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Children’s Clinic, Institute of Clinical Medicine, Faculty of Medicine,
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Author's contribution:

- For Study I, the author set the aims, collaboratively collected data and wrote the paper as the corresponding author.
- For Study II, the author was responsible for designing and conducting the rehabilitation part. The author also participated in statistical data analysis, and in collaborative writing as an equal contributor.
- For Study III–IV, the author set the aims, collaboratively collected data, directed the rehabilitation processes and wrote the papers as the corresponding author.
- For Study V, the author collaboratively set the aims and collected data, and directed the rehabilitation process. The author participated in collaborative writing as an equal contributor.

ABBREVIATIONS

ABI	acquired brain injury
ASD	autism spectrum disorder
ADHD	attention deficit hyperactivity disorder
B1	baseline
B2	primary outcome
B3	secondary outcome
BECTS	benign epilepsy with centro-temporal spikes
BP	blood pressure
BRIEF	Behavior rating inventory of executive function
CR	cognitive rehabilitation
DEX	right
DTT	DiamondTouch Tabletop
EP	epilepsy
EF	executive functions
FAR	facial affect recognition
FE	focal epilepsy
fMRI	functional magnetic resonance imaging
MMT	multitouch-multiuser tabletop
MT	multiteach
mTBI	mild traumatic brain injury
NEPSY	A Developmental NEuroPSYchological Assessment/NEPSY test battery
PS	processing speed
QoL	quality of life
s	second
SC	social competence
SCT	sentence completion test
SIN	left
T	training group
TBI	traumatic brain injury
ToM	theory of mind
VR	virtual reality
H	healthy control group children
HR	heart rate
W	waiting-list group
yrs	years

1. INTRODUCTION

Children with acquired brain injury (ABI) need diagnosis of accompanying cognitive and socio-emotional deficits and neurorehabilitation based on their specific impairments. So far, research and treatments have focused mainly on motor disorders, but the development and compensation of impaired cognitive and social functions is crucial for the child's future academic success and quality of life (QoL). Neurorehabilitation is a systematic intervention designed to compensate for or remediate cognitive and/or behavioural impairments caused by brain injury, improve coping with daily life, increase skills to do what is desired and required, but which is difficult due to the impairment (Robertson & Fitzpatrick, 2008; Sarajuuri & Koskinen, 2006). Cognitive impairments present in 57% of children with epilepsy (Cormack et al., 2007) and in 46% of children after traumatic brain injury (TBI) (Yeates et al., 2005). An efficient direction in paediatric neurorehabilitation has been found in training different functions and subfunctions or components separately. Previous studies have shown positive effects in the treatment of cognitive disorders in children with brain injury (Bangirana et al., 2011; Kerns, MacSween, Vander Wekken, & Gruppuso, 2010; Resch et al., 2018; van't Hooft, 2007).

Furthermore, behavioural and communication problems are often associated with cognitive deficits and learning difficulties in children with ABI. As a result, these children often do not make friends and become victims of bullying and violence or bully others at school. They are also more likely to be prescribed medication for depression, anxiety, or both (Crothers, Linden, & Kennedy, 2007; Ilie et al., 2014). Although ABI is a lifelong problem, its negative impact is most present in QoL, where a compound interaction occurs between injury factors, cognition, and personality (Anderson, Brown, Newitt, & Hoile, 2011).

Cognitive and behavioural interventions have the potential to improve school reintegration for youth with ABI (Lindsay et al., 2015). The use of a computer-based environment is a rapidly developing field in paediatric rehabilitation. It is safe and engaging and allows children to practice the skills they need. Research recommends the use of computer-based interventions that involve active therapist involvement (Cicerone et al., 2000).

New effective tools for the rehabilitation of social skills and cooperation behaviours in children are multitouch-multiuser tabletops (MMT) and virtual reality (VR), which allow children to develop mutual planning, sharing and communication, and practice real-life skills. The trainings have been indicated for various communication and cooperation difficulties, mood disorders, and behavioural problems. Previously, these methods have been commonly used in children with autism spectrum disorders (ASD) (Didehbani, Allen, Kandalaft, Krawczyk, & Chapman, 2016; Zancanaro, 2014; Weiss, Gal, Eden, Zancanaro, & Telch, 2011) and therefore, are in need for development based on specific difficulties in children with other disorders.

The main aim of the current thesis was to develop effective technology-based cognitive and social rehabilitation techniques for children with ABI. Specifically, the studies focused on designing and assessing interventions for attention and visuospatial functions, and social competence in children with epilepsy, TBI or tic disorder aged 8–12 years. Firstly, the cognitive or social profiles of children with ABI were evaluated with neuropsychological assessments prior to the rehabilitation processes. The extent of impairments was described in comparison with healthy age-matched control group children. Secondly, the intervention designs with the ForamenRehab computer program were developed for the cognitive rehabilitation of attention and visuospatial functions in children with epilepsy or TBI. The effect of the rehabilitation was measured immediately after the intervention and over one year later. Thirdly, the structured social rehabilitation model was created for the evaluation and rehabilitation of social competence in children with epilepsy, TBI or tic disorder. The social rehabilitation was based on programs developed for MMT, where children were trained in pairs, and on individual trainings with a VR platform. The effectiveness of the rehabilitation tools was assessed with neuropsychological assessments after the trainings process.

2. REVIEW OF THE LITERATURE

2.1 Children with ABI

ABI is a damage to the brain, that occurred after birth, but is not related to congenital diseases or neurodegenerative disorders (Spreij, Visser-Meily, van Heugten, & Nijboer, 2014). ABI is a range of conditions involving rapid onset of brain injury, including trauma due to head injury or postsurgical damage, vascular accident such as stroke or subarachnoid haemorrhage, cerebral anoxia, toxic or metabolic disorders such as hypoglycaemia, and infection or inflammation (RCP, 2004). The current thesis involves children with the following ABI diagnosis: traumatic brain injury (TBI), epilepsy, and tic disorder. The children with tic disorder participated only in the social rehabilitation study.

TBI has been found to be the most frequent cause of ABI in childhood (Dewan, Mummareddy, Wellons, & Bonfield, 2016; Gazzellini et al., 2012). TBI has been defined as damage to the brain resulting from external mechanical force, such as rapid acceleration or deceleration, impact, blast waves, or penetration (Maas, Stocchetti, & Bullock, 2008). TBI is classified into three categories based on severity: mild, moderate and severe. The incidence rate of childhood TBI in Estonia is 369:100 000, of which mild TBI (mTBI) constitutes up to 70–80% of the cases (Ventsel, Kolk, Talvik, Väli, & Vaikmaa, 2008). The leading cause of TBI among children up to 15 years of age is falls (Thurman, 2016; Ventsel et al., 2008). Among 4–15 years old children, falls present with 55.88% of the cases, followed by road and traffic accidents (as a pedestrian, passenger or cyclist) in 30.88% of the cases (Ventsel et al., 2008).

