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Validation of computer-based FORAMENRehab program for neuropediatric attention and visuospatial assessment

Master's Thesis

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Running head: Validating FORAMENRehab for Neuropediatric Assessment

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Abstract

There is a need for more validated computerized assessment methods in Estonia for neuropediatric patients with cognitive deficits. Attention and visuospatial problems are common in children with epilepsy and traumatic brain injury (TBI). The aim of this study was to validate the use of FORAMENRehab computerized cognitive tasks in attention and visuospatial assessment of children with epilepsy or TBI. 115 children aged 8-12 participated in the study: 60 healthy children without attention or visuospatial deficit and 55 neuropediatric patients with the aforestated problems. The participants completed 9 attention and 7 visuospatial tasks with FORAMENRehab software. A subsample of patients was retested 5 weeks later. They also completed the attention and visuospatial tasks of the neuropsychological assessment battery NEPSY. Analysis of age-appropriate performance in FORAMENRehab revealed, that there were no age-related differences in attention and visuospatial functions between children aged 10-12. Initial evidence for the construct validity of the FORAMENRehab attention and visuospatial modules was found, as tasks that were connected to specific attention components and visuospatial functions loaded together in factor analysis. Evidence for criterion validity was also found, as 8 tasks correlated with similar tasks from NEPSY. Test-retest reliability was satisfactory with 5 out of 15 tasks. The results indicate that although certain tasks need revision, there is preliminary evidence for the usefulness of FORAMENRehab in computer-based cognitive testing.

Keywords: computer-based cognitive assessment, test validation, attention, visuospatial functions, children, epilepsy, traumatic brain injury, TBI

FORAMENRehab arvutiprogrammi valideerimine närvisüsteemi kahjustusega laste tähelepanu ja ruumitaju hindamiseks

Kokkuvõte

Eestis on puudus arvutipõhistest valideeritud meetoditest närvisüsteemi kahjustusega laste kognitiivse defitsiidi hindamiseks. Epilepsia ja ajutraumaga lastel esineb sageli tähelepanu ja ruumitaju funktsioonide kahjustusi. Töö eesmärk oli FORAMENRehab arvutipõhiste testide valideerimine epilepsia või ajutraumaga laste tähelepanu ja ruumitaju profiilide hindamiseks. Uuringus osales 115 last vanuses 8-12: 60 tervet ilma tähelepanu ja ruumitaju häireteta last ja 55 nimetatud häiretega patsienti. Osalejad lahendasid FORAMENRehab programmis 9 tähelepanu ja 7 visuaalruumilist testi. Alamvalim patsiente testiti uuesti 5 nädalat hiljem. Samuti hinnati neid tähelepanu ja ruumitaju testidega neuropsühholoogilisest testipatareist NEPSY. Uurides tervete laste FORAMENRehab testide soorituse seost vanusega ilmnes, et 10-12-aastaste vahel ei esine vanuselisi erinevusi tähelepanu ega ruumitaju tasemes. Esmast kinnitust leidis FORAMENRehab tähelepanu ja ruumitaju moodulite konstruktivaliidsus, kuna ülesanded, mida seostatakse spetsiifiliste tähelepanu ja ruumitaju komponentidega, laadusid ühele faktorile. Kinnitust sai ka kriteeriumivaliidsus, kuna 8 ülesannet seondusid NEPSY sarnaste ülesannetega. Test-kordustesti reliaablus oli rahuldav 5 testi puhul 15-st. Tulemused näitavad, et kuigi mõned ülesanded vajavad parandamist, on olemas esialgne tõendus FORAMENRehab programmi kasulikkuse kohta arvutipõhisel kognitiivsel testimisel.

Märksõnad: arvutipõhine kognitiivne hindamine, testide valideerimine, tähelepanu, ruumitaju, lapsed, epilepsia, ajutrauma

1. INTRODUCTION

1.1. Attention network components

It is widely agreed that attention is not a solid function but rather an umbrella term that involves different, but related functions (Posner, 2008). Attention can broadly be described as the ability to attend to specific stimuli without being distracted by other, irrelevant stimuli (Goodwin, 2012). Attention, concentration and information processing form the basis on which the functioning of other cognitive domains lies and therefore affect greatly the overall psychological wellbeing of the individual (Alexander, Matthews & Murphy, 2015).

Currently there is no universal set of attention components that has been agreed on. Models often contain skills like sustaining attention over time (vigilance), retaining and manipulating information in the mind (working memory), shifting/dividing attention, and resisting interference and distractions (Sohlberg & Mateer, 2001). Attention is closely related to *executive functions* (higher order functions that control the application of other cognitive functions to practice), which are sometimes assessed together with attention (Kemp, Korkman & Kirk, 2001). Abilities like working memory and inhibition have connections to both attention and executive functions (Alexander et al., 2015; Levin & Hanten, 2005). Because of this, attentional models often contain an executive component.

One influential model of attention has been developed by Posner and Petersen (1990). It distinguishes three attentional functions that have independent neural networks and neuromodulators – these are alerting, orienting/reorienting and executive control. *Alerting* is described as achieving and maintaining an activated, response-ready state, *orienting* involves selecting or changing the stimulus that is in the focus of attention and *executive control* serves the function of resolving conflicts between responses. This paradigm has been widely used in numerous studies, involving children with attention deficit hyperactivity disorder and epilepsy (Adólfsdóttir, Sørensen & Lundervold, 2008; Kratz et al., 2011; Tian et al., 2010).

Another popular model was developed by Van Zomeren and Brouwer (1994), based on Posner and Petersen’s (1990) model, Kahneman’s (1973) theory on the intensity and selectivity aspects of attention and the concept of supervisory attentional control by Shallice (1982). The model contains concepts of alertness, vigilance, selective attention, divided attention and flexibility (Tucha et al., 2011). When alertness describes the readiness to focus attention, *vigilance* describes the readiness to respond quickly to stimuli that occur rarely in the course of a long period of time (Van Zomeren & Brouwer, 1987). *Selective* and *divided* attention are correspondingly the ability to focus on target stimuli despite numerous distractions and the ability to focus on multiple stimuli at the same time (Sohlberg & Mateer, 2001). Finally, *flexibility* refers to the ability to willingly shift attentional focus according to need (Van Zomeren & Brouwer, 1994).

A well-known clinical model of attention was proposed by Sohlberg and Mateer in 2001. It builds upon wide-spread theoretical concepts and symptoms observed in patients with traumatic brain injury. Their model contains 5 components: focused, sustained, selective, divided and alternating attention. Despite some difference in terms, their model is essentially quite similar to the one by Van Zomeren and Brouwer (1994). The models share the components of selective and divided attention, although Sohlberg and Mateer (2001) point out that dividing may actually mean rapid shifting of conscious attention between different tasks or a more automatic processing of one of the tasks. Their concept of *focused attention* is similar to alertness and describes the ability to respond directly to stimuli. *Sustained attention* is defined as the ability to persistently respond during continuous and repetitive tasks and involves in their model the abilities of vigilance and working memory. *Alternating attention* is described as mental flexibility, similarly to flexibility in the model of Van Zomeren and Brouwer (1994).

1.2. Visuospatial functions

Similar to attentional processes, there is also a lack of consensus in the domain of visuospatial processes, regarding definitions and theoretical frameworks for classifying skills under this domain (Grossi & Trojano, 2001). In general, visuospatial skills can be described as nonverbal abilities that enable an individual to comprehend and conceptualize visual input and spatial relationships using perceptual and mental information (Corsini, 1999; Grossi & Trojano, 2011).

The visuospatial domain is multifaceted, encompassing visual-perceptual, visual-constructional and visuomotor skills among others (Noggle, Dean & Barisa, 2013; Alexander et al., 2015). Some specific skills involved with the visuospatial domain are the ability to discriminate between objects, distinguish left and right, judge spatial orientation and relationships between objects in space, copying models, understanding symbolic representations (maps and routes) and solving nonverbal problems (Alexander et al., 2015).

