex with the TBI groups. Results showed that inhibitory control performance 2-years post injury was differentially affected by the impact of TBI depending on age at injury. The vulnerability seems most apparent for those injured in early childhood or adolescence, although strong conclusions cannot yet be drawn due to non-significant age group differences during follow-up analyses. Inhibitory control on the level of activities was worse for children with TBI than for typically developing children across childhood and adolescence at the 2-year assessment. Working memory and cognitive flexibility were not impaired after TBI at the group level. Extent, number and volume of brain lesions detected with susceptibility-weighted imaging negatively correlated with adolescent everyday EF behaviour 6 months post-injury. However, given small group sizes, findings from analyses into correlations between EF and brain lesions should be interpreted with caution. The results emphasise the need for long-term follow-up after paediatric TBI during sensitive developmental periods for EF given negative inhibitory control outcomes 2-year post injury.

In **chapter 6,** we conducted a systematic review to provide an overview of available evidence for cognitive interventions for children and adolescents with acquired brain injury. We focused on identifying effective intervention components. Interventions were categorised based on the following main components: (1) metacognition and/or strategy use, (2) (computerised) repeated practice, and (3) external aids. Metacognition and/or strategy use training is directed at providing children instructions on how to 'think about their thinking' and/or how to approach a specific task. Repeated practice interventions are based on the idea that improvements in cognitive functioning can be elicited by repeatedly practicing tasks for a specific cognitive function. External aids, such as diaries, provide compensatory support for cognitive difficulties. We systematically searched electronic literature databases, and we identified additional articles through cross-referencing and by consulting experts in the field. In total, 20 articles describing 19 studies were included. Metacognition and/or strategy use interventions mainly improved psychosocial functioning. Intervention based on repeated task practice improved performance on tasks similar to training. Interventions combining these two components benefited cognitive and psychosocial functioning. External aids improved functioning in the specific area targeted by the external aid, for example memory. Together, available evidence suggests that multi-component rehabilitation, such as combining metacognition/strategy use and repeated task practice, is most promising, as it can lead to improvements in both cognitive and psychosocial functioning of children and adolescents with acquired brain injury. Conclusions remain tentative due to small sample sizes of included studies, heterogeneity regarding outcome measures, intervention and therapist variables, and patient characteristics.

Based on theoretical models and on our findings of chapter 6, we developed a new cognitive intervention combining repeated practice of cognitive tasks with explicit strategy instruction. This new cognitive intervention for children and adolescents with acquired brain injury is described in **chapter 7.** Repeated task practice is presented in the context of a computer-based cognitive retraining (CBCR). For the explicit strategy instruction, we developed a protocol, consisting of function specific and metacognitive strategies. The CBCR provides the opportunity to first explain strategies in a game-like context before linking them to daily life situations. Next, the explicit strategy instruction can promote the use of strategies on cognitive tasks as well as the generalisation to daily life by explicitly relating the newly acquired strategies to relevant daily life areas and contexts. Children and adolescent with acquired brain injury train five times per week for 30 minutes per day at home with the CBCR and attend 45 minutes of explicit strategy instruction per week at their rehabilitation centre or specialised school. All training sessions are planned in a period of 6 weeks. We are currently examining the effectiveness of the intervention in a multicentre trial in the Netherlands. It is expected that the new intervention will elicit significant improvement in children and adolescents with acquired brain injury in terms of cognitive functioning and other areas of functioning, such as participation.

In **chapter 8,** we examined instruments to assess participation in children and adolescent with two frequently occurring neurological conditions: acquired brain injury or cerebral palsy. We systematically searched five electronic databases. We found 37 instruments that had been used to assess participation in our populations of interest. Next, these instruments were mapped to the family of Participation Related Constructs (fPRC). The fPRC provides a novel framework to conceptualise participation. According to the fPRC, participation is defined by two main constructs: attendance and involvement. For the twelve instruments that aligned with attendance and/or involvement, eight had preliminary evidence for measurement properties (i.e. validity, reliability and responsiveness) in children with acquired brain injury or cerebral palsy. Sufficient measurement properties were reported for most of the measures, but no instrument had been assessed on all relevant properties. Overall, current evidence for measurement properties is limited, mainly caused by low methodological study quality.

In **chapter 9,** we report and interpret the main findings from the studies presented in the previous chapters. Methodological strengths and limitations are discussed. Additionally, we describe the implications of our findings and provide suggestions for future research. Together, results of the present thesis indicate that context (both during assessment as well as during intervention) plays an important role in EF outcomes of children and adolescents and should be considered an essential aspect in future research and clinical and educational practice.

Samenvatting

Executieve functies zijn cognitieve functies die verantwoordelijk zijn voor doelgericht gedrag. Zij worden ook weleens *regelfuncties* genoemd. EF bestaan uit verschillende unieke functies. Inhibitie, werkgeheugen en cognitieve flexibiliteit zijn de drie kern EF. Deze kern EF vormen de basis voor complexere EF, zoals plannen, organiseren, initiëren, monitoren, redeneren en strategiegebruik. EF zijn essentieel voor het dagelijks functioneren van kinderen en adolescenten, bijvoorbeeld als het gaat om schools functioneren, gezondheid, participatie in de maatschappij en kwaliteit van leven. De kindertijd en de adolescentie zijn beide belangrijke perioden voor de ontwikkeling van EF. In deze perioden vindt er rijping plaats van zowel de cognitieve functies als ook de onderliggende hersenstructuren. Door onderzoek krijgen we steeds beter inzicht in EF van kinderen en adolescenten. Toch zijn er nog veel onbeantwoorde vragen, bijvoorbeeld welke EF-processen ten grondslag liggen aan taakprestaties van (jonge) kinderen, hoe EF verstoord kunnen raken door niet-aangeboren hersenletsel, en of we EF kunnen verbeteren met interventies. In **hoofdstuk 1** beschrijven we de stand van onze kennis en bespreken we de onderzoeksvragen van dit proefschrift.

In **hoofdstuk 2** bestuderen we welke cognitieve processen een rol spelen tijdens het uitvoeren van een verbale vloeiendheidstaak (*verbal fluency task*). In totaal hebben 225 basisschoolkinderen van 4 tot 6 jaar meegedaan aan dit onderzoek. De kinderen kregen de instructie om binnen één minuut zoveel mogelijk dieren te op noemen. De verbale vloeiendheidstaak kan gebruikt worden om verschillende cognitieve functies te meten, zoals woordkennis, lexicale toegang en verschillende EF, zoals cognitieve flexibiliteit, monitoring en strategiegebruik. Als uitkomsten van de verbale vloeiendheidstaak hebben we de totale woordproductiviteit en twee procesmaten onderzocht: gemiddelde clustergrootte en omschakelingen (oftewel *switches*). De procesmaten geven ons inzicht in de rol van EF in de uitvoering van de verbale vloeiendheidstaak. Gemiddelde clustergrootte weerspiegelt het gebruik van een strategie om woordkennis op te halen. Omschakelingen zijn een aanwijzing voor cognitieve flexibiliteit. Leeftijd beïnvloedde alle verbale vloeiendheidsuitkomsten lineair: de oudere kinderen in onze groep produceerden meer woorden, maakten grotere clusters en maakten meer omschakelingen. Deze bevindingen suggereren dat procesmaten, zoals gemiddelde clustergrootte en omschakelingen, ook bij jonge kinderen van 4 tot 6 jaar inzicht kunnen geven in processen die ten grondslag liggen aan succesvolle uitvoering van een verbale vloeiendheidstaak. Bij toekomstig onderzoek naar verbale vloeiendheidsprestaties rekening worden gehouden met factoren zoals geslacht van een kind en opleidingsniveau van de ouders, aangezien deze een rol bleken te spelen bij sommige uitkomsten van een verbale vloeiendheidstaak (namelijk totale woordproductiviteit en omschakelingen) van jonge kinderen.