Epilepsy is a common and serious neurological disorder and epileptic seizures affect the functioning of the central nervous system. The estimated prevalence rate of epilepsy is 0.5–1% in the general population (Chung, Hsieh, Lai, & Huang, 2014). Overall incidence rate of paediatric epilepsy is 50:100 000 (Sander, 2003). The incidence rate of childhood epilepsy in Estonia is up to 86.3/100 000 (Veri et al., 2018). The range of aetiologies and risk factors for the development of epilepsy varies with age (Bell & Sander, 2001; Sander & Shorvon, 1996). The International League Against Epilepsy (ILAE) classification of the epilepsies presents the following epilepsy types: focal epilepsy, generalized epilepsy, combined generalized and focal epilepsy, and an unclassified epilepsy group (Scheffer et al., 2017). The current thesis focuses on children with focal epilepsy diagnosis.

Tics have been defined as involuntary, sudden, rapid, brief, repetitive stereotyped movements or vocalizations. The presence of motor tics is the basic symptom in all tic disorders. Tics may be "simple" by involving individual muscle groups or movements, or "complex" by involving coordinated patterns of movement (Singer & Walkup, 1991). Transient tics are relatively common, affecting 20% of school-age children (Scahill, Specht, & Page, 2014).

2.2 Cognitive and social profiles in children with ABI

2.2.1 Impairments of cognitive and social functions

ABI can result in impairments in cognition, language, motor function, sensory processing and emotional disturbances. Clearly expressed cognitive deficit and socio-emotional dysfunctions have been found in children with ABI (Kaldoja & Kolk, 2012; Kolk, Ennok, Laugesaar, Kaldoja, & Talvik, 2011; Kolk & Talvik, 2002; Toome et al., 2013). Previous studies have found cognitive deficits in attention (Bender, Marks, Brown, Zach, & Zaroff, 2007; Kolk, Beilmann, Tomberg, Napa, & Talvik, 2001; Rathouz et al., 2014; Zilli, Zanini, Conte, Borgatti, & Urgesi, 2015), memory (Kernan et al, 2012), executive functions (EF) (Bender et al, 2007; Piccinelli et al., 2008; Zilli et al, 2015), visuospatial abilities (Kolk et al., 2004/2001), and social functioning (Genizi, Shamay-Tsoory, Shahar, Yaniv, & Aharon-Perez, 2012; Zilli et al, 2015). These cognitive deficits, especially the impairments in information processing speed, may be accompanied by difficulties in focusing attention to visual or auditory stimuli in communication. Corresponding to our earlier studies, research has demonstrated cognitive deficits that can greatly complicate everyday communication abilities and behaviours in these children (Janusz, Kirkwood, Yeates, & Taylor, 2002; Rodenburg, Stams, & Meijer, 2005). Moreover, if the cognitive abilities are intact, the socio-emotional processing may still be impaired (Tonks, Williams, Frampton, Yates, & Slater, 2007). Neuropsychological assessments help to define the extent and type of cognitive and social deficits following ABI, and the potential and strategies to rehabilitate the patient.

2.2.2 Attention function and impairments in children with epilepsy and TBI

Attention is one of the key components of cognitive functioning combining processes that enable a person to concentrate on specific cognitive tasks while ignoring others (Loring & Meador, 1999). Sohlberg & Mateer (2017) described attention as a multidimensional cognitive process that affects other dimensions of cognition–learning, memory, communication, problem solving, and perception. Based on diverse theoretical backgrounds, different models of attention components have been developed. Sohlberg & Mateer (2017, 2001) developed a clinical model of attention by which the attention function consisted of five components: focused, sustained, selective, alternating and divided attention. *Focused attention* is a person's ability to respond to specific visual, auditory, or tactile stimuli (Wood, 1988). *Sustained attention* (sometimes regarded to as *vigilance*) is the capability to maintain attention on a task for long periods. It also involves other aspects of the attentional process, including effort and motivation (Wood, 1988). *Selective attention* is known as the capacity to focus on important stimuli, while ignoring irrelevant information by selecting among many available stimuli (e.g., listening to a specific voice in a room with many people talking at the same time) (Pashler, 1999). A person with deficits in this attention component would be easily distracted by irrelevant stimuli, including both external and internal distractions (like worry or rumination) (Sohlberg & Mateer, 2001). *Alternating attention* refers to a mental flexibility of shifting the focus of attention and moving between tasks, therefore, choosing the information to be processed (Sohlberg & Mateer, 2001). *Divided attention* is the ability to attend to competing stimuli simultaneously (Styles, 2005). Two or more behavioural responses could be required to divide attention, e.g., driving while listening to the radio (Sohlberg & Mateer, 2001). Wood (1988) stressed that divided attention is the attentional capacity as well as the focusing of attention for recognizing important cues. Also, *tracking component* of attention has been described, where attention is needed while doing another mental task (Lezak, 2004).

Attention impairments are often present in various disorders, e.g., epilepsy (Goker et al., 2019; Guzeva, Belash, Guzeva, Guzeva, & Anastazi, 2009), TBI (Catroppa, Anderson, Morse, Haritou, &, Rosenfeld, 2006; Laatsch et al., 2007; Levin et al., 2007; Max et al., 2004), schizophrenia (Cornblatt & Keilp, 1994), and brain tumours (Brière, Scott, McNall-Knapp, & Adams, 2008).