Different authors have defined various cognitive abilities that relate to the visuospatial domain. *Visual perception* is described by Hayes and Stratton (2013) as the analysis and interpretation of information received through the visual system. Thee major areas of visual perception are sensory organization, information processing and spatial organization (Haber & Hershenson, 1973). *Visual recognition* can be defined as the act or process of perceiving or identifying visual information as matching to or being the same as existing information in the mind (Colman, 2009). *Visual-constructional* ability is the ability to construct a complex object by arranging its details in appropriate spatial positions (Grossi & Trojano, 2001). An intermediate function between the visuospatial and attentional domain is *visuospatial attention,* which determines the efficiency with which attention can be spread across the visual field (Achtman, Green & Bavelier, 2008). *Visual organization* is the ability to compose elements in the visual field into whole objects (Bertenthal, Campos & Haith, 1980).

1.3. Development of attentional and visuospatial functions

When evaluating attention and visuospatial abilities in childhood, it is important to use age-appropriate methods and test norms, as certain aspects of these functions are still in the course of development. Rapid increase in neuropsychological test performance is found to occur before age 9, changes occurring later are more moderate (Korkman, Kemp & Kirk, 2001). Regarding attention, Chelune and Baer (1986) describe that children achieve adult levels in sustained attention by age 10. Passler, Isaac and Hynd (1985) found evidence that children develop the ability to inhibit attention to irrelevant stimuli by age 10 and mastery in it is achieved around age 12. In visuospatial abilities, visuomotor and visual scanning abilities are found to develop before school age, visual-perceptual skills are almost fully developed by age 8-9, while visual-constructional ability starts to form only when the aforementioned skills are acquired (Del Giudice et al., 2000). This information is important to take into account in pediatric neuropsychology, as common syndromes like epilepsy and traumatic brain injury (TBI) that occur in crucial stages can disrupt the course of cognitive development.

1.4. Epilepsy-related cognitive deficits

A common neurological disorder associated with cognitive impairment is childhood epilepsy. Epilepsy is a condition characterized by unprovoked recurrent convulsive or non-convulsive seizures, which result from an abnormal excessive electrical discharge in cerebral neurons (Pryse-Phillips, 2009; Bradley, 2004). Epilepsy is classified into generalized and focal epilepsy according to seizure type. In generalized epilepsy, seizures involve both hemispheres and reflect a dysfunction of the whole brain or major brain systems, while in focal epilepsy, seizures originate from one or more discrete brain regions (Pryse-Phillips, 2009). In Estonia, the incidence of childhood epilepsy is 45 per 100 000 (Beilmann, Napa, Sööt, Talvik & Talvik, 1999).

Studies of children with epilepsy often report attention and executive problems, but impairment in visuospatial skills, memory and language has also been found. (Germano et al., 2005; Kolk, Talvik & Laine, 2004; Kolk, 2006). Attention and executive deficits are wide-spread across many different epileptic syndromes. Dunn, Austin Harezlak and Ambrosius (2003) found 58% of children with epilepsy were at risk for attention problems. Tian and colleagues (2010) tested the functioning of attention subtypes in generalized epilepsy and found the executive component to be impaired but not the more basic alerting and orienting components. Raud, Kaldoja and Kolk (2015) tested children with generalized and focal epilepsy and found impaired attention and executive functions in both groups. Spatial orientation and spatial memory have been found to be disrupted in various epileptic syndromes related to the temporal and occipital lobes, but also in some types of general epilepsy (Völkl-Kernstock, Willinger & Feucht, 2006; Pavone et al., 2001; Hernandez et al., 2003).

1.5. Traumatic brain injury related cognitive deficits

TBI is another prevalent condition that can result in cognitive problems. It is defined as a physical injury to the brain tissue that temporarily or permanently impairs brain function (Parikh, Koch & Narayan, 2007). TBI is graded as mild, moderate or severe using the Glasgow coma scale (Teasdale & Jennet, 1974). In Estonia, the incidence of pediatric TBI is 369 per 100 000 population (Ventsel et al., 2008).

The extent of cognitive damage in TBI is correlated with trauma severity (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005). Typical cognitive deficits are similar to epilepsy, as TBI patients also have problems in attention, memory, speed of information processing and executive functions (Max et al., 2004; Catroppa & Anderson, 2009; Konrad, Gauggel, Manz & Schöll, 2000; Kaldoja, Mirka & Kolk, 2008). Specific impairments of visuospatial, visuo-perceptual or construction skills are less common, though they may occur as a result of a focal injury or severe generalized damage (Tyerman & King, 2009). It has not been extensively studied, what kind of visuospatial deficits are most frequent in TBI. To characterize the attentional domain, the divided and sustained attention are most vulnerable to injury, followed by shifting attention and selective attention (Ginstfeldt & Emanuelson, 2010); focused attention is found to be least impaired (Anderson, Fenwick, Manly & Robertson, 1998).

1.6. Need for new cognitive assessment tools in children with TBI and epilepsy

The occurrence of attention and visuospatial problems in TBI and epilepsy illustrates the need for specific attention and visuospatial assessment tools for the neuropediatric population. Profiling children's strengths and weaknesses plays an important role in making choices about medical treatment (including medication, surgery and rehabilitation) and education, to help these children achieve their full academic and occupational potential (Morrison, 2010). Attention and visuospatial assessment has to be able to recognize deficits in different components of functions. This is needed for specifically targeted rehabilitation, which has been suggested to be more effective than general cognitive training, as shown in attention research by Sturm, Wilmes, Orgaß and Hartje (1997). Sensitive tools are needed to detect subtle attentional or visuospatial problems.

Traditionally, neuropsychological evaluation involves using test batteries that give an overview of the patient's intelligence and cognitive functioning, including attention and visuospatial perception. Occasionally, single tests and test batteries for specific cognitive domains are used.

Intelligence scales allow to rule out intellectual disabilities before cognitive assessment, but some tasks from these scales are also used to assess cognitive deficits. For example, the Wechsler Intelligence Scale for Children (WISC) visuospatial subtests are shown to be sensitive to visuospatial impairments in epilepsy (Gülgonen, Demirbilek, Korkmaz, Dervent, & Townes, 2000). WISC subtests Arithmetic and Digit Span have been used to measure attentional functioning and working memory (Perugini, Harvey, Lovejoy, Sandstrom, & Webb, 2000). In the Kaufman Assessment Battery for Children (K-ABC), the visuospatial module includes the Rover task requiring route planning skill, and the Triangles task requiring visual-constructive abilities (Kaufman & Kaufman, 1983). The Gestalt Closure task is used to measure visual-perceptual capacities (Deltour, Quaglino, Barathon, De Broca, & Berquin, 2007).

A frequently used neuropsychological test battery for children is the NEPSY (A Developmental Neuropsychological Assessment), which is also applied in the current study as an objective method for evaluating neurological patients' cognitive skills. The NEPSY battery was developed by Marit Korkman, Ursula Kirk and Sally Kemp and translated into Estonian in 1995 (Kemp et al., 2001; Kolk, Beilmann, Tomberg, Napa, & Talvik, 2001). The test has been designed to assess both acquired and congenital dysfunctions and was one of the first neuropsychological batteries to be developed specifically for children (Kemp et al., 2001; Ahmad & Warriner, 2001). The Estonian version has been widely used in clinical work and scientific study in the Children's Clinic of Tartu University Hospital (Kolk et al, 2001; Raud et al., 2015; Ilves et al, 2014). The battery's validity has been previously tested by several research teams (Schmitt & Wodrich, 2004; Ahmad & Warriner, 2001). However, as with most traditional tests, administration and scoring of NEPSY is time consuming, taking up to 4 hours in total. The battery also does not assess specific visuospatial functions or attention components separately.