In **hoofdstuk 3** beschrijven we een longitudinaal onderzoek naar de ontwikkeling van prestaties op een ontwerp-vloeiendheidstaak (*design fluency task*), waaraan 228 kinderen meededen. De ontwerp-vloeiendheidstaak is het non-verbale equivalent van een verbale vloeiendheidstaak. Kinderen die meededen aan het onderzoek moesten binnen één minuut zoveel mogelijk verschillende ontwerpen maken door lijnen te trekken in een symmetrische vijfpuntsmatrix. Net als bij de verbale vloeiendheidstaak uit hoofdstuk 2 is de prestatie op een ontwerp-vloeiendheidstaak afhankelijk van verschillende cognitieve functies, waaronder dezelfde EF die betrokken zijn bij verbale vloeiendheidsprestaties (namelijk cognitieve flexibiliteit, monitoring en strategiegebruik). Om de verschillende betrokken EF te ontwarren, onderzochten we de totale ontwerpproductiviteit, clustering en omschakelingen (oftewel *switches*), vergelijkbaar met de vloeienheidsuitkomsten uit hoofdstuk 2. Kinderen waren 4 tot 6 jaar bij aanvang van het onderzoek en werden driemaal gemeten, waarbij elke meting ongeveer één jaar na de vorige meting plaatsvond. De totale ontwerpproductiviteit nam toe met een hogere startleeftijd en over de tijd. Overschakelingen namen toe met de startleeftijd en tot het tweede meetmoment, maar niet tot het derde meetmoment. Clustering kwam daarentegen pas bij het derde meetmoment vaker voor dan aan het begin van de studie. De resultaten suggereren dat kinderen hun benadering van de ontwerp-vloeiendheidstaak aanpassen wanneer ze de taak meerdere keren uitvoeren, of dat er individuele verschillen zijn met betrekking tot de leeftijd waarop kinderen hun taakaanpak aanpassen. Er was geen verschil tussen jongens en meisjes wat betreft de uitkomsten. Het opleidingsniveau van de ouders was positief geassocieerd met de totale ontwerpproductiviteit, maar niet met omschakelingen of clustering. Dit suggereert dat clustering en omschakelingen minder afhankelijk zijn van het opleidingsniveau van ouders dan andere cognitieve functies die bij de ontwerp-vloeiendheidstaak betrokken zijn, zoals motorische vaardigheden en visuospatieel vermogen. Het gebruik van clustering tijdens een verbale vloeiendheidstaak (zie hoofdstuk 2) maar niet tijdens een ontwerp-vloeiendheidstaak suggereert dat EF-processen bij jonge kinderen context-specifiek kunnen zijn.

In **hoofdstuk 4** hebben we onderzocht of context-specificiteit van EF-processen ook een rol speelt bij een interventie gericht op deze EF-processen. Specifiek bekeken we of een korte instructie van EF-processen op een bepaalde complexe figuurtaak ook leidt tot verbeteringen in EF-processen op een andere complexe figuurtaak. Complexe figuurtaken vereisen dat kinderen eerst een figuur kopiëren en deze later opnieuw uit het geheugen reproduceren. Taakprestaties zijn onder andere afhankelijk van EF zoals organisatie en strategiegebruik. Aan het experiment namen 98 basisschoolkinderen in de leeftijd van 9 tot 12 jaar deel. Kinderen tekenden eerst het Rey-Osterrieth Complexe Figuur (ROCF). Ongeveer een maand later werden ze gerandomiseerd om het ROCF opnieuw te voltooien (1) met strategie-instructie, of (2) in het standaardformaat. De strategie-instructie bestond uit het achtereenvolgens presenteren van de verschillende elementen van het ROCF, te beginnen met de elementen die cruciaal zijn voor de organisatie van het figuur, en eindigend met de details. Als posttest tekenden alle kinderen het Modified Taylor Complex Figuur (MTCF). De belangrijkste organisatorische elementen van het MTCF zijn dezelfde als die van het ROCF, zoals de grote rechthoek. Tekeningen werden beoordeeld op hun organisatie, accuratesse en benodigde tijd. De groep die de strategie-instructie had ontvangen scoorde hoger op organisatie van het uit het geheugen getekende MTFC dan de groep die geen strategie-instructie ontving. Daarentegen was er geen verschil tussen de groepen in de organisatiescores voor de gekopieerde figuren, de accuratesse van de getekende figuren en de benodigde tijd voor de taak. Instructies op EF-processen lijken EF-processen te verbeteren in een context met een minimum aan irrelevante stimuli (dat wil zeggen, tijdens het tekenen van complexe figuren uit het geheugen). Kinderen die een strategie hadden geleerd in een bepaalde context (tijdens het kopiëren van het ROCF) konden deze ook toepassen in een andere context (tijdens het tekenen van het MTCF uit het geheugen). Echter, het gebruik van deze nieuwe strategie zorgde alleen voor een verbeterde organisatie, maar niet voor een hogere accuratesse. Mogelijk hebben kinderen explicietere instructies nodig, waarbij ze het verband tussen de nieuwe strategie en andere relevante contexten leren. In hoofdstuk 6 en 7 bespreken we hoe expliciete strategietraining EF kan beïnvloeden bij kinderen en adolescenten met niet-aangeboren hersenletsel.

In **hoofdstuk 5** bekeken we of EF 6 maanden of 2 jaar na traumatisch hersenletsel (THL, een specifieke vorm van niet-aangeboren hersenletsel) verschillen tussen kinderen en adolescenten van verschillende leeftijdsgroepen. De drie kern EF inhibitie, werkgeheugen en cognitieve flexibiliteit werden onderzocht doormiddel van taken (ook wel genoemd 'op het niveau van functies') en doormiddel van vragenlijsten ('op het niveau van activiteiten'). Gebaseerd op eerdere onderzoeken en in overeenstemming met ontwikkelingsspurts, categoriseerden we 105 kinderen en adolescenten met THL en 42 kinderen zonder THL in vier leeftijdsgroepen: vroege kinderjaren (5 tot 6 jaar), midden kinderjaren (7 tot 9 jaar), late kinderjaren (10 tot 12 jaar) en adolescentie (13 tot 15 jaar). De kinderen en adolescenten zonder THL waren gematcht met de THL-groepen wat betreft leeftijd en geslacht. Onze resultaten laten zien dat inhibitie-uitkomst 2 jaar na letsel afhangt van de leeftijd ten tijde van letsel. Vooral deelnemers die THL opliepen in de vroege kinderjaren of in de adolescentie lijken kwetsbaar voor inhibitieproblemen 2 jaar na letsel. Echter, vervolganalyses toonden geen significante verschillen tussen leeftijdsgroepen aan, waardoor er nog geen definitieve conclusies kunnen worden getrokken. Inhibitie op het niveau van activiteiten 2 jaar na letsel was slechter voor alle kinderen en adolescenten met THL vergeleken met normaal ontwikkelende kinderen en adolescenten. Werkgeheugen en cognitieve flexibiliteit lieten op groepsniveau geen verslechtering zien na THL. Omvang, aantal en volume van hersenlaesies, gedetecteerd met susceptibility-weighted imaging, waren negatief gecorreleerd met dagelijks EF-gedrag van adolescenten 6 maanden na letsel. Echter, gegeven de kleine groepsgroottes moeten bevindingen van analyses naar correlaties tussen EF en hersenlaesies voorzichtig worden geïnterpreteerd. De resultaten benadrukken het belang van lange-termijn follow-up na THL bij kinderen en adolescenten, gegeven de gevonden inhibitieproblemen 2 jaar na letsel.