Among other cognitive deficits, children with epilepsy have been found to show clearly expressed dysfunctions in different attention components (Austin et al., 2001; Dunn, Austin, Harezlak, & Ambrosius, 2003; Engle & Smith, 2010; Fastenau, Dunn, & Austin, 2006; Hermann, 2006; Kolk, Talvik, & Laine, 2004; Kolk et al., 2001; Thieux et al., 2019). Impairments in overall attention (Engle & Smith, 2010; Glügönen et al., 2000; Kolk et al., 2001; Rathouz et al., 2014), sustained attention (Baglietto et al., 2001; Piccirilli et al., 1994; Semrud-Clikeman & Wical, 1999) and selective attention (Drapeau, Gosselin, Peretz, & McKerral, 2019; Kolk et al., 2001) have been described. Both modalities, visual and auditory attention, have been found to be negatively affected (Aldenkamp et al., 2000; Massa et al., 2001; Metz-Lutz et al., 1999). Some previous findings suggest that specifically children with localization-related epilepsy may be at risk of deficits in attentional control (Gascoigne et al., 2017). Attention impairment is closely linked to impairments in other cognitive functions, like working memory (Lenartowicz, 2014; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011), EF (Biederman et al., 2004; O'Brien, Dowell, Mostofsky, Denckla, & Mahone, 2010) and social competence (Drapeau et al., 2019). Deficits in phonological, visuo-perceptual and memory skills have also been reported in children with epilepsy (Kolk et al., 2004/2001). Attention is crucial for learning and thus, impairments in this function have been found to contribute to major negative influences on academic and social competences (Danckaerts et al., 2010; Fastenau, Shen, Dunn, & Austin, 2008; Genizi et al., 2012; Kinsella, 1998; Mayes, Calhoun, & Crowell, 2000; Nixon, 2001). Children with epilepsy and attention impairment present with significantly higher frequency of intellectual disability and specific learning disorders compared to children with epilepsy without attention problems (Goker et al., 2019). Sustained problems with cognitive functioning also impact children's future employment (Chamberlain, 1995).

2.2.3 Visuospatial functions and impairments in children with epilepsy

The ability of the visual system to process spatial relations between objects or parts of an object is imperative in processing of visual information (van der Ham & Borst, 2011). Visuospatial functions are an important element of intellectual ability and involve multiple processes (Linn & Petersen, 1985; Uttal et al., 2013). Various components of visuospatial functions have been recognized in research (see Table 1).

Table 1. Components of visuospatial functions and the abilities involved.

Components	Abilities involved
1. Spatial perception	Determine spatial relationships
2. Mental rotation	Rotate two- or three-dimensional figures
3. Spatial visualization	Manipulate spatially presented information
4. Visual recognition	Recognize faces/objects/categories
5. Visual organization	See object/picture as sum of parts
6. Visual attention	Process certain areas of visual field
7. Visuospatial perception	Represent physical environment in mind
8. Visual-motor abilities	Integrate perceptual and motor processes

Linn & Petersen (1985) posited that visuospatial functions are skills in representing, transforming, generating and recalling information that is symbolic and non-linguistic. They differentiated three categories of visuospatial abilities: spatial perception, mental rotation and spatial visualization. Spatial perception would be the ability to determine spatial relationships with respect to the orientation of their own bodies, while ignoring distracting information. Mental rotation is the ability to rapidly and accurately rotate a two- or three-dimensional figure. Spatial visualization is the ability to manipulate complex spatially presented information with multiple solution strategies (Linn & Petersen, 1985). Visual recognition is the ability to recognize faces, objects or categories and to respond to visual information (Kolb & Whishaw, 2003). Visual organization or visuospatial constructive cognition has been defined as the ability to see an object or a picture as a sum of parts and then to construct a duplicate of the original from these parts (Mervis, Robinson, & Pani, 1999). Visual attention has been described as the privileged processing of information coming from a certain area of the visual field (Cave & Bichot, 1999). Visuospatial perception is defined by Donnon, DesCôteaux & Violato (2005) as the ability to represent physical environment in one’s mind and the movements to be performed in that environment.

There are various reasons why the research of visuospatial functions in children is important. For example, such skills as visual-motor abilities, visuospatial organization, visual discrimination, and the ability to integrate perceptual and motor processes are all required for a child to learn to count or perform simple arithmetic calculations (Assel, Landry, Swank, Smith, & Steelman, 2003). Moreover, visuospatial skills have been found to predict achievements in mathematics (Assel et al., 2003; Carlson, Rowe, & Curby, 2013). A study with first grade students found a strong relationship between academic performance in math, reading, writing and skills such as visual-motor integration, visual perception, hand control and overall motor proficiency (Pienaar, Barhorst, & Twisk, 2014). In addition, research by Simms, Clayton, Cragg, Gilmore & Johnson (2016) found that visuospatial skills and visuomotor integration were significantly correlated with number line estimation tasks, which has a significant relationship between mathematical achievement. Wai, Lubinski & Benbow (2009) conducted a longitudinal study and found that spatial skills predict achievement in the STEM (science, technology, engineering and mathematics) domains. Visuospatial skills have been found to undergo a stage of rapid development at 10 years of age (Tonks, Yates, Slater, Williams, & Frampton, 2009), which is why it is especially important to be assessed and treated in children with ABI at that age range.

Impairments in visuospatial functions are often present in children with ABI (Groffman, 2016; Parisi et al., 2012; Tonks et al., 2009). A study assessing visuospatial skills in children with focal epilepsy (FE) showed that patients with left side focus had deficits in categorization, verbal long-term memory and visuospatial analysis (Riva, Saletti, Nichelli, & Bulgheroni, 2002). Parisi et al. (2012) assessed neuropsychological impairment in children with epilepsy and, also in children affected by both epilepsy and migraine. They found that all the children with epilepsy, with and without migraine, had deficits in visual-spatial analysis and visual attention. In addition, it has been found that children with newly diagnosed FE, prior to medication, developed deficits in attention, short-term memory and visuo-perceptual functions (Kolk et al., 2001). Furthermore, Danielsson & Petermann (2009) found deficits in spatial perception and visual-constructive skills in children with Rolandic epilepsy [or benign epilepsy with centro-temporal spikes (BECTS)]. In TBI, half of the children faced visual-spatial memory dysfunction, and one-third slower processing speed and impaired visual-spatial planning (Mirka, Kolk, Kaldoja, Auväärt, & Talvik, 2010). Impairment in visual-spatial performance may also be a correlate of psychosocial risk during later teenage years and adulthood in children with ABI: the more impaired visual-spatial skills were, the greater the degree of socioemotional behaviour disturbance was reported by the children (Tonks et al., 2009).

2.2.4 Social competence and deficit in children with epilepsy, TBI and tic disorder

Social competence is a multidimensional concept that reflects a child's capacity to integrate behavioural, cognitive and affective skills to diverse social contexts. Social competence reflects the ability to use social skills based on a person's perceptions and understanding of the social environment (Smith, Polloway, Patton, Dowdy, & Doughty, 2015). The components of social communication are social interaction (e.g., speech style and context, politeness), Theory of Mind (ToM), emotional competence, joint attention, EF, and pragmatics (e.g., body language, eye contact) (Nelson, 1978; Timler, Olswang, Coggins, 2005; Yeates et al., 2007). The Heuristic Socio-Cognitive Integration of Abilities Model (SOCIAL) explains how cognitive, socio-emotional, communicative, biological and environmental dimensions interact to predict social functioning within a developmental framework (Saltzman-Benaiah & Lalonde, 2007). The ability to interpret social situations could be associated with good social competence.