An overview of some tests and test batteries of attention and visuospatial functions is compiled by Alexander and colleagues (2015). For example, the Trail Making Test, which requires consecutively connecting numbers and letters, is used to assess attention, processing speed and mental flexibility. The Hooper Visual Organization Test requires the child to mentally reassemble fragments of drawings to determine familiar objects and is used to measure visual analysis, synthesis and mental rotation. Although individually, these tests might be quicker, it is necessary to conduct several tests to minimize task-specific deviations, increase the likelihood of measuring true ability and analyze patterns of impairment within a cognitive domain (Nass & Frank, 2010). Pediatric neuropsychology is in need of tests that are efficient, specific, non-exhausting and engaging for children, but traditional paper and pencil tests cannot fulfill all of these criteria. A possible solution is to develop modern computer-based assessment methods.

1.7. Computer-based methods for children

Computer-based methods are currently not very common in pediatric neuropsychological practice. Pediatric neuropsychologists have not been extensively surveyed but an overall study of neuropsychologists in North America (including those working with children) found computerized tests were rarely used and made up only 6% of all tests in use (Rabin et al., 2014). Camara, Nathan & Puente (2000) found neuropsychologists mainly use the help of technology for scoring tests. This is not surprising, as until recently, there were very few computer-based methods available and even now, research on the equivalence of these with paper and pencil tests is only starting to be published.

First attempts at computerizing pediatric neuropsychological tests were done in the seventies, with Peabody Picture Vocabulary Test, where administration was fully computerized (Klinge & Rodziewicz, 1976). However, software that helps the experimenter administer the test and record answers is still preferred to automatic tests. For example, digital administration software has recently been developed in the United Sates for tablet computers that enables digital testing with WISC-V and NEPSY-II (Daniel, Wahlstrom, & Zhang, 2014; Daniel, 2013).

1.8. Computerized attention assessment

While the tests discussed above are adaptations from paper and pencil tests, original computer-based tests have started to emerge for the domain of attention. The development of new attention measures might be driven by the growing number of children diagnosed with attention disorders. Differing from paper and pencil testing, computerized testing enables to record multiple response variables simultaneously and time them precisely.

A number of computerized test paradigms have been developed in attention research, mostly using simple stimuli to which the child has to respond to by pressing a button. The stimuli are combined in various ways, creating conditions where the response time and accuracy give information about the functioning of different aspects of attention. Some examples of this kind of tests are the Continuous Performance Test (Conners, et al., 2000) and its variations, Test for Attentional Performance (Zimmermann & Fimm, 2002) and the Attention Network Test (Fan, McCandliss, Sommer, Raz, & Posner, 2002).

Sturm and colleagues (1997) give examples of tasks that enable to measure each aspect of attention. According to their overview, alertness is mostly measured by simple reaction time tasks where the difference between two conditions is analyzed: a condition where a warning stimulus precedes the target stimulus and another, where no warning is presented. Selective attention is measured by tasks where the subject has to choose the correct stimuli to react to and ignore others. Divided attention is usually measured by a dual-task where the subject has to follow and react to correct stimuli from two sources of information at the same time. Sustained attention is measured by tasks where the subject has to keep paying attention for a long time in order to find correct stimuli that often appear between distractors. If the correct stimuli appear scarcely in a task like this, it is thought to measure vigilance.

1.9. Computerized visuospatial assessment

There are fewer computer-based methods for visuospatial evaluation than there are for attention and hardly no computerized and validated tests to comprehensively assess the different abilities in the visuospatial domain. A battery assessing memory, but also aspects of both attention and some visuospatial skills is The Cambridge Neuropsychological Testing Automated Battery (CANTAB). It was originally developed by Fray, Robbins and Sahakian (1996) as a diagnostic tool for dementia in adults but has since then been shown to be suitable for studying neuropsychological functioning in children (Luciana, 2003). The battery has 13 subtests, measuring the domains of Visual Attention, Visual Memory and Working Memory/Planning. The battery is completely non-verbal, except for test instructions. It has also been used to study children with epilepsy and other disorders (Luciana, 2003).

A visuospatial figure-tracing tablet-computer test has been designed by Giammarco and colleagues (2016) where the child has to trace lines with a stylus pen to draw geometric forms. Comparing the drawing speed and precision with results from paper and pencil writing tasks and K-ABC-II visuospatial subtests, they found that the children’s accuracy (less oscillations from the target lines) correlated with their visual-spatial and visual-motor integration skills for boys and general visual cognition for girls.

1.10. *Advantage of computer-based assessment*

The advantage of computer-based testing is that it allows for precise control over task presentation and automated recording of results (Alexander et al., 2015). In addition, it enables to measure multiple parameters at once with greater accuracy and to randomize stimuli (Parsons, 2016). Computerized administration is well suited for sustained attention (especially vigilance) tasks, as these must be repetitive and reactions measured precisely (Luciana, 2003). Computerized testing might also be good to better isolate specific functions for testing, for example measure visuospatial skills separate from the motor component (Luciana, 2003). In addition, adding a computer-game-like quality to the testing might raise children's intrinsic motivation to do the tasks, as has been shown with learning games (Tüzün, Yılmaz-Soylu, Karakuş, İnal, & Kızılkaya, 2009).

1.11. *Validation of cognitive tests*

Reviews of cognitive assessment methods have stressed the need for more validated methods, especially for the pediatric population. (Olson, Jacobson & Van Oot, 2012). Describing the validity, reliability and norms of a test is vital in the development of methods that enable to measure true ability and accurately assess deficits. According to Onwuegbuzie and colleagues (2007), tests are often assessed in one or more of 3 aspects of validity: content-related, criterion-related and construct-related validity. Empirically, the latter 2 can be studied. Criterion-related validity is a measure of how much the scores of the instrument are related to an external variable believed to directly measure the underlying concept. Construct-related validity is a measure of how much the instrument can be interpreted as a meaningful measure of the concept. Investigating the reliability of a measure is also an essential part of validation, as a measure needs to produce reliable results in order to be valid.

Currently, the selection of validated modern assessment methods for pediatric patients in Estonia is poor. There is a lack of evidence-based cognitive assessment methods available for the neuropediatric population and mostly, the psychometric properties of the methods have not been studied in Estonian children. This is even more the case with computer-based tests, which have many advantages over traditional measures, but have not yet gained popularity in Estonia. This highlights the need to develop and validate more computerized neuropsychological tests for the Estonian patients.

1.12. *Using FORAMENRehab in neuropsychological practice*

This study focuses on validating the FORAMENRehab software for cognitive assessment. FORAMENRehab is a commercially developed program originally designed for rehabilitation of cognitive functions in adults (Koskinen & Sarajuuri, 2002). The attention and visuospatial modules of this program have been previously adapted for Estonian patients by Cognuse LLC (2009) and for use in pediatric rehabilitation and assessing its effect (Saard, 2012; Siimon, 2012). The software is currently used for neuropediatric rehabilitation in the Children's Clinic of Tartu University Hospital. Previous studies by our research team have focused on the program's effectiveness in training different attention and visuospatial components and in promoting both short and long term positive outcome in children's cognitive functioning (Kaldoja et al., 2015; Saard, Kaldoja, Bachmann, Pertens & Kolk, 2017; Bachmann, 2016). During the implementation of the modules in Estonia, a set of tasks from the module was adapted by our team to measure children's baseline functioning before training and to assess training outcome (Kaldoja et al., 2015). This study is the first to examine the suitability of this set of tasks for objectively assessing attention and visuospatial impairment outside of training context.