Het doel van **hoofdstuk 6** was het creëren van een overzicht van onderzoeken naar de effectiviteit van cognitieve interventies voor kinderen en adolescenten met niet-aangeboren hersenletsel. Daarbij hebben we ons specifiek gericht op het identificeren van effectieve interventiecomponenten. Interventies werden gecategoriseerd op basis van de volgende componenten: (1) metacognitie en/of strategiegebruik, (2) herhaalde oefening, en (3) externe hulpmiddelen. Metacognitie en/of strategietraining is erop gericht om kinderen instructies te geven over hoe ze kunnen 'denken over hun denken' en/of hoe ze een specifieke taak moeten aanpakken. Herhaalde oefeninterventies zijn gebaseerd op het idee dat verbeteringen in cognitief functioneren kunnen worden bereikt door herhaaldelijk dezelfde taken te oefenen die gericht zijn op een specifieke cognitieve functie. Externe hulpmiddelen, zoals dagboeken, bieden compenserende ondersteuning voor cognitieve problemen. We doorzochten systematisch vier elektronische literatuurdatabases en we identificeerden aanvullende artikelen via referentielijsten van geïncludeerde artikelen en door deskundigen in het veld te raadplegen. In totaal zijn 20 artikelen opgenomen die 19 onderzoeken beschrijven. Metacognitie en/of strategietraining verbeterden vooral het psychosociaal functioneren. Interventies op basis van herhaald oefenen verbeterde de prestaties op taken die vergelijkbaar waren met de taken die gebruikt werden tijdens de interventie. Interventies die deze twee componenten combineren, leken te zorgen voor verbeteringen in zowel cognitief als psychosociaal functioneren. Externe hulpmiddelen verbeterden het functioneren in het specifieke gebied waarop het hulpmiddel was gericht, bijvoorbeeld het geheugen. De beschikbare gegevens suggereren dat interventies bestaande uit meerdere componenten, zoals een combinatie van metacognitie en/of strategiegebruik en herhaald oefenen, veelbelovend zijn omdat deze kunnen leiden tot verbeteringen in zowel het cognitieve als psychosociale functioneren van kinderen en adolescenten met niet-aangeboren hersenletsel. Conclusies blijven voorlopig vanwege kleine steekproefgroottes van geïncludeerde studies, heterogeniteit met betrekking tot uitkomstmaten, interventie- en therapeutvariabelen en patiëntkenmerken.

Gebaseerd op theoretische modellen en op onze bevindingen uit hoofdstuk 6 ontwikkelden we een nieuwe cognitieve interventie voor kinderen en adolescenten met niet-aangeboren hersenletsel. De interventie, beschreven in **hoofdstuk 7**, combineert herhaald oefenen van cognitieve taken met expliciete strategie-instructie. Kinderen en adolescenten oefenen zelf herhaald cognitieve taken via computerspellen. De computerspellen bieden de mogelijkheid om eerst strategieën in een speelse context te leren voordat ze worden gekoppeld aan dagelijkse situaties. Voor de expliciete strategie-instructie hebben we een protocol ontwikkeld dat bestaat uit functie-specifieke en metacognitieve strategieën. De expliciete strategie-instructie ondersteunt het gebruiken en oefenen van strategieën tijdens de computerspellen. Door de strategieën expliciet te relateren aan relevante dagelijkse situaties en contexten willen we de generalisatie van het gebruik van de strategieën bevorderen. Kinderen en adolescenten trainen 5 keer per week gedurende 30 minuten per dag thuis op de computer en krijgen 45 minuten expliciete strategie-instructie per week op hun revalidatiecentrum of gespecialiseerde school. Alle trainingssessies vinden plaats gedurende een periode van 6 weken. We onderzoeken momenteel de effectiviteit van de interventie in een multicenter onderzoek in Nederland. We verwachten dat de nieuwe interventie bij kinderen en adolescenten met niet-aangeboren hersenletsel een significante verbetering teweegbrengt in cognitief functioneren en andere leefgebieden, zoals participatie.

Participatie staat voor het kunnen meedoen in de maatschappij. In **hoofdstuk 8** hebben we instrumenten onderzocht waarmee we participatie kunnen meten bij kinderen en adolescenten met twee vaak voorkomende neurologische aandoeningen: niet-aangeboren hersenletsel en cerebrale parese. Daarvoor hebben we systematisch vijf elektronische databases doorzocht. We vonden 37 instrumenten die zijn gebruikt om participatie in de bovengenoemde populaties in kaart te brengen. Vervolgens legden we deze instrumenten langs een nieuw model voor participatie en gerelateerde constructen (in het Engelse: family of Participation Related Constructs [fPRC]). Volgens het fPRC wordt participatie gedefinieerd door twee hoofdconstructen: aanwezigheid en betrokkenheid. We vonden 12 instrumenten die aanwezigheid en/of betrokkenheid konden meten. Voor acht van deze instrumenten is er enig bewijs voor meeteigenschappen (validiteit, betrouwbaarheid en responsiviteit) bij kinderen en adolescente met niet-aangeboren hersenletsel of cerebrale parese. Meeteigenschappen van voldoende kwaliteit werden gevonden voor de meeste instrumenten, maar geen enkel instrument was beoordeeld op alle relevante eigenschappen. Al met al is het huidige bewijs voor meeteigenschappen beperkt, voornamelijk veroorzaakt door lage methodologische kwaliteit van de onderzoeken.

In **hoofdstuk 9** rapporteren en interpreteren we de belangrijkste bevindingen uit de onderzoeken die in de voorgaande hoofdstukken zijn gepresenteerd. We bespreken methodologische sterktes en beperkingen. Daarnaast beschrijven we de implicaties van onze bevindingen en geven we suggesties voor toekomstig onderzoek. Samen geven de resultaten van dit proefschrift aan dat de context (zowel tijdens het meten van EF als bij EF-interventies) een belangrijke rol speelt bij de EF-uitkomsten van kinderen en adolescenten. In toekomstig onderzoek als ook in de klinische praktijk en in het onderwijs moet er daarom rekening worden gehouden met de context waarin EF worden gemeten en geoefend.

Valorisation

The main aim of this thesis was to contribute to scientific knowledge about assessment and intervention of executive functions (EF) in children and adolescents. The meaning and significance of our findings for researchers and future studies have been described in the previous chapters. In the following valorisation paragraphs, we discuss the relevance as well as practical applications and implications of our findings in a broader societal context.

Relevance

EF is an umbrella term that incorporates many different cognitive functions, such as inhibitory control, working memory, cognitive flexibility, planning, organising, initiating, monitoring, reasoning, and strategy use [1, 2]. Behaviour associated with (un)successful EF in children's and adolescents' daily life becomes evident all throughout daily life. For example, a child being able to raise his/her hand and wait his/her turn when the teacher asked a question, shows signs of good inhibitory control. In contrast, a child who does not stay seated at the dinner table after repeated warnings from the parents may indicate unsuccessful inhibitory control. A teacher explaining to her pupils that they will start the day with some math exercises instead of grammar practice as they usually do, requires the children to be flexible in their thinking and acting. A father asking his adolescent daughter to first go to her room to get her jacket, then run to the basement to grab a shopping bag, and finally come to the kitchen, requires the daughter to use her working memory to remember the different steps of the instruction.

Previous studies have shown that EF are positively associated with children's and adolescents' mental and physical health, school functioning, participation, and quality of life [3-9]. Consequentially, difficulties with EF may have a significant negative impact on daily functioning. For example, being repeatedly scolded for not raising a hand in class or standing up from the dinner table may negatively affect a child's self-confidence. Not being able to remember multiple steps of an instruction may lead an adolescent to avoiding situations where these type of instructions are likely to occur, for example in after school activities.