Childhood is a period of rapid development of social skills. Most of the time these skills develop naturally without any need for special attention. The development of social competence is regarded as one of the best predictors of later behavioural, social and academic success, and of present and future behavioural and emotional problems (John, 2001).

However, ABI can affect the development of age-appropriate social and cooperation skills (Martinez, Carter, & Legato, 2011) and thereby reduce children's QoL (Ryan et al., 2016).

Ten percent of typically developed children exhibit socio-emotional problems (Anderson, Beauchamp, Rosema, & Soo, 2014). However, social problems become more severe as a secondary consequence of neurological conditions. Social skills impairment with low peer acceptance and decreased social support is common in patients with ABI (Anderson et al., 2017). In paediatric patients with ABI, social competence deficit present in more than 50% of the cases in TBI, epilepsy, and tic disorders. Still, it remains unclear how common these problems are (Greenham, Spencer-Smith, Anderson, Coleman, & Anderson, 2010). Social deficit is characterized by persistent difficulties in the social use of verbal and nonverbal communication. The main struggles of paediatric patients with social dysfunctions relate to social anxiety, conflict resolution, social cues understanding, self-regulation, self-expression, executive dysfunctions and fewer friends (Prigatano, 2000; Root et al., 2016; Ryan et al., 2019; Topal, Demir Samurcu, Taskiran, Tufan, & Semerci, 2018). Studies in children with epilepsy have shown affected ToM skills consisting of significantly lower ability to understand other people's mental states, like false belief, intentional lying, and sarcasm (Raud, Kaldoja, & Kolk, 2015; Stewart et al., 2019). In addition, children with epilepsy assessed humour differently and found humour less funny than healthy children in these studies. However, humour and laughter are considered important indicators of children's interpersonal, affective, and socio-cognitive abilities (Suits, Tulviste, Ong, Tulviste, & Kolk, 2011). Children with epilepsy are more frequently victims of bullying (42%) (Hamiwka et al., 2009) and demonstrate social deficits in 43.8% of cases (Tse, Hamiwka, Sherman, & Wirell, 2007). In children with tic disorders, epidemiological data have shown severe social deficits in 19% (McGuire, Hanks, Lewin, Storch, & Murphy, 2013) and victimization in 27% of patients (Storch et al., 2007). TBI in young children also negatively impacts social competence and social problem-solving (Ganesalingam et al., 2011; Yeates et al., 2004). Children with TBI have been found to present with social deficits in 75% of cases (Bergland & Thomas, 1991). Emotion recognition deficits are frequent in TBI patients (Drapeau, Gosselin, Peretz, & McKerral, 2017; Spikman, et al., 2013), which can be considered as markers for behavioural difficulties and impaired self-awareness. As emotion recognition can be objectively measured early after injury, it allows for early detection and treatment to prevent further behavioural problems (Spikman, et al., 2013). Change in social communication is one of the most difficult problems for people with TBI and their loved ones. Communication abilities, and affective and behavioural functioning make a substantial contribution to social integration outcomes (Struchen et al., 2011). Various authors have reported increasing social problems after TBI throughout childhood, including few friendships, rejection by peers, lack of guilt and empathy (Anderson et al., 2017; Rubin, Coplan, & Bowker, 2009; Temkin, Corrigan, Dikmen, & Machamer, 2009). Furthermore, children with mTBI exhibited increased difficulty with self-regulation, interaction and autonomy, even before the injury; after the trauma the socio-emotional state deteriorated significantly (Kaldoja & Kolk, 2012).

Acquired social dysfunction is multifaceted, and often remains poorly understood and underdiagnosed (Ryan et al., 2016). There is still a lack of information about children with impaired social communication skills accompanied by such neurological disorders as epilepsy, TBI, and tic disorder. The interventions should address the multifaceted needs of youth when they return to school as the effects of ABI are complex and affect several areas of functioning (Lindsay & Edwards, 2013).

2.2.5 Brain injury in developing brain

The recovery patterns of children and youth with ABI differ from those of adults as children's brains continue to develop into young adulthood and latent brain injury-related challenges may not become readily apparent until children enter adolescence and adulthood (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2009; Anderson, 2003). Research suggests that early injuries may have a substantial impact on the child's further cognitive development: children up to 19 years old with ABI could experience neurological and cognitive changes for weeks, months, or years following reintegration to home and school environments (Anderson et al., 2009).

TBI has been often used as a model to understand the impact of early brain injury on brain structure and functioning. Diffuse axonal injury is thought to be the main contributor to cognitive impairments following TBI (Arfanakis et al., 2002). Poorer performance on a wide range of cognitive functions in the medium to long-term follow-up (>4 weeks) has been associated with decreased white matter integrity (Roberts, Mathias, & Rose, 2016). Significant associations have been shown between cognitive performance, injury severity and age. For children who sustained severe injury, younger age at injury was associated with minimal or no recovery after injury (Anderson et al., 2005). Also, developmental plasticity plays a crucial role in determining language outcomes among children with early focal brain injury (Vicari et al., 2000) as well as age at injury predicts social cognition (Anderson et al., 2017). Greater lesion volume, lower socioeconomic status, and family burden contribute to poorer social relationships (Anderson et al., 2017). School-age children with TBI are at risk for persistent symptoms of behaviour problems, especially in more severe TBI cases or if the injury occurs at a younger age (Taylor et al., 2015). Aggressive behaviour, mood lability, and social isolation have been found to increase with age in patients with ABI (Geraldina et al., 2003; Ylvisaker et al., 2007). Previous findings also highlight the vulnerability of younger children to poorer development of functional academic skills (Prasad, Swank, & Ewing-Cobbs, 2017). Biological, neurobehavioural, psychosocial, and environmental factors all contribute to the child's recovery from TBI (Catroppa, Anderson, Beauchamp, & Yeates, 2016).