1.13. Aims of the study

The main aim of this study is to evaluate the validity of the FORAMENRehab program's use in cognitive assessment of different attentional and visuospatial components and in identifying attentional and visuospatial deficits in neuropediatric patients. To fulfill this aim, patients' computer-based testing results are compared to results obtained from the attention and visuospatial domains of the NEPSY battery and correlation patterns between the tasks are analyzed. Age-appropriate performance on the tasks is determined by analyzing the results of healthy children. The specific objectives are formulated as follows:

1) To assess the criterion validity of the FORAMENRehab modules by studying, if performance on the FORAMENRehab tasks correlates with performance on the NEPSY tasks of attention and visuospatial functions.
2) To assess the construct validity of the FORAMENRehab modules by comparing the solution of an exploratory factor analysis with theoretical knowledge about the constructs of attention and visuospatial functions.
3) To determine age-appropriate levels of performance for each of the FORAMENRehab tasks.
4) To assess the test-retest reliability of the FORAMENRehab modules with neuropediatric patients.

2. METHODS

2.1. Participants

A total of 115 children aged 8-12 participated in the study (68 boys and 47 girls, age *M*=10.32, *SD*=1.45). Of these, 60 were healthy children (age *M*=10.50, *SD*=1.36), whose teachers and parents confirmed they had no problems with attention or visuospatial functions. The children were recruited from ordinary schools in Tartu and via email advertisements. The remaining 55 participants were patients in the Department of Neurology and Neurorehabilitation in the Children's Clinic of Tartu University Hospital (age *M*=10.11, *SD*=1.54) who were recruited for the study in the clinic. The patients' group had either a diagnosis of epilepsy (*n*=42) or brain trauma (*n*=13). Children who had been diagnosed with other diseases of the central nervous system and children treated with any psychotropic medication other than antiepileptic drugs during the study period were excluded from the study.

Inclusion criteria for the control group were: 1) age between 8-12 years, 2) no problems in attention or visuospatial abilities, 3) good understanding of Estonian language, 4) no physical disabilities or developmental problems.

Inclusion criteria for the study group were: 1) age between 8-12 years, 2)diagnosis of epilepsy or brain trauma, 3)neuropsychologist confirmed deficits in attention and/or visuospatial abilities, 4)good understanding of Estonian language, 5)no physical disabilities or developmental problems.

Informed consent for the study was obtained in writing from the participants' parents and orally from the participants. The study was approved by The Research Ethics Committee of the University of Tartu (no 255/M-10 18.01.2016).

2.2. Research methods

2.2.1. FORAMENRehab

The Attention and Visuospatial modules of FORAMENRehab Cognitive Rehabilitation Software were used in the study. The Attention module tasks are divided under 4 components: Focused Attention, Sustained Attention, Divided Attention and Tracking. The component Tracking involves processes described as alternating attention or flexibility in attention literature. The Visuospatial module tasks are also divided under 4 components: Visual Recognition, Visual Organization, Visual Attention and Visuospatial Perception. This allocation is made by the authors of the software and has not been previously scientifically tested. For each task, the user can view instructions and sample solutions, adjust difficulty levels and view results. The tasks themselves are playful and generally last 1-4 minutes, making them non-exhausting for children. The program varies certain parameters of the tasks on each administration (e.g. different numbers, order of stimuli and distractors), making the tasks more resistant to practice effects while keeping the difficulty level intact. The difficulty levels used in this study have been previously used in studies by Bachmann (2016) and Saard et al. (2017). Descriptions of each task can be found in Table 1.

The program records different variables for each task, including solving time/reaction time, number and percentage of correct responses, number and percentage of errors, types of errors and percentage of deviation. This allows for detailed analysis of the results.

Table 1: Description of FORAMENRehab tasks

Task	**Description of the task**
Attention module	
Focused attention	
Visual Selection	Different colored dots appear in different locations on screen. Participant must press a button when a red dot appears and ignore other colors.
Auditory Selection	Participant must press the space bar when a specific sound is heard and ignore other sounds.
Sustained attention	
Picture Search	Screen is filled with small pictures of everyday objects. Participant must find all of certain pictures as fast as possible.
Number Search	A table of 2-digit numbers appears on screen. Participant must find a pair in each row as fast as possible.
Divided attention	
Paced Search	2 rows of symbols move from left to right. Participant must search both rows simultaneously for symbols and press a button when symbols reach the target location in the middle of the screen.
Addition	Participant must mentally add 5 numbers that briefly appear on screen.
Word Recognition	2 rows of symbols move from left to right. Participant must search both rows simultaneously for animal names and press a button when these reach the target location in the middle of the screen.
Tracking	
Tracking	Participant must follow a moving red circle with their eyes and press a button when the center of the circle changes to black.
PASAT	A series of numbers are heard at an equal pace. During the task, the participant must always add the most recent number heard to the number heard before. Answers are clicked on screen.
Visuospatial module	
Visual recognition	
Circle Following	Participant must keep a dot inside a moving circle using the mouse cursor.
Line Orientation	Participant must match the orientation of colored lines to an example that is shown.
Visual organization	
Geometric Pattern	Participant must identify 3D objects after briefly seeing fragments of them on the screen.

Visual attention	
Spatial Attention	Participant must point out the location of a dot briefly appearing in a matrix by indicating the correct row and column.
Visuospatial perception	
Cubes	Participant must count the cubes in a 3D design
Construction	Participant must use small dual-colored tiles to recreate a pattern that is shown.
Maze	Participant must find the way through a maze using the arrow keys while avoiding the walls and wrong paths.

2.2.2. NEPSY

The NEPSY battery was used to provide an objective measure of the neurological patients' cognitive deficits. The version of NEPSY used is designed for 7-12 year olds and consists of 30 tests which are divided into five domains of cognitive functioning. For the current study, tests from two NEPSY domains were used. Firstly, the domain of Attention and Executive Functioning which contains the tests Tower, Auditory Attention, Visual Attention, Statue, Design Fluency, and Knock and Tap. Secondly, the domain of Visuospatial Functioning which contains the tests Design Copying, Arrows, Block Construction, Finding the Path and Picture Puzzles. Detailed descriptions of the tests can be found in a study by Korkman and colleagues (2001) and the NEPSY manual (Korkman, Kirk & Kemp, 1997).

The approach of the NEPSY battery differs in some aspects from FORAMENRehab. Firstly, NEPSY tasks measure both attention and executive functions, unlike FORAMENRehab, which has a separate module of tasks (not included in this study) that focuses on executive functions (FORAMENRehab Executive Functions and Problem Solving, 2007). The tasks Tower, Statue and Design Fluency have been described to be more related to executive functions than attention, although no official division is made by NEPSY authors (Korkman et al., 1997). Secondly, NEPSY does not formally assess different components of attention and visuospatial functions, making comparisons with FORAMENRehab components more difficult. Thirdly, some NEPSY tasks (Statue, Design Fluency, Knock and Tap, Design Copying) have a considerable motor attention or fine motor component, which cannot be replicated in FORAMENRehab tasks.

2.3. Procedure

Both the healthy controls and the patients were tested individually in a quiet environment. The control group children were tested either in the Tartu University Hospital Children's Clinic, at school or in a quiet room in their home and the patients were tested in the clinic.

The control group children and the patients completed the FORAMENRehab assessment in one experimenter-guided session with a duration up to 101 minutes including instruction time. Mean time spent on tasks was 50.73 minutes (*SD*=9.52) for healthy children and 63.00 minutes (*SD*=12.48) for patients. FORAMENRehab software was run on a 16-inch screen laptop with a Windows 7 operating system. To examine test-retest reliability, a subsample of patients (*n*=24) was administered the FORAMENRehab tasks for a second time 5 weeks after the first assessment. Healthy children were not retested as the main aim of the study was to validate the tests for use with neuropediatric patients and the data that could be gathered was limited by a larger research project this study was a part of.

The subsample also completed the NEPSY modules of Attention and Executive Functions and Visuospatial functions, which lasted up to 90 minutes with instruction time. For NEPSY, the traditional paper and pencil version was used. Both the FORAMENRehab and the NEPSY tasks were administered in random order. The children were allowed to take short breaks during testing when they needed to.