Given the importance of EF for daily functioning, there is a pronounced interest in EF from educational and clinical professionals working with children and adolescents. In their daily work, these professionals may frequently use, or want to use, assessment tools to understand the level of EF of a child or adolescent in relation to other cognitive functions such as attention, as well as in relation to the child's or adolescent's behaviour, such as school functioning, participation or quality of life. In turn, interventions for EF may be used when a problem with EF was identified. A common cause of difficulties with EF in children and adolescents is acquired brain injury [10-15]. In the Netherlands, 19.000 children and adolescents are diagnosed with acquired brain injury each year [16]. These children and adolescents may have EF deficits, potentially causing them to have difficulties waiting their turn in class, being flexible in their thinking when a schedule changes, or remembering instructions that entail multiple steps. It is therefore important that we can provide evidence-based recommendations on how *to assess* EF and how to approach EF difficulties with *interventions.* In this thesis, we offer insights into both of these aspects regarding EF in children and adolescents.

In terms of *EF assessment,* findings of the studies presented in this thesis indicate that, at least in young children, the use of EF may be specific to the task or the context of the behaviour. This means that children may employ their EF when approaching one task, but not when performing another task. Professionals making use of EF assessment should be aware that outcomes of various tasks, supposedly tapping into the same or similar EF processes, might differ. For example, even though the verbal fluency task and the design fluency task are often thought to be each other's verbal respectively non-verbal equivalent, children may not rely on the same (EF) processes to perform both of these tasks. Young children may use EF such as monitoring and cognitive flexibility in a context that is familiar to them, for example, when trying to name animals as is the case in the verbal fluency task. In contrast, in an unfamiliar, more abstract context, for example when creating abstract designs in the design fluency task, children may not employ the same EF. Moreover, the context specificity of EF may not only apply to EF tasks, but also to the use of EF in daily life. For example, a young child who is able to organize his or her desk drawer at school might not necessarily be able to organize also his or her toys at home. This may potentially be caused by the inability of a (young) child to transfer the use of EF in one situation to another context.

In terms of *EF interventions,* educational and clinical professionals may find it relevant to know that wide-ranging improvements in EF or in associated daily functioning cannot be easily achieved by trying to improve a specific EF in an isolated context. The use of popular brain training programs provides an illustrative example. These programs often propose that repeated playing of a game to train a specific EF, such as working memory, will lead to improvements in working memory, but also for example in school functioning and daily behaviour. Unfortunately, there is increasing evidence that these training programs only lead to very specific improvements in the trained (EF) tasks, but not in other areas of functioning. To improve a wider range of functioning, children and adolescents may not only need repeated practice but also additional support in the use of EF in various contexts. Before initiating an EF intervention, educational and clinical professionals may thus want to consider the ultimate goal of the intervention and to adapt the intervention to that goal. For example, if the intervention goal is to help an adolescent to improve the ability to follow instructions in class, the intervention may consist of practicing attentional control and working memory, but also give clear directions and strategies on how to use these skills in the classroom context. Explicit strategy training, as we developed and described in chapter 7 of this thesis, may provide a useful tools for this purpose.

Target groups

The knowledge generated with the studies of this thesis may be of interest to a large and diverse audience. In our studies, we investigated EF in children and adolescents with and without acquired brain injury.

Educational professionals working with children and adolescents with and without acquired brain injury may gain new knowledge about EF from our studies. Educational professionals can include classroom teachers, remedial teachers and mentors. The results of the studies presented in this thesis may inspire them to pay more attention to EF that potentially underlie school functioning and classroom behaviour of their pupils. Moreover, they may benefit from the new insights into EF interventions, described in chapter 4 and 6, suggesting that the context provided in an intervention may play a role in generalization of EF improvement. When bringing EF interventions into their daily teaching, they may include clear examples of contexts that are relevant for the child or adolescent taking part in the intervention.

In a clinical context, children and adolescents with acquired brain injury are often treated by a multidisciplinary team consisting of rehabilitation physicians, neuropsychologists, occupational therapists and psychologists. *Neuropsychologists and occupational therapists* may use findings of our review described in chapter 6 to select an appropriate cognitive intervention. Specifically, intervention purely consisting of repeatedly practicing a task (such as the brain training programs mentioned above) may not be useful to achieve meaningful changes in daily functioning, as mentioned above. In contrast, interventions based on metacognition or strategy use training have the potential to improve children's and adolescent's daily behaviour, and, when combined with repeated cognitive practice, may be able to improve daily cognitive functioning. Clinical professionals working with children and adolescents with acquired brain injury are currently already applying our new intervention described in chapter 7 in the context of our ongoing trial.

A variety of clinical professionals may benefit from the overview of participation instruments we present in the review in chapter 8. The results of that review may support the selection of instruments to assess participation in children and adolescents with acquired brain injury. On the one hand, we describe how the participation instruments align with contemporary conceptualizations of participation. On the other hand, we provide an overview of their psychometric properties, which are essential to consider for valid and reliable assessment. The Child and Adolescent Scale of Participation [17, 18] is currently the only participation instrument available that aligns with current participation definition and has been examined for its psychometric properties in the Netherlands. However, many other participation instruments are available. When selecting an instrument to measure participation in children and adolescents with acquired brain injury, clinical professionals should be aware of the advantages and disadvantages of these various instruments.

A final potential target group for the results of our study are *parents and caregivers*. Some of our studies show that level of parental education, which may be a proxy for parent-child interaction, can influence EF, at least in young children. Awareness of their own influence on their child's EF may facilitate parents' and caregivers' understanding of children's behaviour and functioning. For parents or caregivers of a child or adolescent with acquired brain injury, it may be relevant to know that consequences of brain injury are not always apparent immediately after the injury, making long-term vigilance for potential difficulties necessary (chapter 5). Moreover, the insight provided by chapter 6, that merely practicing EF by repeating EF tasks may not yield wide-ranging effects, may dampen enthusiasm regarding popular computerized brain training programs and thereby protect parents from unnecessary costs. As an alternative, they may consider intervention options that include explicit strategy instruction to support generalization of EF improvement to daily life.

Activities and products

The work of a researcher is not complete once research data have been analysed and published. An essential task of a researcher should be to make efforts to clarify theoretical and practical implications, to disseminate the findings, and, if applicable, assist those who may try to develop or apply products, services and activities based on these findings.

Findings of this thesis have been presented at multiple *national and international conferences*. Many of these conferences are also attended by clinical practitioners and educational professionals. Moreover, results have also been discussed at clinical symposia and in expert meetings in clinical settings, such as rehabilitation centres. In the Netherlands, we are strongly involved in a network of professionals working with children and adolescents with acquired brain injury, facilitating the dissemination of our findings and products. To communicate new insights with the general public, our research on cognitive interventions for children and adolescents was presented in a *newspaper article* in De Limburger and was discussed in the *local radio show* RTV Maastricht Het Beleg.

Our work has led to several concrete products. To bridge the gap between our scientific findings and educational practice, we are currently preparing an evidence-based *brochure about EF for educational professionals*. This brochure includes a description of EF and their developmental pathways, clear examples of EF behaviour, as well as tips and suggestions on how to approach EF difficulties in children and adolescents. For clinical professionals working with children and adolescents with acquired brain injury, we created an overview of available cognitive interventions and their effectiveness (chapter 6), which was published in an international peer-reviewed journal. We also made an overview of instruments to assess participation of these children and adolescents (chapter 8). By presenting these overviews at clinical symposia and to interested professionals, we aim to assist professionals in using the overviews in their daily clinical practice. Finally, we developed a new cognitive intervention for children and adolescents with acquired brain injury. A detailed description of this intervention is provided in chapter 7 of this thesis.