The basis for impairments in patients with epilepsy has been found in decreased functional connectivity and reorganization of brain functions, which influence cognitive abilities (Datta et al., 2013; Pitkänen & Sutula, 2002; Zhang et al., 2009). Rathouz et al. (2014) reported in their study that cognitive deficits in children with epilepsy remained stable up to 6 years without evidence of progressive worsening or recovery. This constitutes as a prevalent problem in the educational quality of these children as they may be less able to learn and acquire new skills from their environment. It is necessary to rehabilitate the deficits early on, because these increase the clinical burden and, also impair the patients' QoL (Farina, Raglio, & Giovagnoli, 2015). Although cognitive impairments are frequent in all paediatric groups with epilepsy (attention impairment has been found to be present in 11.8% in 5 to 18-year-old patients), they are more frequent in childhood period in children up to 11 years of age (Goker, Yilmaz, Eraslan, Colak Sivri, & Aydin, 2019).

In general, results from various studies indicate that cognitive and social assessments, interventions and long-term follow-ups are needed for children with ABI. Rehabilitation psychologists and specialists should be aware of the special challenges of the evaluation and intervention in children with brain injuries, with unique consideration to varying aetiologies, age groups, differences in outcome, developmental concerns, and educational planning (Slomine & Jones, 2019).

2.3 Cognitive and social rehabilitation in children with ABI

One of the most suitable treatment methods to facilitate cognitive remediation is cognitive rehabilitation (CR), which is a concept that refers to planned systematic therapeutic approaches to improve information processing (Cope, 1995). CR has previously been called the “Cinderella of children’s health, education and social services” (Pinto et al., 2005). CR methods are crucial in ABI remediation, especially training specific components of an impaired function.

Various studies have found positive outcome of CR in adult patients with ABI (Koorenhof, Baxendale, Smith, & Thompson, 2012; Radford, Lah, Thayer, &Miller, 2011; Resch et al., 2018). CR together with the use of a teaching strategy has been found to be the effective solution for adults with epilepsy (Langenbahn et al. (2013). However, for now, relatively few studies have focused on CR in children. Resch & colleagues (2018) have concluded that multi-component rehabilitation, combining metacognition and strategy-use with drill-based training has been most promising, as it can lead to improvements in both cognitive and social functioning of children with ABI. Still, the existing studies had small sample sizes, heterogeneity regarding outcome measures, intervention and therapist variables, and patient characteristics (Resch et al., 2018). It has been pointed out by several authors that well-controlled studies are needed in paediatric CR that help link rehabilitation clinicians, educators, children, and their families (Limond & Leeke, 2005; Lindsay et al., 2015; Shaw, 2014; Slomine & Locascio, 2009). There is a lack of modern interventions for children with ABI and the need to utilize new neurorehabilitation programs as most ABI intervention research has focused on adults (Reistetter & Abreu, 2006). There still exists a necessity for good intervention designs in CR for children with brain injuries (Ross et al., 2011). The following studies should also take into consideration the school and home environments as well as consider the distinct needs and abilities of each child. Karch, Albers, Renner, Lichtenauer, & von Kries (2013) have concluded that positive training effect has only been proved with individual training programs and guidance. Thus, this kind of approach should be most effective.

2.3.1 Brain plasticity and neurorehabilitation

Plasticity is the “capacity of a system to respond to normal or aberrant developmental or lesion-induced changes in the internal or external environments by adopting new, stable, developmentally appropriate phenotypes and/or restoring old phenotypes” (Dennis et al., 2013). Neuroplasticity is known as the ability of the nervous system to change its structure and function during the processes that underlie learning and memory (Johnston, 2009). The purpose of neuroplasticity is to adjust with environmental changes and recover impaired functions after brain lesion. During learning processes, specific activated neurons change the strength of their connections when responding to the presented stimuli and neural networks make adaptations, which include increases in dendritic complexity (Dennis et al., 2013). By training specific cognitive functions, the neural paths for these abilities are activated. Following studies using functional magnetic resonance imaging (fMRI) or electroencephalogram (EEG) recordings to assess the effect of cognitive trainings in individuals with ABI have found support for this mechanism. Research in patients with multiple sclerosis has demonstrated that intensive attention rehabilitation improved the overall cognitive functioning and affected neural plasticity as increased brain activity was seen in fMRI (Cerasa et al., 2013; Filippi et al., 2012). In a study with adult TBI patients, significant EEG changes were found following attention skills training with the Captain's Log computer program (Stathopoulou & Lubar, 2004). Kim et al. (2009) also studied TBI patients and found that after training the improved performance of attention tasks was accompanied by changes in attentional network activation. Kolb et al. (2010) stated that animal studies have demonstrated identifiable systems, which underlie the beneficial effects of rehabilitation. Furthermore, normally developing 6-year-old children have also been found to show a more adult-like pattern in EEG after attention training (Rueda et al., 2005). The previous study concluded that the executive attention network appeared to develop under strong genetic control, but still, was subject to educational interventions during development. Gordon & Maggio (2012) have concluded that multidisciplinary studies using neurophysiology and MRI are needed in the evidence research of rehabilitation for paediatric ABI.

In all ABI cases, rehabilitation of cognitive and social skills is thought to be one of the most suitable treatment methods supporting brain plasticity and functional reorganization (Ilves et al., 2016; Ilves et al., 2013; Kolk et al., 2012; Kolk et al., 2011). Training-induced plasticity of the so-called "social brain" has been studied in ASD, where patients show facial affect recognition (FAR) impairments associated with hypoactivation of the social brain regions. After the computer-based training, the patients improved on behavioural FAR tests, and cerebral response to implicit affect processing tasks increased bilaterally. The training improved explicit FAR and neuronal responses during implicit FAR, indicating neuroplasticity in the social brain in ASD (Bölte et al., 2015).

2.3.2 Computer-based cognitive rehabilitation

CR in children with cognitive impairments is nowadays mainly developed as computer-based interventions. This type of rehabilitation is efficient, because there is a possibility of making the programs more and more interesting and, therefore, attractive to children. We cannot forbid children from using computers on daily basis, but we should instead use the positive educational influence that computers may provide (Žumárová, 2015). Good compliance in trainings lasting for many weeks have shown that children accept computer-based interventions well (Karch et al., 2013). The use of new technology as a promising method to implement rehabilitation interventions for children with ABI has been emphasized (Bogdanova, Yee, Ho, & Cicerone, 2016; Corti et al., 2019). Evidence from numerous studies suggests improvements in cognitive functions following computerized rehabilitation for ABI populations, but further studies are needed for the development of guidelines and standardized protocols (Bogdanova et al., 2016).

2.3.2.1 Attention rehabilitation

Sohlberg and Mateer have created the fundamental Attention Process Training (APT), which is a therapeutic program for direct training of different attention processes or components (Sohlberg & Mateer, 2017; Sohlberg, Johnson, Paule, Raskin, & Mateer, 1994). It is a hierarchical, multilevel treatment to remediate attention impairments in brain-injured persons. In this process, it is important to establish baseline results for all the attention components separately. Ross & colleagues (2011) concluded in their systematic review of psychological interventions for children that there is a need for further, better controlled research in this important area, and the rehabilitation designs should consider the needs and abilities of each individual child.