2.4. Data analysis

Statistical analysis was conducted using the programs Microsoft Excel 2013 and IBM SPSS Statistics (version 21). Non-parametric tests were used with variables that were measured on the ordinal scale or not normally distributed. Children whose response times and reaction patterns in a task indicated that they had not complied with instructions, were considered outliers and not included in analysis of that task. The maximum number of outliers per task was 2. Spearman correlations and explorative factor analysis were used to study criterion and construct validity. Shapiro-Wilk criterion was used to assess normality. Bonferroni adjusted alpha-levels were computed in cases of multiple comparisons and are reported below tables.

3. RESULTS

3.1. Computation of FORAMENRehab scores

A summarized task score was calculated for each FORAMENRehab task to incorporate the multiple variables that defined successful performance. In tasks where solving time was fixed, the score was computed as the difference between correct responses and commission errors. In tasks where solving time was also descriptive of cognitive functioning, the following formula was used: *(correct responses – commission errors)/time spent*. In the Sustained Attention tasks Picture Search and Number Search, the formula was *(correct responses – commission errors)*correct responses/time spent*. This allowed to take into consideration the children who could sustain their attention on the task for longer, finding more targets but also taking more time. One visuospatial task (Circle Following) was excluded from analysis due to a recording error of the program.

3.2. Ability of FORAMENRehab tasks to detect attentional and visuospatial problems

The Mann-Whitney *U* test was used to check that children with epilepsy and TBI could be handled as a unitary group of neuropediatric patients with attention and visuospatial deficits. Analysis revealed no differences between groups in age or any of the 15 task scores (p>.05), allowing for a single patient group to be formed.

In order to validate FORAMENRehab tasks in assessing attentional and visuospatial deficits, the tasks' ability to discriminate healthy children from children with attentional and visuospatial impairment was studied. The Mann-Whitney *U* test and Chi-square confirmed that healthy children and patients did not differ significantly in age (U=1407, p=.175) nor gender ($\chi^2(1, N=115)=2.892$, p=.089). The scores of the healthy children and patients were compared using either an independent samples t-test or its nonparametric analogue Mann-Whitney test. Healthy children had significantly higher scores than patients in 7 out of 9 attention tasks and 6 out of 6 visuospatial tasks (see Table 2). In the remaining 2 attention tasks – Visual Selection and Auditory Selection – there was a tendency for patients to score lower, but the difference was not statistically significant. As these 2 tasks were unable to distinguish healthy children from patients with deficits in attention, results regarding these tasks must be interpreted with caution.

Table 2: Comparison of FORAMENRehab results of healthy children and patients

	M±SD		Test statistic
	Patients	Healthy	
1.visual selection	0.84±0.16	0.86±0.18	*t*(108)=.814
2.auditory selection	0.72±0.17	0.75±0.14	*t*(104)=.962
3.picture search	28.07±9.88	35.65±8.76	*U*=921***
4.number search	0.28±0.17	0.41±0.23	*U*=963.5**
5.paced search	4.52±6.04	12.02±9.41	*U*=824***
6.addition	3.93±3.05	7.29±2.39	*U*=654***
7.word recognition	3.96±3.59	5.86±4.08	*U*=1147**
8.tracking	12.04±4.51	13.90±2.71	*U*=1114**
9.PASAT	5.16±3.60	11.69±5.70	*U*=558.5***
Visuospatial tasks			
1.line orientation	0.96±0.04	0.98±0.02	*U*=745.5***
2.geometric pattern	9.31±3.45	11.17±2.98	*t*(111)=3.069**
3.spatial attention	8.56±4.53[a]	14.57±5.13[a]	*U*=589***
4.cubes	0.81±0.98[a]	1.83±1.42[a]	*U*=840.5***
5.construction	0.31±0.27[a]	0.79±0.48[a]	*U*=593***
6.maze	0.31±0.16	0.47±0.23	*U*=864***

a – raw data rescaled (multiplied by 100) for better viewing
M: mean; *SD*: standard deviation; *p*: error probability. ***p*<0.01; ****p*<0.001

3.3. Construct validity: Relationships between FORAMENRehab tasks

Correlations among the attention tasks and visuospatial tasks were analyzed to assess, whether the individual tasks measured similar underlying skills. This was done separately for the healthy children group and the patient group. Significant correlations of the healthy group are displayed in Tables 3 and 4. All the tasks had significant correlations with at least one other task. The statistical significance of the correlations was high in case of most tasks ($p<.001$). However, after applying the Bonferroni correction, correlations with the attention task Picture Search became non-significant.

The patient group correlations are displayed in Tables 5 and 6. In the patients group, there were fewer significant correlations between tasks and some of the patterns among them were different. For example, the relationship between FORAMENRehab Focused Attention category tasks was more pronounced in the patient group, as the tasks Visual Selection and Auditory Selection were strongly correlated in the patients group, but only moderately in the healthy group. The Sustained Attention category tasks were also strongly related in the patient group but only moderately in the healthy group. The task PASAT from FORAMENRehab Tracking category was strongly correlated in the healthy group with the Sustained Attention category task Number Search and the tasks in the Divided Attention category Paced Search, Addition and Word Recognition. However, in the patient group, the latter correlations were weak and non-significant after the Bonferroni correction.

In the visuospatial module, correlation patterns between healthy children and patients were mostly similar. All of the tasks had multiple correlations with other tasks except Geometric Pattern which did not have any significant correlations after Bonferroni correction. The task with the strongest correlations with others was Construction for the healthy group and Maze for the patient group, although both tasks had moderate to strong correlations with other tasks in both the control group and patient group. The tasks Cubes, Construction and Maze, which were all from the same category (Visuospatial Perception) displayed moderate to strong correlations.

Table 3: Spearman correlations between attention tasks in healthy children group

	1.	2.	3.	4.	5.	6.	7.	8.
1.visual selection								
2.auditory selection	**.46*****							
3.picture search	.38**	.03						
4.number search	**.51*****	.41**	.37**					
5.paced search	.24	**.47*****	.30*	**.58*****				
6.addition	.37**	**.46*****	.18	**.43****	.40			
7.word recognition	**.51*****	**.49*****	.21	**.54*****	**.56*****	**.45*****		
8.tracking	.34**	.39**	.13	.25	**.46*****	.32*	.28*	
9.PASAT	**.41****	.24	.30*	**.58*****	**.54*****	**.51*****	**.45*****	.27*

Note: **p*<0.05; ***p*<0.01; ****p*<0.001 (uncorrected significance levels). Level of significance with Bonferroni correction criterion: *p*=0.001 (significant values in bold).

Table 4: Spearman correlations between visuospatial tasks in healthy children group

	1.	2.	3.	4.	5.	6.
1.line orientation						
2.geometric pattern	.09					
3.spatial attention	**.44****	.30*				
4. cubes	.30*	.33*	.36**			
5.construction	**.55*****	.24	**.59*****	**.43****		
6. maze	**.38****	.16	**.51*****	.23	**.49*****	

Note: **p*<0.05; ***p*<0.01; ****p*<0.001 (uncorrected significance levels). Level of significance with Bonferroni correction criterion: *p*=.003 (significant values in bold).