Innovation

In terms of EF assessment, our studies suggest that studying EF processes underlying broader cognitive task performance can provide insight in young children's EF. As a next step, it should be examined how these processes are associated to daily life functioning, such as school performance. If outcomes from EF process assessment and daily life functioning are found to be associated, process measures may form an interesting addition to current clinical and/or educational assessment.

In terms of EF intervention, current available interventions for children and adolescents, both with and without acquired brain injury, are mostly focused on trying to *train* EF. Specifically, they underlie the assumption that by practicing certain EF tasks, EF performance will improve on those tasks, but also on other tasks and in daily life. Unfortunately, changes in other tasks or daily life are only minimal. In our review in chapter 6, we therefore made an effort to disentangle the effective components of cognitive interventions for children and adolescents with acquired brain injury. There are currently no recommended cognitive interventions for these children and adolescents. Our new intervention meets a current need for new, protocoled intervention. In the intervention, we apply state of the art knowledge about effectiveness of intervention components by combining EF practice with strategy instruction.

Implementation

To disseminate our findings among educational professionals, we are currently preparing an implementation plan for the brochure described above. We aim to distribute the brochure across educational professionals throughout the south of the Netherlands. Moreover, the brochure will also become available online.

The new intervention described in chapter 7 is currently being investigated for its effectiveness. The intervention protocol is currently already available at eight rehabilitation centres and specialized school across the Netherlands, where the intervention is currently being examined for effectiveness. The study is expected to be completed in July 2020, after which the collected data will be analysed. If the intervention proves to be effective in improving children's and adolescents' EF and/or functioning in other life areas, the intervention will be made available for use in rehabilitation centres and specialized schools across the Netherlands. When designing the study into the effectiveness of the new intervention, we took into account the potential for future implementation. Health care providers are limited in the time they can use to provide care to a child or adolescent due to constraints in, for example, health insurance coverage. A new intervention would therefore mostly be used *instead of* another intervention, rather than *in addition to* another intervention. Our new intervention is being investigated as an alternative to the care currently provided by the rehabilitation centre or school. If found to be effective, the intervention can therefore be easily and without additional costs be implemented in daily clinical practice.

We developed the intervention specifically for children and adolescents with acquired brain injury. However, difficulties with EF also occur in other populations, such as children and adolescents with learning disabilities or with attention deficit hyperactivity disorder. Moreover, a recent review of cognitive interventions for these populations have indicated that, similar to results found in our review in chapter 6, explicit strategy instruction is a promising component [19]. Our intervention may therefore be of interest for professionals working with other populations than children and adolescents with acquired brain injury. If needed, the intervention can also be translated for use in other countries.

References

1. Anderson P. Assessment and development of executive function (EF) during childhood. *Child Neuropsychology.* 2002;8(2):71-82.
2. Diamond A, Ling DS. Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience*. 2016;18:34-48.
3. Borella E, Carretti B, Pelegrina S. The specific role of inhibition in reading comprehension in good and poor comprehenders. *Journal of Learning Disabilities.* 2010;43(6):541-52.
4. Diamond A. Executive functions. *Annual Review of Psychology.* 2013;64:135-68.
5. Galvin J, Froude EH, McAleer J. Children's participation in home, school and community life after acquired brain injury. *Australian Occupational Therapy Journal.* 2010;57(2):118-26.
6. Gathercole SE, Pickering SJ, Knight C, Stegmann Z. Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology.* 2004;18(1):1-16.
7. Levin HS, Hanten G, Li X. The relation of cognitive control to social outcome after paediatric TBI: Implications for intervention. *Developmental Neurorehabilitation.* 2009;12(5):320-9.
8. Rosema S, Crowe L, Anderson V. Social function in children and adolescents after traumatic brain injury: A systematic review 1989–2011. *Journal of Neurotrauma.* 2012;29(7):1277-91.
9. Ylvisaker M, Feeney T. Executive functions, self-regulation, and learned optimism in paediatric rehabilitation: a review and implications for intervention. *Pediatric Rehabilitation*. 2002;5(2):51-70.
10. Anderson V, Catroppa C. Recovery of executive skills following paediatric traumatic brain injury (TBI): A 2 year follow-up. *Brain Injury.* 2005;19(6):459-70.
11. Babikian T, Asarnow R. Neurocognitive outcomes and recovery after pediatric TBI: meta-analytic review of the literature. *Neuropsychology.* 2009; 23(3):283-96.
12. Catroppa C, Anderson V. Neurodevelopmental outcomes of pediatric traumatic brain injury. *Future Neurology*. 2009;4(6):811-21.
13. Mangeot S, Armstrong K, Colvin AN, Yeates KO, Taylor HG. Long-term executive function deficits in children with traumatic brain injuries: Assessment using the Behavior Rating Inventory of Executive Function (BRIEF). *Child Neuropsychology.* 2002;8(4):271-84.
14. Sesma HW, Slomine BS, Ding R, McCarthy ML. Executive functioning in the first year after pediatric traumatic brain injury. *Pediatrics.* 2008;121(6):e1686-e95.
15. van Heugten C, Hendriksen J, Rasquin S, Dijcks B, Jaeken D, Vles J. Long-term neuropsychological performance in a cohort of children and adolescents after severe paediatric traumatic brain injury. *Brain Injury*. 2006;20(9):895-903.
16. de Kloet A, Hilberink S, Roebroeck M, Catsman-Berrevoets C, Peeters E, Lambregts S, et al. Youth with acquired brain injury in The Netherlands: A multi-centre study. *Brain Injury.* 2013;27(7-8):843-9.
17. Bedell G. Further validation of the Child and Adolescent Scale of Participation (CASP). *Developmental Neurorehabilitation.* 2009;12(5):342-51.
18. de Kloet AJ, Berger MA, Bedell GM, Catsman-Berrevoets CE, van Markus-Doornbosch F, Vliet Vlieland TP. Psychometric evaluation of the Dutch language version of the Child and Family Follow-up Survey. *Developmental Neurorehabilitation.* 2015;18(6):357-64.
19. Kassai R, Futo J, Demetrovics Z, Takacs ZK. A meta-analysis of the experimental evidence on the near-and far-transfer effects among children's executive function skills. *Psychological Bulletin*. 2019;145(2):165.

Dankwoord

Dit dankwoord is het laatste stuk dat ik schrijf om dit proefschrift compleet te maken. Het is onvoorstelbaar hoe bijzonder, leerzaam en gezellig de afgelopen jaren zijn geweest. Wat mooi, dat ik hier degenen kan bedanken die dit proefschrift, en ook mij, hebben gemaakt tot wat het is.

Caroline en Petra, wat een geluk dat jullie mij hebben begeleid in dit promotietraject. Door jullie heb ik ontzettend veel geleerd en heb ik er daarnaast ook nog eens enorm van genoten. Bedankt voor de steun en begeleiding die jullie mij gaven als dat nodig was, en de vrijheid die ik kreeg om mezelf verder te ontwikkelen en mijn eigen weg te vinden in het onderzoek. Vaak genoeg was het jullie vertrouwen in mij dat ervoor zorgde dat ik ook vertrouwen kreeg in mezelf. *Caroline,* ik heb enorme bewondering voor jou. Jouw motivatie en enthousiasme voor je vakgebied vind ik aanstekelijk en inspirerend. Je hebt ervoor gezorgd dat mijn eigen liefde voor onderzoek alleen maar gegroeid is. Je drukt mij, en je andere promovendi en postdocs, altijd op het hart dat er naast werk nog zoveel ander dingen zijn om van te genieten. Jouw openheid maakt het mogelijk dat ik tijdens onze overleggen niet alleen onderzoeker ben, maar ook volledig mezelf. *Petra,* met één woord kun jij een probleem oplossen waar ik zelf al uren over na heb gedacht. Soms vroeg ik me af waarom ik die oplossingen zelf niet kon bedenken. Gelukkig was dat ook niet nodig, want jij was er altijd om mee te denken. Jouw oog voor detail houdt mij scherp en heeft menig hoofdstuk in dit proefschrift beter gemaakt. Bedankt voor je positiviteit en je oprechte interesse in de onderzoeken en in mij, ik had me geen fijnere co-promotor kunnen wensen.