Previous studies have either evaluated the efficacy of a specific intervention for attention remediation or incorporated different cognitive domains, including attention. The most effective method is found to be attention training separately from other cognitive domains. In a review by Backeljauw and Kurowski (2014) they found that the best practice was intensive attentional training as demonstrated in the Galbiati study (Galbiati et al., 2009).

A thorough review by Cicerone et al. (2011) of recent studies with children with TBI and stroke found significant positive evidence for rehabilitation of cognitive functions, including attention. Together with their previous reviews the authors have examined 370 intervention studies. On this comprehensive basis they implicated that the training should be addressed to specific attention components and teaching strategies for contributing to generalization. Furthermore, Backeljauw & Kurowski (2014) concluded that the reviewed ABI studies demonstrated similar positive training effect as the TBI studies, and the described results may be generalized. Therefore, the programs that are at first developed for a single ABI diagnosis may afterwards effectively be expanded into the rehabilitation of other ABI diagnosis.

Various studies have described specific computer-based rehabilitation designs for attention impairment in children with ABI. African children surviving cerebral malaria (Bangirana et al., 2011/2009) and children with HIV (Boivin et al., 2010) were trained with Captain's Log cognitive training software configured for attention and memory skills. Results showed immediate benefit of these specific neuropsychological functions. The same program has also been found to elicit positive outcome in attention function in survivors of childhood cancer (Hardy, Willard, & Bonner, 2011). Lee, Harn, Sohlberg, &

Wade (2012) presented outcome data from three pilot participants with TBI who completed an intervention with computerized Attention Improvement Management (AIM) program. After the training, the participants showed clinically meaningful improvements on attention outcome measures and generalization of metacognitive strategies, trained within the program, to contexts outside of therapy. Galbiati et al. (2009) also trained children with TBI and found attention-specific neuropsychological training to significantly improve attention performance. In addition, it also positively affected children's adaptive skills. In a pilot study by Luton, Reed-Knight, Loiselle, O'Toole, & Blount (2011), the researchers used a short version of the Cognitive Remediation Programme (CRP) aimed at improving attention in 6 to 15-year-old children diagnosed with neurological disorders and attention problems. Children completed a six-module programme after which they showed improved attention measured both by parents' reports and children's performance on tasks. Significant improvement in attention components after computerized training has also been shown in children with foetal alcohol spectrum disorders (Kerns et al., 2010; Pei & Kerns, 2012).

Attention remediation training has also been successfully used in children with attention deficit hyperactivity disorder (ADHD) (Rabiner, Murray, Skinner, & Malone, 2010; Shalev, Tsal, Mevorach, 2007; Sohrabi, 2013). A study with ADHD children by Shalev and colleagues (2007) reported an eight-week intervention with the Computerized progressive attentional training (CPAT) program where parents reported a significant decline in children's inattentive symptoms. Also, the children improved in reading comprehension and speed of copying passages in academic performance. Rabiner and colleagues (2010) conducted a study for students in first grade with attention difficulties evaluating the impact of two computer-based interventions–Computerized Attention Training (CAT) and Computer Assisted Instruction (CAI). Results showed that teachers rated a moderate decline in attention problems for all children who completed either of the interventions. Gains in reading fluency and in teacher ratings of academic performance were reported for students receiving CAI. Also, positive effect of computer-based neuropsychological training has been reported by Amonn, Frölich, Breuer, Banaschewski, and Doepfner (2013) in their study with children with ADHD aged 6–13 years. Specific training for 12 to 15 weekly sessions focusing on attentional dysfunction resulted in significant improvement in the trained parameters and symptoms of inattention and deportment.

Also, different reviews and meta-analyses have stressed the positive effect of attention training in children with ABI (Bogdanova et al., 2016; Cernich, Kurtz, Mordecai, & Ryan, 2010; Rohling, Faust, Beverly, & Demakis, 2009) and importance of guidance in developing strategies (Cicerone et al., 2011; Slomine & Locascio, 2009).

As for epilepsy, very few studies have investigated the effects of CR programs for accompanied attention impairments. The amount of research is yet modest compared to other ABI diagnoses and has mostly been conducted with adult patients with epilepsy. In a study with adults with focal seizures, Engelberts and colleagues (2002) used two training methods for attention rehabilitation – the Retraining Method and the Compensation Method – and found both to be effective in improving the patients' neuropsychological outcomes. Gupta and Naorem (2003) stated that after a 6-week specific cognitive training (including training attention deficits) that used both paper and pencil tasks, and real-life activities for patients with epilepsy, overall improvement in cognitive performance occurred. Also, the authors noted the importance of identifying and targeting specific cognitive deficits. However, in children with epilepsy the research about attention training is still extremely limited and requires further development.

2.3.2.2 Visuospatial rehabilitation

Less research could be found on the methods of computer-based CR for visuospatial impairments in children or adults. Some studies have shown positive effects of programs in individuals with stroke (Park & Yoon, 2015). More often, computer-based CR (including VR) has been used to treat adult patients with visual neglect (Cicerone et al., 2016; Ogourtsova, Souza, Archambault, & Lamontagne, 2017). Still, evidence supports the effectiveness of interventions for visuospatial functions after TBI or stroke, along with other cognitive functions after ABI (Cicerone et al., 2016). Studies with healthy individuals have presented data of the usefulness of drill-based computerized interventions, which showed that playing video and computer games could stimulate visuospatial abilities even after a limited training period (Green & Bavelier, 2007; Haier, Karama, Leyba, & Jung, 2009; Lau-Zhu, Holmes, Butterfield, & Holmes, 2017). In paediatric ABI, studies using remote home-based computerized training programs have shown improvements in visuospatial abilities after cognitive interventions (Corti et al., 2019).

2.3.3 Multiuser and virtual social rehabilitation

Some studies have demonstrated evidence that supports the use of social communication interventions both for children (Yang & Wang, 2015; Weiss et al., 2011) and adults (Dahlberg et al., 2007; Helffenstein & Wechsler, 1982; McDonald et al., 2008). Still, rehabilitation of social skills has mostly remained untreated. So far, mainly behavioural methods have been used for social rehabilitation (Timler, 2008; Timler, Olswang, & Coggins, 2005; Vernon, Schumaker, Deshler, 1996). Early intervention and training could improve the long-term outcome and the QoL in children with ABI (Tse et al., 2007).