Table 5: Spearman correlations between attention tasks in patient group

	1.	2.	3.	4.	5.	6.	7.	8.
1.visual selection								
2.auditory selection	**.69*** **							
3.picture search	.37**	**.46** **						
4.number search	.21	.28	**.56*** **					
5.paced search	-.00	.07	.21	.24				
6.addition	.21	.26	**.57*** **	**.65*** **	.39**			
7.word recognition	.38**	.36*	**.49*** **	**.53*** **	.30*	**.59*** **		
8.tracking	.25	.27	**.49*** **	.21	.14	.40**	.29*	
9.PASAT	.19	.23	.23	.34*	.06	.33*	.29*	.17

Note: **p*<0.05; ***p*<0.01; ****p*<0.001 (uncorrected significance levels). Level of significance with Bonferroni correction criterion: *p*=0.001 (significant values in bold)

Table 6: Spearman correlations between visuospatial tasks in patient group

	1.	2.	3.	4.	5.	6.
1.line orientation						
2.geometric pattern	.09					
3.spatial attention	.29*	.28*				
4. cubes	.19	-.08	.24			
5.construction	**.40** **	.25	**.47*** **	**.40** **		
6. maze	**.39** **	.12	**.61*** **	.32*	**.57*** **	

Note: **p*<0.05; ***p*<0.01; ****p*<0.001 (uncorrected significance levels). Level of significance with Bonferroni correction criterion: *p*=0.003 (significant values in bold)

3.4. Construct validity: Factor analysis

The correlation tables revealed that many of the tasks had average strength correlations with each other, which provided initial support that the task sets were suitable for factor analysis. To examine construct validity of the FORAMENRehab attention and visuospatial modules, an exploratory factor analysis with maximum likelihood extraction was conducted. This method was selected because there are several competing models of attention and visuospatial functions in the literature. Initially, direct Oblimin method was chosen for rotation of the factors, as it was assumed that factors measuring aspects of attention or visuospatial functions would be related. However, when factors displayed low correlations, Varimax rotation was chosen. Factors were extracted based on the Kaiser criterion and visual inspection of the scree plot. Healthy children's and patients' results were analyzed separately, as differences in the correlation matrixes for each group suggested the possibility of different connections between tasks.

3.4.1. Attention model of healthy children

Sampling adequacy of the healthy children data was shown by the Kaiser-Meyer-Olkin measure (KMO=0.769) and Bartlett's test of sphericity (χ^2 (36) = 162.968, p < .001). Initial analysis extracted 2 factors with eigenvalues greater than 1. After removing the task Tracking that had low correlations (<.40) with both of the factors, a 2-factor solution remained. The first factor had large correlations with the Divided Attention tasks Addition, Word Recognition and Paced Search, suggesting it should be labeled Divided Attention. Correlations were also large with the task Auditory Selection. The second factor had a large communality with the task Picture Search and moderate communality with the other Sustained Attention task Number Search, suggesting it could be labeled Sustained Attention. The 2 factors of the resulting model explained a total of 62.7% of the variance of the data. The first factor explained 49.0% of the data variance and the second factor explained 13.7% of the variance. The final model can be seen in Table 7.

Table 7: Attention model of healthy children

Task	Factor 1 *Divided attention*	Factor 2 *Sustained attention*	Communality
addition	**.76**	-.13	.51
word recognition	**.73**	-.03	.52
auditory selection	**.72**	-.08	.48
paced search	**.67**	.12	.53
PASAT	**.60**	.15	.45
visual selection	**.43**	.35	.43
picture search	-.05	**.72**	.49
number search	.45	**.48**	.63

3.4.2. Attention model of patients

For the patient group, sampling adequacy was also shown by the Kaiser-Meyer-Olkin measure (KMO=0.787) and Bartlett's test of sphericity (χ^2 (36) = 129.704, p < .001). The extracted model also had 2 factors. After stepwise removing of the tasks Tracking and PASAT that had low correlations (<0.4) with the factors, the new factor correlation matrix indicated orthogonality of factors (r=.35) so the Varimax rotation was applied. The final 2-factor solution explained 69.2% of variance of the data. The first factor explained 48.1% of variance and had the largest correlations with the tasks Addition, Number Search, Word Recognition and Paced Search, which require storing information in the mind while performing a task – therefore the factor could be labeled Working Memory. The second factor explained 21.1% of the variance and had strong correlations with the Focused Attention tasks Auditory Selection and Visual Selection, which both require alertness and reacting quickly to the right stimuli. Therefore this factor can be labeled Focused Attention. The final model can be seen in Table 8.

Table 8: Attention model of patients

Task	Factor 1 *Working Memory*	Factor 2 *Focused Attention*	Communality
addition	**.87**	.15	.77
number search	**.72**	.23	.58
word recognition	**.65**	.33	.36
paced search	**.60**	-.04	.53
picture search	**.48**	.47	.46
auditory selection	.15	**.83**	.71
visual selection	-.07	**.81**	.66

3.4.3. Visuospatial model of healthy children

For the healthy group, the Kaiser-Meyer-Olkin measure of sampling adequacy was 0.823 and Bartlett's test of sphericity was significant (χ^2 (15) = 104.884, p < .001). Only one factor was extracted in factor analysis of the data. After removing the task Geometric Pattern, which had a weak correlation with the factor (0.34), the remaining 1-factor model explained 49.5% of the variance of the data. The tasks with strong correlations with the factor were Construction, Spatial Attention, Maze and Cubes. Line Orientation had a moderate correlation. The tasks with the strongest correlations all involve a component of perceiving objects' relations in space, which allowed to label the factor as Spatial Perception. The final model can be seen in Table 9.

Table 9: Visuospatial model for healthy children

	Factor 1 *Spatial Perception*	Communality
construction	**.82**	.67
spatial attention	**.78**	.61
Maze	**.75**	.57
Cubes	**.62**	.39
line orientation	**.50**	.25

3.4.4. Visuospatial model of patients

For the patient group, the Kaiser-Meyer-Olkin measure of sampling adequacy was 0.734 and Bartlett's test of sphericity was significant (χ^2 (15) = 61.060, p < .001). Initially, 2 factors were extracted based on the Kaiser criterion and examination of the scree plot. As the factors were orthogonal based on the factor correlation matrix (*r*=.12), Varimax rotation was used. After stepwise removal of the tasks Geometric Pattern and Cubes which had low correlations (<.40) with the factors, a 1-factor model remained which had high correlations with the task Maze, Spatial Attention, Construction and Line Orientation. As the task was most closely related to the tasks requiring perceiving spatial relationships, the factor might be labeled as Spatial Perception. The factor explained 43.6% of variance of the data. The final model can be seen in Table 10.

Table 10: Visuospatial model for patients

	Factor 1 *Spatial perception*	Communality
Maze	**.75**	.56
spatial attention	**.73**	.53
construction	**.64**	.41
line orientation	**.51**	.26

3.5. Normative data and score standardization of the FORAMENRehab tests

To study how task performance was related to children's age and gender in groups of children with or without attention and visuospatial impairment, the healthy children and patient groups were analyzed separately. After applying the Bonferroni correction, healthy children's scores were significantly correlated with age in 10 out of 15 tasks. These were the attention tasks Visual Selection, Auditory Selection, Number Search, Paced Search, Addition, Word Recognition, Tracking and PASAT, and the visuospatial tasks Spatial Attention and Construction. Correlation strength ranged between 0.34 and 0.64. Patients' performance was not as strongly related to age: 5 out of 15 task scores correlated with age (after Bonferroni correction) and the strength of correlations ranged between 0.38 and 0.53. Gender was not significantly related to task performance in either groups.

As FORAMENRehab results needed to be compared to NEPSY results, which are expressed as age-dependent standard scores, children's scores on these tasks required standardization taking their age group into account. The healthy controls' sample size (*n*=60) enabled to divide the children into 3 age groups with equal age spans. Initially, the groups were formed as follows: Younger (*n*=19, age=8 years 0 months to 9 years 8 months), Middle (*n*=22, age=9 years 8 months to 11 years 4 months) and Older (*n*=19, age=11 years 4 months to 12 years 12 months).