Een belangrijk woord van dank gaat uit naar *alle kinderen en jongeren en hun ouders, verzorgers en leerkrachten* die mee hebben gedaan aan de verschillende onderzoeken in dit proefschrift. Jullie bijdrage aan de wetenschap is onmisbaar.

Hartelijk dank aan *de leden van de beoordelingscommissie,* prof. dr. C. van der Vleuten, dr. J. Hendriksen, dr. L. Jonkman en prof. dr. J. Swaab, voor het beoordelen van mijn proefschrift.

Arend, mede door jouw enthousiasme voor projecten met kinderen en jongeren met hersenletsel hebben we aan het begin van dit promotietraject samen het BrainLevel onderzoek opgezet. Onverwachts komt mijn promotie eerder dan het einde van het onderzoek. Ik hoop dat we ons ook de komende maanden nog verder kunnen inzetten om het onderzoek mooi af te ronden, en dat we in de toekomst nog samen kunnen werken aan vele mooie projecten.

Veel dank aan *alle revalidatiecentra en speciale scholen en alle behandelaren* die de afgelopen jaren mee hebben gewerkt aan het BrainLevel onderzoek. Een speciaal woord van dank gaat uit naar *alle centrumonderzoekers*: Femke, Marleen, Suzanne en Mayken, Ingrid. Roeli, Carla en Liesbeth, Ben en Martine. Bedankt voor jullie inzet voor het onderzoek, en dat jullie je niet gek hebben laten maken als ik weer mailde over nieuwe mogelijke deelnemers.

Alle Hej-collega's, het is speciaal om te zien hoe sterk het Nederlandse netwerk is van onderzoekers, clinici en andere praktijkprofessionals als het gaat om kinderen en jongeren met hersenletsel. In elke vergadering en op elk congres luister ik met plezier naar jullie ervaringen en presentaties. Bedankt dat jullie de afgelopen jaren steeds met mij hebben meegedacht over het BrainLevel onderzoek en over andere projecten. Ik hoop dat we ons ook in de toekomst samen verder kunnen inzetten voor 'onze' speciale doelgroep.

Jeroen, Anne en Irene, het IPBIS-congres in Belfast was een van de gezelligste congressen tot nu toe. Misschien krijgen jullie me in New York wel zo ver om karaoke te zingen.

Cathy and Vicki, thank you for having me at MCRI. Thank you for the warm welcome, for the academic guidance and for the inspiration you gave me. *Edith and Nikita*, many thanks for all the lovely lunches and tea breaks at MCRI. It is great that we still keep in touch, even though we are literally an ocean apart. To the *co-authors* of the paper in chapter 5: thank you for the great teamwork, I learned many things from you.

Bedankt aan *alle co-auteurs* van de hoofdstukken in dit proefschrift, en *collega's van lopende projecten*. Jullie vele verschillende ideeën en perspectieven geven mij steeds weer nieuwe inzichten en helpen erbij om het beste te halen uit de papers en projecten.

Voor veel onderzoeken in dit proefschrift hebben zich naast bovenstaande onderzoekers ook stagiaires ingezet. *Rachel, Rebecca, Iris, Noëlle, Lisanne, Michelle, Silke en Amber*, bedankt voor jullie bijdrage. Rachel, een speciaal bedankje voor jou: jij hebt veel geholpen bij het maken van alle trainingsmaterialen voor de nieuwe BrainLevel interventie. Door jou staat de high score van veel spellen in het oefenaccount op ongekende hoogte!

Irene, het is gelukt! Samen hebben wij de afgelopen maanden met hetzelfde tijdsschema onze proefschriften afgerond. Met jou kon ik praten over alles wat die laatste fase met zich mee bracht, maar ook over onderzoek bij kinderen en jongeren met hersenletsel in het algemeen. Ik heb veel bewondering voor hoe je jouw prachtige onderzoek hebt gerund naast de 1001 andere dingen die je altijd doet. Ik hoop op nog vele gezellige lunches, congressen en logeerpartijen in de toekomst.

Laura, het is bijzonder hoe goed wij elkaar in de afgelopen jaren hebben leren kennen. Je was meteen mijn allerliefste koffie- thee-, en kletscollega, maar al snel werd je zelfs mijn buurvrouw en een van mijn beste vriendinnen. Doordat we tegelijkertijd aan onze onderzoeken werkten, begrepen we precies welke verschillende fasen we doorliepen. De keren dat we samen in pyjama onze onderzoeken en, nog belangrijker, de rest van onze levens, hebben besproken, zijn niet meer te tellen. Jij hebt de afgelopen jaren ontzettend leuk gemaakt, en ik ben dan ook heel blij dat je bij mijn verdediging mijn paranimf wilt zijn. Op onze vriendschap!

Carina, voor mijn promotie ben je mijn paranimf, maar boven alles ben je mijn liefste zusje. Van de buitenkant is het niet altijd te zien, maar qua innerlijk lijken we heel veel op elkaar. Steven luistert vaak lachend naar onze FaceTime-gesprekken waarin we binnen de kortste keren van Nederlands, naar Engels naar Duits wisselen. Je kent mij door en door, en inmiddels ook dit proefschrift, omdat jij veel hoofdstukken op taal en spelling hebt nagekeken. Dankjewel dat we alles samen kunnen delen, van het grootste geluk tot de kleinste gebeurtenis (zoals het dragen van een watermeloen).

Alle collega's van NP&PP, jullie zorgen ervoor dat ik elke dag weer met plezier naar de UNS40 kom. *Esther,* wat hebben we het vaak gehad over onze onderzoeken en over toekomstplannen voor een 'kinder-onderzoeksgroep'. Je interesse, begrip en vrolijkheid hebben me vaak weer nieuwe energie gegeven. *Peter,* we delen een voorliefde voor woordgrappen en het lezen van reacties van anderen op nieuwsberichten; perfecte voorwaarden voor een mooi student-journal! *Nadia,* het is me nog niet gelukt om jouw enthousiast te maken voor Kerst, maar misschien lukt dat dit jaar wel nog? *Arjan,* de open sfeer die jij als afdelingshoofd creëert, maakt voor mij dat het comfortabel voelt om successen te vieren maar ook de moeilijke kanten van onderzoek doen te delen. *Annemie,* in februari 2015 kreeg ik een telefoontje van jou: wanneer ik zou beginnen aan mijn promotietraject? Dat ik de maandag na dat telefoongesprek al kon beginnen was het eerste, maar zeker niet het laatste, dat jij voor mij hebt geregeld. Als ik door alle (papier)bomen het bos niet meer zag, wist jij altijd raad. Dankjewel voor al je ondersteuning.

Alle lieve kantoorgenoten van de afgelopen jaren: Melloney, Anneke, Robbie, Eva, Anne en Eri, wat is kantoor 2.753 toch een fijne plek. *Anne en Eva (en Eliza en Stefan),* jullie hebben mij aan het begin van het promotietraject geholpen om letterlijk en figuurlijk de weg te vinden. Ik denk nog vaak aan veel van jullie wijze woorden. *Eri,* jouw tomeloze energie geeft me altijd een positief gevoel. *Robbie*, toen je Melloney en mij kwam vergezellen, hoopten we dat we je niet gek zouden maken met onze dagelijkse overpeinzingen over van alles en nog wat. Gelukkig gebeurde dat niet: wat waren de gezamenlijke kantoorjaren gezellig!