Today's technology can be a safe and motivating way of engaging children in social interaction in social rehabilitation techniques. The potential of novel technological interfaces like multitouch-multiuser tabletops (MMT) and VR to deliver advanced rehabilitation, has not been sufficiently utilized so far. Previous research has targeted only a small fraction of patients, e.g., ASD (Chen, 2012; Didehbani et al., 2016; Hourcade, Bullock-Rest, & Hansen, 2011; Weiss et al., 2011). Using MMT instead of personal computers in a group problem solving task promoted cooperation, open discussion and mutual understanding in healthy adults (Bause, Brich, Wesslein, & Hesse, 2018). In children the touchscreen facilitated easy interactions and allowed the instructor to participate as well (Wang & Reid, 2011). It supported interaction among co-located users and provided additional opportunities for flexible collaboration (Buxton, 2013; Silva, Raposo, & Suplino, 2014; Weiqin, 2012). Harris (2009) reported that DiamondTouch Tabletop (DTT) technology encouraged children to talk to each other about their joint actions. DTT has been used mainly in studies concerning collaboration in children with ASD. The application "NoProblem" was designed to teach ASD children social conversation and interaction skills (Weiss et al., 2011). Although DTT was found as an effective medium for children with ASD (Mohi, 2016; Weiss et al., 2011; Yang & Wang; 2015), new studies should be considered for children with ABI.

Along with MMT methods, training social scenarios in VR has substantially improved social skills in children with ADHD or ASD (Bashiri et al., 2017; Didehbani et al., 2016; Zhao, Swanson, Weitlauf, Warren, & Sarkar, 2018). The VR environment is experiential and intuitive, as well as being a shared information context for children's interaction (Bricken, 1991). Research has generally indicated that VR is an effective learning tool (Adams, Feng, Liu, & Stauffer, 2019), which creates a captivating synthetic environment for the user, simulating real-world scenarios. The advantages of using VR are flexibility, non-threatening practice of skills and precise performance measurement (Bashiri, Ghazisaeedi, & Shahmoradi, 2017; Didehbani et al., 2016). VR programs have been found to be more effective than traditional rehabilitation programs for three mechanisms: excitement, cognitive fidelity, and physical fidelity (Howard, 2017). Participants have been experiencing social scenes and interactions with avatars in VR realistically enough to feel like they were in the social context interacting in real time (Parsons & Mitchell, 2002). Performance-based assessment to measure socio-cognitive functioning through VR tools has been described, which is therefore a viable method to adopt (Gilboa, Fogel-Grinvald, & Chevignard, 2018). Generalization of skills to real-world situations has been evident in children with ADHD (Bashiri et al., 2017). Still, so far there are no data indicating which social components are the most responsive for interventions.

Taken together, there is a lack of effective treatment protocols for children, especially using modern supportive technologies for cognitive and social interventions. Paediatric intervention needs more motivation compared to adults', and the trainings must be interesting, therefore, novel directions and innovations must be developed. Computer-based and VR interventions elicit better cooperation with patients who apparently enjoy using technological devices (Boydell et al., 2014; Corti et al., 2019; Howard, 2017; Palermo, Valenzuela, & Stork, 2004).

2.4 Summary of the literature review

Cognitive functions like attention, visuospatial abilities and social competence are often impaired in children with ABI, but evidence-based neurorehabilitation has remained undeveloped. It is critical to know the underlying neuropsychological mechanisms of the impaired functions to choose the most effective treatment options. The literature review indicated that the use of new technologies has been found to be an effective method to be implemented in rehabilitation. Still, most of the research of ABI interventions has focused on adult patients. The lack of modern neurorehabilitation possibilities for children with ABI exists. Therefore, there is a need for more rigorously designed and better controlled research, and for implementing new evidence-based programs in the area of paediatric CR. The development of guidelines and standardized intervention protocols for clinicians and therapists is crucial for incorporating rehabilitation programs as part of treatments for children with ABI. Practical recommendations in the field of paediatric neurorehabilitation using next-generation devices is necessary.

3. AIMS OF THE THESIS

The main aim of the research was implementing new computer-based and MMT/VR programs in cognitive and social neurorehabilitation for children with ABI aged 8–12 years. The studies of the thesis focused on developing and assessing the paediatric rehabilitation designs for the remediation of the following cognitive functions: attention, visuospatial abilities, and social competence.

The specific aims were:

1. To evaluate the cognitive and social profiles of children with ABI (Studies I, IV, V).
2. To develop and assess the effectiveness of the cognitive rehabilitation method–ForamenRehab program, in the remediation of attention impairments in children with epilepsy and TBI (Studies II–III).
3. To develop and assess the effectiveness of the ForamenRehab program in the remediation of visuospatial impairments in children with epilepsy (Study IV).
4. To develop a structured social rehabilitation model for the evaluation and remediation of social deficit in children with epilepsy, TBI and tic disorder (Study V).
5. To provide clinical implications for paediatric neurorehabilitation (Studies II–V).

4. PARTICIPANTS AND METHODS

4.1 Participants

Children with ABI

In the cognitive assessment and rehabilitation of attention and visuospatial functions (Studies I, III, IV), 29 children aged 8–12 years (mean age 10.1 yrs, SD=1.53) with a diagnosis of epilepsy participated (21 boys and 8 girls) (see Table 2 for data of participants for all studies). The age group was chosen due to methodological considerations: 1) the children were required to attend a general education school and have basic reading and mathematical skills; 2) it is an important age range to diagnose cognitive impairments to prevent further academic problems. Participants were chosen according to the following inclusion criteria:

- previously diagnosed focal epilepsy diagnosis confirmed by child neurologist;
- attention and/or visuospatial impairments confirmed with neuropsychological assessment (included attention and visuospatial subtests from the NEPSY assessment battery) by a certified clinical neuropsychologist;
- fluency in Estonian.

Exclusion criteria included other documented diseases involving the central nervous system (e.g., stroke, tumours, encephalitis, cerebral palsy), psychiatric co-morbidity (e.g., primary attention deficit hyperactivity disorder, anxiety disorder, mental retardation (IQ levels below 70), children with visual or auditory problems, and treatment with any psychotropic medication other than antiepileptic drugs during the rehabilitation period.