However, in all of the 10 tasks either the Younger and the Middle group (Auditory Selection) or the Middle and the Older children group (remaining 9 tasks) did not significantly differ in performance according to the Mann-Whitney *U* Test, indicating that a relatively stable level of functioning is achieved around middle childhood and the changes occurring later are very subtle. This suggested that dividing the children into 2 age groups is more appropriate. Therefore, only 2 groups were formed: Younger (*n*=27, aged 8 years 0 months to 10 years 5 months) and Older (*n*=33, aged 10 years 6 months to 12 years 12 months). Results of the healthy children groups on each of the age-related tasks can be found in Table 11. The tasks Picture Search, Line Orientation, Geometric Pattern, Cubes and Maze were not related to age and therefore age groups were not formed for these tasks. The means and standard deviations of the healthy children group for these tasks can be found in Table 10. Patients' results were standardized in reference to the corresponding age group's normative data.

Table 11: Scores of age groups of healthy children

	Younger (*n*=27) *M*±*SD*	Older (*n*=33) *M*±*SD*	*U*
Attention tasks			
visual selection	0.80±0.16	0.93±0.16	255.5**
auditory selection	0.69±0.13	0.79±0.13	250*
number search	0.31±0.21	0.45±0.22	227.5**
paced search	7.52±7.20	15.44±9.61	224**
addition	6.19±2.91	8.35±1.40	218**
word recognition	3.94±3.81	7.30±3.77	240**
tracking	12.67±4.13	14.68±0.98	238**
PASAT	9.48±5.46	13.97±4.98	217**
Visuospatial tasks			
spatial attention	0.11±0.03	0.18±0.05	90.5***
construction	0.65±0.43[a]	0.96±0.49[a]	253.5*

Note: a - raw score scaled (multiplied by 100) for better viewing
M: mean; *SD*: standard deviation; *U*: Mann-Whitney statistic; *p<0.05; **p<0.01; ***p<0.001

3.6. Criterion validity of FORAMENRehab – comparison with NEPSY tasks

To study the criterion validity of FORAMENRehab, the task scores of 24 patients were correlated with their NEPSY results. As NEPSY uses age-related standardized scores for assessment, the patients' FORAMENRehab scores were also standardized, using normative data from the healthy children.

In the attention domain, significant correlations were discovered between FORAMENRehab and 2 out of 6 NEPSY tasks. NEPSY task Auditory Attention was strongly correlated with Visual Selection (r_S=.59, p=0.01), Auditory Selection (r_S=0.64, p=0.006), Number Search

(r_S=0.57, p=0.012) and PASAT (r_S=0.67, p=0.002). Knock and Tap correlated strongly with the FORAMENRehab task Tracking (r_S=0.56, p=0.024). The FORAMENRehab tasks Picture Search, Paced Search, Addition and Word Recognition and NEPSY tasks Tower, Visual Attention, Statue and Finding Shapes did not display significant correlations.

In the visuospatial domain, significant correlations were discovered between 3 FORAMENRehab tasks and 3 NEPSY tasks. The FORAMENRehab task Geometric Pattern was correlated with the NEPSY task Finding Pictures (r_S=0.71, p=0.002). The task Spatial Attention was correlated with NEPSY task Blocks (r_S=.73, p=0.001). In addition, the FORAMENRehab task Construction had a significant relationship with the NEPSY tasks Arrows (r_S=0.62, p=0.004) and Blocks (r_S=0.65, p=0.003). The FORAMENRehab tasks Line Orientation, Cubes and Maze and NEPSY tasks Copying and Finding the Path did not display significant correlations with NEPSY tasks.

3.7. Reliability of FORAMENRehab

Results from the repeated FORAMENRehab testing of the patient subgroup (n=24) were analyzed to assess reliability of the tasks. Performance in the two sessions was significantly correlated in 7 out of 9 attention tasks and 3 out of 6 visuospatial tasks (see Table 12). Reliability coefficients ranged between 0.38 and 0.70. The tasks with the highest reliability were Number Search, Auditory Selection, and Construction. The tasks with the lowest reliability coefficients were PASAT and Geometric Pattern. The tasks Paced Search, Tracking, Line Orientation, Spatial Attention and Cubes did not display reliability.

Table 13: Test-retest reliability of FORAMENRehab tasks (patients)

	r_S
Attention tasks	
1.visual selection	.43*
2.auditory selection	**.68*** **
3.picture search	.45*
4.number search	**.70*** **
5.paced search	.26
6.addition	**.58** **
7.word recognition	**.58** **
8.tracking	.31
9.PASAT	.39*
Visuospatial tasks	
1.line orientation	.30
2.geometric pattern	.38*
3.spatial attention	.24
4.cubes	.15
5.construction	**.64** **
6.maze	.45*

Note: r_S: Spearman correlation coefficient *p<0.05 **p<0.01 ***p<0.001

Wilcoxon sign-rank test and paired samples t-test were used to determine whether there was a practice effect. A practice effect was revealed for the attention task Paced Search (Z=-2.659, p=0.008, Mdn1=1.04, Mdn2=10.03). In the visuospatial domain, there was a practice effect with the tasks Cubes (Z=-1.997, p=0.046, Mdn1=0.005, Mdn2=0.015) and Construction (Z=-2.091, p=0.037, Mdn1=0.0029, Mdn2=0.0042). Effect sizes for these practice effects were calculated with the formula $Z/(N_1+N_2)$ where N_1 and N_2 are the number of observations for each trial. Effect sizes were average for the Paced Search task (r=0.38) and Construction (r=0.32), but small for the Cubes task (r=0.29).

4. DISCUSSION

The main aim of the study was to assess the validity of FORAMENRehab tasks in testing attention and visuospatial functions of children with neurological disorders. For this purpose, the construct validity of the attention and visuospatial modules was assessed via factor analysis and criterion validity was assessed by comparing results in FORAMENRehab with results in NEPSY tasks. Age-appropriate levels of functioning were found using healthy children's data. Test-retest validity was also studied with a subsample of patients.

The basis for validating FORAMENRehab tasks in assessing attention and visuospatial deficits in neuropediatric patients was established, as healthy children scored significantly higher than patients with attention and visuospatial problems on 7 out of 9 attention tasks and all 6 of the visuospatial tasks. Patients also had a tendency to score lower in the remaining 2 tasks, although the difference was not statistically significant. This could be because these two tasks are related to the Focused Attention component, which is the most basic component of attention and might be less impaired in patients.

4.1. Construct validity of FORAMENRehab

Construct validity was assessed by performing an exploratory factor analysis on the results of healthy children and patients. Factor analysis was conducted separately for patients and healthy children, as correlation patterns were different for these groups and fewer tasks were correlated in the patient group, especially in the domain of attention. Most notably, correlations between the Tracking domain task PASAT and Sustained and Divided Attention tasks were stronger in the healthy group. This could be explained with patients having decreased connectivity between brain networks, which has been found to be related to cognitive impairment in both TBI and epilepsy (Bonnelle et al., 2011; Killory et al., 2011).

The factor solutions for attention were also different between patients and controls. For the control group, the two factors that emerged could be labeled Divided Attention and Sustained Attention, while the factors in the patient group could be labeled Working Memory and Focused Attention. This provides evidence for construct validity, as the factors that emerged from tasks that grouped together were logically interpretable as aspects of attention. Analysis of the visuospatial tasks produced a 1-factor model in both groups of children. The model indicated that many of the visuospatial tasks share the requirement of a specific skill that can be interpreted as perceiving an object's location in space.

In case of both modules, the 4-factor structure suggested by the developers of FORAMENRehab or any other popular model of attention could not be extracted. This is primarily due to the small number of tasks in analysis, as this limits the number of factors that can emerge and increases the influence of more general characteristics of cognitive functions on the results. In order to obtain further proof of the construct validity of FORAMENRehab, factor analysis could be repeated with more tasks by also including the tasks currently used only in rehabilitation. Also, analysis should be repeated with a larger sample. Kline (2014) has pointed out that samples smaller than 100 could sometimes provide misleading results, although the sampling adequacy measures in this study provided good results and the ratio of participants to variables was greater than 5 (as recommended by Tabachnick and Fidell, 2007). Even though these findings are somewhat limited, initial evidence suggests that FORAMENRehab tasks could be useful in assessing different aspects of cognitive functions, especially attention.