Het is speciaal, dat we elkaar nog steeds regelmatig zien (en dat we dan subtiel blikken uitwisselen als iemand een taalfoutje maakt). *Melloney en Anneke,* bedankt voor jullie geduld in de afgelopen maanden. Jullie tolereerden zonder scheve blikken de bergen aan onderzoeksmateriaal waarmee ik ons 'extra' bureau volstapelde. We hebben de afgelopen jaren veel met elkaar gedeeld, waarvoor we menig keer de kantoordeur moesten sluiten. Laat het vooral weten als de deur weer even dicht moet.

Lieve mensen van het EHL: Ieke, Daan, Fleur, Jessica, Annemarie, Johanne, Bert, Melloney, Anneke, Irene, Roos, Rudolf en Caroline. Bedankt voor alle gezellige overleggen, koppen koffie bij de Bakery en natuurlijk de congressen in Praag en Granada. Wat is het mooi, om samen met jullie het EHL te vormen.

Milou, Gian, Ghis, Fred en Ed, jullie zijn al ruim 15 jaar mijn beste vrienden. Gezellige afspraken met jullie laten me steeds weer merken wat het belangrijkste is in het leven. Jullie zijn mijn paranimfen van het leven.

Timo, schon mal vielen Dank für die Foto's die du machst während der Verteidigung!

Veronica en Ton, een weekendje bij jullie zorgt altijd voor de nodige rust en ontspanning. Bedankt, dat jullie mij in Zeeland thuis laten voelen.

Papa und Mama, eure Tür steht immer für mich offen, und wenn sie mal zu ist, darf ich meinen eigenen Schlüssel benutzen. Danke, dass ihr immer für mich da seid.

Liebe Oma, zu wissen, dass deine und Opa's Liebe bedingungslos ist, hat mir oft geholfen die Doktorarbeit im richtigen Perspektiv zu sehen. Viele meiner schönsten Erinnerungen, kommen bei euch aus Östringen.

Steven, zoals je weet, kan ik een kort verhaal met heel veel woorden vertellen. Gelukkig begrijpen we elkaar ook vaak zonder woorden. Zonder jou had ik de afgelopen jaren menig maal mijn balans verloren. Bedankt dat je bent wie je bent en dat je mij laat zijn wie ik ben. Wat heb ik zin om ook de rest van ons leven samen door te brengen.

About the author

Christine Resch was born on 17 January 1990 in Aachen, Germany. In 2008, she completed her secondary education at College Rolduc in Kerkrade with distinction (cum laude). In the same year, she started studying psychology at the Faculty of Psychology and Neuroscience at Maastricht University. After earning her bachelor's degree, she travelled to Córdoba, Argentina, to complete a grant-aided psychology internship at a school for children and adolescents with mental and physical disabilities. In 2012, Christine was selected for the two-year research master programme Cognitive and Clinical Neuroscience with a specialisation in Neuropsychology. After obtaining her Research Master degree, she started her PhD projects at the department of Neuropsychology and Psychopharmacology at Maastricht University under supervision of prof. dr. Caroline van Heugten and dr. Petra Hurks. In 2017, Christine visited prof. dr. Vicki Anderson and dr. Cathy Catroppa at the Murdoch Children's Research Institute in Melbourne, Australia, to work on a project examining executive function outcomes after paediatric brain injury. Next to the studies described in this thesis, Christine collaborated with researchers from the Open University in Heerlen on various studies into interventions for children's executive functions and sensory processing. Moreover, Christine and her supervisors created a care guide for children and adolescents with acquired brain injury in Limburg, which was funded by Johanna Kinderfonds and CZ Fonds. Currently, Christine is working as a postdoctoral researcher at the same department where she completed her PhD projects. In December 2019, she will start a 2.5-year postdoc project studying time perception in healthy adolescents and adolescents with neurological disorders. For this project, she has recently received funding from The Netherlands Initiative for Education Research (NRO). The project will take place in collaboration with the centre for neurological learning disabilities and developmental disorders at Kempenhaeghe, Heeze.

Publications and presentations

International publications

Resch, C., Anderson, V. A., Beauchamp, M. H., Crossley, L., Hearps, S. J., van Heugten, C. M., ... & Catroppa, C. (2019). Age-dependent differences in the impact of paediatric traumatic brain injury on executive functions: A prospective study using susceptibility-weighted imaging. *Neuropsychologia, 124,* 236-245.

Resch, C., Keulers, E., Martens, R., van Heugten, C., & Hurks, P. (2019). Does strategy instruction on the Rey-Osterrieth Complex Figure task lead to transferred performance improvement on the Modified Taylor Complex Figure task? A randomized controlled trial in school-aged children. *The Clinical Neuropsychologist, 33(1),* 108-123.

Resch, C., Rosema, S., Hurks, P., de Kloet, A., & van Heugten, C. (2018). Searching for effective components of cognitive rehabilitation for children and adolescents with acquired brain injury: A systematic review. *Brain Injury, 32(6),* 679-692.

Van Heugten, C., Renaud, I., & **Resch, C.** (2017). The role of early intervention in improving the level of activities and participation in youths after mild traumatic brain injury: a scoping review. *Concussion, 2(3),* CNC38.

Nederkoorn, C., Dassen, F. C., Franken, L., **Resch, C.**, & Houben, K. (2015). Impulsivity and overeating in children in the absence and presence of hunger. *Appetite, 93,* 57-61.

Resch, C., Martens, R., & Hurks, P. (2014). Analysis of young children's abilities to cluster and switch during a verbal fluency task. *The Clinical Neuropsychologist, 28(8),* 1295-1310.

Resch, C., Keulers, E., Martens, R., van Breukelen, G., van Heugten, C., & Hurks, P. Young children's performance on a design fluency task: Longitudinal data on total design productivity, clustering and switching. Submitted.

Resch, C., van Kruijsbergen, M., Ketelaar, M., Hurks, P., Adair, B., Imms, C., de Kloet, A., Piskur, B., & van Heugten, C. Instruments to assess participation of children with acquired brain injury and cerebral palsy: a systematic review of measurement properties. Submitted.

Resch, C., Hurks, P., de Kloet, A., & van Heugten, C. Computer-based cognitive retraining combined with explicit strategy instruction: rationale and description of a new cognitive intervention for children and adolescents with acquired brain injury. Submitted.

Other publications

Resch, C., Roberts, R., Hurks, P., & Van Heugten, C. (2019). *Keuzewijzer voor kinderen en jongeren met hersenletsel in Limburg* [Care guide for children and adolescents with acquired brain injury in Limburg]. Expertisecentrum Hersenletsel Limburg, Maastricht, the Netherlands.

Resch, C., van Heugten, C., Hurks, P., & de Kloet, A. (2017). Serious gaming voor kinderen met NAH. [Serious gaming for children with acquired brain injury]. *Attent, 31,* 8-9.

Presentations at international conferences

Hurks, P., **Resch, C.,** Meijs, C., de Groot, R., van der Wurff, I. & *Paying attention to sensory processing and executive functions at school* [Aandacht voor sensorische prikkelverwerking en executieve functies in het onderwijs]. Onderwijs Research Dagen (2019, Heerlen, the Netherlands). Oral presentation.

Resch, C., van Kruijsbergen, M., Ketelaar, M., Hurks, P., Adair, B., Imms, C., de Kloet, A., Piskur, B., & van Heugten, C. *Instruments to assess participation of children with acquired brain injury or cerebral palsy: a systematic review of measurement properties.* Annual meeting of the European Academy of Childhood Disability (2019, Paris, France). Poster.

Resch, C., van Kruijsbergen, M., Ketelaar, M., Hurks, P., Adair, B., Imms, C., de Kloet, A., Piskur, B., & van Heugten, C. *Instruments to assess participation of children with acquired brain injury or cerebral palsy: a systematic review of measurement properties.* Neuropsychological Rehabilitation Special Interest Group of the World Federation for NeuroRehabilitation (2019, Granada, Spain). Short oral presentation & poster.

Resch, C., van Kruijsbergen, M., Ketelaar, M., Hurks, P., Adair, B., Imms, C., de Kloet, A., Piskur, B., & van Heugten, C. Participation as the ultimate outcome of paediatric rehabilitation: a systematic review of measurement properties. International Conference on Paediatric Acquired Brain Injury (2018, Belfast, Ireland). Oral presentation.

Resch, C., Anderson, V., Beauchamp, M., Crossley, L., Hearps, S., van Heugten, C., Hurks, P., Ryan, N., & Catroppa, C. *Age-dependent differences in the impact of paediatric traumatic brain injury on executive functions: A prospective study using susceptibility-weighted imaging.* International Conference on Paediatric Acquired Brain Injury (2018, Belfast, Ireland). Poster.

Resch, C., Rosema, S., Hurks, P., de Kloet, A., & van Heugten, C. *Effective components of cognitive interventions for children with ABI: A systematic review.* Neuropsychological Rehabilitation Special Interest Group of the World Federation for NeuroRehabilitation (2018, Prague, Czech Republic). Oral presentation.

Van Heugten, C., Renaud, I., & **Resch, C.** *Early interventions directed at activities and participation of children with mild TBI: A scoping review.* Neuropsychological Rehabilitation Special Interest Group of the World Federation for NeuroRehabilitaion (2018, Prague, Czech Republic). Poster.

Resch, C., Keulers, E., Martens, R., van Heugten, C., & Hurks, P. *Does strategy instruction on the Rey-Osterrieth Complex Figure task lead to transferred performance improvement on the Modified Taylor Complex Figure task? A randomized controlled trial in school-aged children.* Conference of the European Network on Psychoeducational Assessment, Intervention and Rehabilitation (2018, Leiden, the Netherlands). Oral presentation.

Van Heugten, C., Renaud, I., & **Resch, C.** *Early interventions directed at activities and participation of children with mild TBI: A scoping review.* International Conference on Paediatric Acquired Brain Injury (2017, Rome, Italy). Poster.

Presentations at national conferences

Resch, C., Rosema, S., Hurks, P., de Kloet, A., van Heugten, C. *Cognitive interventions for children with brain injury: what works?* Revant symposium, Childhood brain injury: what's new, what's next? (2019, Breda, the Netherlands). **Invited oral presentation.**

Resch, C., Meijs, C., de Groot, R., van der Wurff, I., & Hurks, P. *Cognitive intervention for typically developing children and children with brain injuries: comparing two systematic reviews.* Neuropsychology and Psychopharmacology Annual Department Research Day (2019, Maastricht, the Netherlands). Oral presentation.

Resch, C., Meijs, C., de Groot, R., van der Wurff, I., & Hurks, P. *Paying attention to sensory processing and executive function at school* [Aandacht voor sensorische prikkelverwerking en executieve functies in het onderwijs]. Jeugd in Onderzoek (2019, Amsterdam, the Netherlands). Poster.

Resch, C., Anderson, V., Beauchamp, M., Crossley, L., Hearps, S., van Heugten, C., Hurks, P., Ryan, N., & Catroppa, C. *Age-dependent differences in the impact of paediatric traumatic brain injury on executive functions: A prospective study using susceptibility-weighted imaging.* Faculty of Psychology and Neuroscience Research Day (2019, Maastricht, the Netherlands). Poster.

Resch, C., & Renaud, I. *Can I join? Perspective on participation of children with brain injury.* Annual symposium of the Limburg Brain Injury Center (2019, Roermond, the Netherlands). Oral presentation.

van Heugten, C. & **Resch, C.** *How to find the right care: health care guides for children and adults with brain injury.* Annual symposium of the Limburg Brain Injury Center (2019, Roermond, the Netherlands). Oral presentation.

Resch, C., Meijs, C., de Groot, R., van der Wurff, I., & Hurks, P. *Classroom interventions targeting sensory processing and executive functions of school-aged children: A systematic review comparing and contrasting different intervention approaches.* NRO inspiratiebijeenkomst (2018, Utrecht, the Netherlands). Oral presentation.

Resch, C., van Kruijsbergen, M., Ketelaar, M., Hurks, P., Adair, B., Imms, C., de Kloet, A., Piskur, B., & van Heugten, C. *Instruments to assess participation of children with acquired brain injury or cerebral palsy: a systematic review of measurement properties.* Dutch Congress of Rehabilitation Medicine (2018, Groningen, the Netherlands). Oral presentation.

Resch, C., van Kruijsbergen, M., Ketelaar, M., Hurks, P., Adair, B., Imms, C., de Kloet, A., Piskur, B., & van Heugten, C. *Assessing participation of childred with brain injury: a systematic review of measurement properties*. Brain Awareness Week (2018, the Hague, the Netherlands). **Invited oral presentation.**

Resch, C., Keulers, E., Martens, R., van Heugten, C., & Hurks, P. *Strategy instruction on the Rey-Osterrieth Complex Figure. A randomized controlled trial in school-aged children.* Neuropsychology and Psychopharmacology Annual Department Research Day (2018, Maastricht, the Netherlands). Oral presentation.

Resch, C., Hurks, P., & van Heugten, C. *De juiste zorg op het juiste moment: keuzewijzer voor kinderen met hersenletsel in Limburg.* Bijzondere BIJZOndeR Adelante (2017, Hoensbroek, the Netherlands). Poster.

Resch, C., Hurks, P., de Kloet, A., & van Heugten, C. *Computer-based cognitive retraining combined with explicit strategy instruction for children and adolescents with ABI.* Brain Awareness Week, (2017, the Hague, the Netherlands). Poster.

Resch, C., Hurks, P., de Kloet, A., & van Heugten, C. *Computer-based cognitive retraining combined with explicit strategy instruction for children and adolescents with ABI.* Bijzondere BIJZOndeR Adelante (2016, Hoensbroek, the Netherlands). Poster. **Awarded with the first prize for best presentation.**

Resch, C., Wierenga, R., Hurks, P., de Kloet, A., & van Heugten, C. *Computer-based cognitive retraining combined with explicit strategy instruction for children and adolescents with ABI.* Hersenletselcongres [Brain Injury Conference] (2016, Ede-Wageningen, the Netherlands) Oral presentation.

Resch, C., Hurks, P., de Kloet, A., & van Heugten, C. *Computer-based cognitive retraining combined with explicit strategy instruction for children and adolescents with ABI.* Faculty of Psychology and Neuroscience Research Day (2016, Maastricht, the Netherlands). Poster.

Resch, C., Hurks, P., de Kloet, A., & van Heugten, C. *Computer-based cognitive retraining combined with explicit strategy instruction for children and adolescents with ABI.* World Congress on Brain Injury (2016, the Hague, the Netherlands). Poster.

Resch, C., Hurks, P., de Kloet, A., & van Heugten, C. Effectiveness of digital cognitive training for children with acquired brain injury. Brain Awareness Week (2015, the Hague, the Netherlands). **Invited oral presentation.**

Presentations and workshops for children

Resch, C. & van Heugten, C. *How does your brain work?* KidzCollege (2019, Maastricht, the Netherlands). Oral presentation.

Resch, C. & Terneusen, A. *How does your brain work and what happens when you learn?* Next Level Kids (2019, Heerlen, the Netherlands). **Invited workshop.**

Resch, C. & Wijenberg, M. *What does a neuropsychologist do?* Wiekentschool (2017, Maastricht, the Netherlands). **Invited workshop.**