4.2. Age-related performance

Analysis revealed that the patients' scores were less related to age, which is not surprising, as patients exhibit different levels of impairment, diminishing the effect of age. Healthy children's performance indicated that younger children scored lower than older children on the visuospatial task Construction, all but one tasks of attention and the visuospatial task Spatial Attention, which is related to both cognitive domains. The age effect in tasks diminished around age 10, which might be due to the development of some cognitive functions stabilizing around that age or children mastering skills required to perform these tasks. This is in accordance to developmental literature, which suggests that the maturation of attention takes place during childhood, where most of the development takes place before age 10 (Passler et al., 1985; Chelune & Baer, 1986). Accordingly, in the visuospatial domain, most skills reach maturity by school age, while visual-constructional skills develop around age 10 (Giudice et al., 2000). Therefore, scoring FORAMENRehab tasks needs to take children's age into account, but mainly to separate children aged 8-10 from older children.

4.3. Criterion validity of FORAMENRehab

Investigating the criterion validity of FORAMENRehab revealed some strong correlations between the Attention module tasks and 2 tasks from the NEPSY Attention and Executive Functions domain: Auditory Attention and Knock and Tap. The NEPSY task Auditory Attention was related to FORAMENRehab tasks Visual Selection, Auditory Selection, Number Search and PASAT, which are categorized in the program under Focused Attention, Sustained Attention and Tracking. These connections to different attention components can be explained by the two subtests that NEPSY Auditory Attention is composed of. The first subtest requires the child to selectively attend to auditory stimuli, which explains correlations to tasks with similar demands in FORAMENRehab - Visual Selection and Auditory Selection (Visu-Petra, Benga & Miclea, 2007). The second part of Auditory Attention involves maintaining a complex cognitive set and sustaining attention, which explains relationships with the tasks PASAT and Number Search. The NEPSY task Knock and Tap was related to FORAMENRehab task Tracking, which is somewhat surprising, as Knock and Tap has a large motor component and is more complex than Tracking. Both tasks, however, require maintaining response readiness for a longer duration and mental flexibility. Further investigation is needed, why the NEPSY task Visual Attention did not correlate with the similar task Picture Search from FORAMENRehab. It is possible, that this was influenced by differences in task characteristics (black and white line drawings and marking answers with a pencil in NEPSY, colored pictures and clicking in FORAMENRehab).

It was not particularly surprising that FORAMENRehab did not display any correlations with the tasks Tower, Statue and Design Fluency, as they are thought to have a large executive function component. For example, Tower and similar tasks have long been used to study planning and other executive functions (Krikorian, Bartok, & Gay, 1994). Similarly, in the task Design Fluency planning, self-monitoring and inhibition are necessary to succeed (Visu-Petra et al., 2007). The modalities NEPSY tasks measure are also different. For example, the task Statue requires motor attention, which is not incorporated into FORAMENRehab tasks. The task Design Fluency has a stronger component of hand-eye coordination than any of the FORAMENRehab tasks.

Results also showed that the FORAMENRehab divided attention tasks Addition, Paced Search and Word Recognition did not correlate with any NEPSY tasks. However, task descriptions in the NEPSY manual reveal that divided attention is not a specific task demand in any NEPSY tasks, explaining the lack of correlations (Korkman, et al., 1997).

In the visuospatial domain, the FORAMENRehab task Geometric Pattern was correlated with the NEPSY task Picture Puzzles, which is not surprising, as both of these require distinguishing complex visual stimuli from a set of similar distractor stimuli. The FORAMENRehab task Spatial Attention was correlated with the NEPSY task Block Construction. Although the tasks are visually very different, they both require perceiving objects' relations in space. The FORAMENRehab task Construction was related to the NEPSY tasks Block Construction and Arrows, and shares task requirements with both. Construction entails both manipulation of the position of geometric objects and perceiving detail to total object relations (Block Construction), but also perceiving directions of objects (Arrows) (Korkman et al., 1997).

Surprisingly, the FORAMENRehab task Line Orientation did not correlate with Arrows, although the former also requires perceiving directions. It might be that the added component of manipulating these lines makes the FORAMENRehab task more complex. Also, the FORAMENRehab task Maze did not correlate with the NEPSY task Finding the Path, which have some similarities. However, Maze involves a motor component and moving an object through a more complex set of paths than Finding the Path has.

To conclude, FORAMENRehab Attention tasks Visual Attention, Auditory Attention, Number Search, PASAT and Tracking, and Visuospatial tasks Geometric Pattern, Spatial Attention and Construction showed adequate criterion validity, as tasks with similar attentional and visuospatial requirements were highly correlated. It appears there are tasks in FORAMENRehab involving focusing attention, sustaining attention, maintaining (complex) response readiness and self-regulation. In the visuospatial domain, there are tasks involving perceiving spatial relations and directions, distinguishing and manipulating objects and perceiving detail to total relations. Still, there are some FORAMENRehab tasks, which did not display criterion validity. Further comparisons are needed with cognitive tests that are known to measure specific attention and visuospatial domain components, to gather further evidence about FORMENRehab's ability to assess the whole range of attention and visuospatial functions.

4.4. Test-retest reliability

The analysis of test-retest reliability with the patient group produced varied results between tasks. Tasks like Number Search, Auditory Selection, Addition, Word Recognition and Construction displayed adequate reliability. However, some tasks like Paced Search, Tracking, Line Orientation, Spatial Attention and Cubes were not reliable. One reason for this might be that there was a 5-week interval between tests, which means that the patients' results might have been affected by fluctuations in the course of the disorder or changes in treatment. Secondly, as it was previously noted, the program varied some aspects of the tasks (numbers, order of stimuli) on each administration. This reduces the effect of practice, but also reduces reliability. Although the program is designed to keep difficulty levels constant, the specific content of tasks displaying low reliability should be examined in detail to determine any content-specific aspects that might affect the tasks' difficulty for children. Further studies of reliability should also include the healthy children group, to analyze participant-specific factors that might affect retest performance. Reliability should also be checked with a shorter time interval between test and retest. The tasks displaying a practice effect – Paced Search, Cubes and Construction should be reviewed.

4.5. Limits of the study and future directions

As the first study investigating the validity of FORAMENRehab tasks in cognitive assessment, the findings are somewhat limited. Future studies could involve a larger sample size of healthy children and include ages beyond 12 to investigate in more detail, how FORAMENRehab task performance is affected by changes in children's normal attentional and visuospatial development. To further confirm the modules' suitability for neuropediatric patients, children with other neurological diagnoses could also be included.

More thorough research is needed to determine which aspects of functions are measured by the tasks and whether the FORAMENRehab attention and visuospatial modules can be used to provide a comprehensive overview of a child's attentional and visuospatial functioning. Test-retest reliability also needs to be established by reviewing task content, including healthy children and controlling for participant-specific variables affecting performance. In addition, future studies could investigate other aspects of FORAMENRehab's validity. For example the visuospatial module's predictive validity in predicting children's future functioning in math and science could be tested. Additionally, it could be important to assess FORAMENRehab's convergent and discriminant validity, to study how specific the tasks are in determining attention and visuospatial deficits.

4.6. Conclusion

The study displayed preliminary evidence for the validity of assessing attention and visuospatial functions with computer-based FORAMENRehab modules. 8 of the tasks correlated with NEPSY neuropsychological tests with similar cognitive demands, providing criterion validity and some of the FORAMENRehab tasks thought to measure similar aspects of attention and visuospatial functions grouped together in correlations and factor analysis, providing construct validity. The study presented important information in advancing computer-based neuropsychological measures for Estonian pediatric patients, for which there is a great need. Results obtained from this study can be used to further develop and improve FORAMENRehab to be able to incorporate it into neuropsychological practice as a modern, engaging assessment tool.

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