In the pilot study (Study II), eight patients between the ages of 9–12 years (mean age 11.14 yrs, SD=0.90) with attention impairment participated in the attention rehabilitation: 3 with epilepsy (mean age 11.07 yrs, SD=0.87) and 5 with mTBI diagnosis (mean age 11.19 yrs, SD=1.02). There were 3 boys with epilepsy, 4 boys with mTBI and one girl with mTBI. In mTBI group the mean time since injury was 3.79 years (SD=0.51). The inclusion and exclusion criteria were the same as in the Studies I, III, IV (described above), with one additional inclusion criterion: previously diagnosed mTBI (Glasgow Coma Scale 14–15, ICD-10 S06.0).

For creating and testing the structured social rehabilitation model (Study V), 22 children with ABI (epilepsy, TBI or tic disorder) aged 8–13 years participated: 12 completed the entire training program (M=11.10 yrs, SD=1.54) and 10 were in the waiting-list group (M=10.69 yrs, SD=1.70). This age group was chosen as children's social problems become more evident at this period. The patients were selected by paediatric neurologists from the children admitted to the Children's Clinic of Tartu University Hospital and from the outpatient clinic. Participants were chosen according to the following inclusion criteria: diagnosis of TBI, epilepsy and/or tic disorder with previously confirmed social deficit by neuropsychologists; fluency in Estonian. Exclusion criteria were: mental retardation; psychiatric comorbidity; treatment with any psychotropic medication other than antiepileptic drugs during the rehabilitation period; and neurological conditions other than epilepsy, TBI, or tic disorder.

Healthy control group children

To obtain the data for typically-developed children, the neurologically-healthy comparison group was created. All the studies (I–V) included age-matched healthy control group children (see Table 2). The children were recruited from ordinary schools in Tartu city and county with general education setting. Children with any known neurologic or psychiatric diagnosis were excluded from the control groups. In Studies I, III, IV 19 neurologically-healthy children aged 8–12 years (11 boys and 8 girls) participated. In Study II the control group was composed of 18 healthy children (9 boys and 9 girls) aged 9–12 years. The healthy children's control group for Study V was composed of 10 children aged 8–13 years.

Table 2. Data of participants in all the studies.

Study / group	**Nr of children**	**Sex**	**Mean age (yrs)**	**Diagnosis**
Studies I, III, IV				
Children with ABI	29	21 M / 8 F	10.10	29 EP
Healthy children	19	11 M / 8 F	*age-matched*	–
Study II				
Children with ABI	8	7 M / 1 F	11.14	3 EP / 5 mTBI
Healthy children	18	9 M / 9 F	*age-matched*	–
Study V				
Children with ABI	22	18 M / 4 F	10.90	15 EP / 4 TBI / 3 tics
Healthy children	10	8 M / 2 F	*age-matched*	–

Nr–number, yrs–years, ep–epilepsy, mTBI–mild traumatic brain injury, M–male, F–female

All the studies were approved by The Research Ethics Committee of the University of Tartu and carried out in the Department of Pediatrics and Neurology in the Children's Clinic of Tartu University Hospital, Estonia. Parental written consent and child's verbal agreement to participate in the intervention were attained.

4.2 Methods

4.2.1 Evaluation and rehabilitation tools

4.2.1.1 Evaluation and rehabilitation of cognitive impairments

The FORAMENRehab Cognitive Rehabilitation Software® (ForamenRehab) is a computer-based tool for cognitive assessment and rehabilitation that was developed by Koskinen and Sarajuuri (2002) in Finland. The clinical experiences of the applicability of ForamenRehab software in adults with ABI have been effective (Koskinen & Sarajuuri, 2004; Sarajuuri & Koskinen, 2006). Firstly, the software was adapted into Estonian with permission from the authors, and the beta version for children was created (Saard, 2012). In the current research (Studies I–IV), the baseline assessment levels of the Attention and Visuospatial modules of the ForamenRehab program were established and used to identify each child's profile of attention and visuospatial functions. Thereafter, the intervention protocols for the Attention (see Table 3) and Visuospatial modules of the program were created and used in the cognitive rehabilitation process.

The cognitive tasks in the modules had been divided into four attention and four visuospatial components. The menu structure, toolbar, and icons of the software were illustrative; each task had clear written instructions as well as a model animation. The parameters of each task were adjustable. The results were given both in numerical tables and graphs. Several outcomes were recorded for every application: solving and/or reaction time, number of correct responses, and subcategories of mistakes (omission errors, premature responses, commission errors, and total number of errors – sum of omission and commission errors).

In addition, in Studies III and IV the generalized cognitive effect of the training was assessed with the Behaviour Rating Inventory of Executive Function (BRIEF) (Gioia, Guy, Isquith, & Kenworthy, 1996) and the parents' questionnaire, which was created for the purpose of the current research. This involved questions about the child's attention state, visual performance, behavioural manifestations of attention and concentration, general school-performance and the rehabilitation. As parents filled the questionnaires at three different time-points, the long-term changes in comparison of before and after the training were seen.

Table 3. Tasks divided under three difficulty levels in attention rehabilitation with ForamenRehab.

Focused attention			
Easy level	**Medium level**	**Difficult level**	**Affected attention functions**
Visual Reaction Time Task	Visual Reaction Time; Auditory Warning Visual Choice Reaction Time Task	Visual Multiple Choice Reaction Time Task	Attention activation, alertness and selectivity: simple visual or auditory reaction (intrinsic vigilance); tasks with warning (phasic activation of attention) or with distracting stimuli (selective attention and reaction inhibition).
Auditory Reaction Time Task	Auditory Reaction Time; Visual Warning Auditory Choice Reaction Time Task	Auditory Multiple Choice Reaction Time Task	
Sustained attention			
Easy level	**Medium level**	**Difficult level**	**Affected attention functions**
Single Figure Search with letter, number, symbol I, symbol II, or picture search (easy level settings)	(medium level settings)	(difficult level settings)	Continuous attention, high ratio of relevant stimuli.
Series Search with letter, number, figure, or symbol series search (easy level settings)	(medium level)	(difficult level)	
Paced Search with Single Target (target length – 2 characters)	(target length – 4 characters; target shifting interval – faster)	(target length – 7 characters)	
Repeated pairs search (numbers; symbols – large font)	(numbers; symbols – small font; letters – large font)	(letters – small font)	Continuous attention, high ratio of disturbing stimuli.

Complex attention			
Easy level	**Medium level**	**Difficult level**	**Affected attention functions**
Paced Search with Dual Targets (target length – 2 characters)	(target length – 4 characters)	(target length – 7 characters)	Dual tasks: dividing and shifting attention, cognitive flexibility.
Addition; Single Number (series length – 4 digits)	(series length – 5–7 digits)	Addition; Dual Numbers	Single addition: dividing attention, working memory.
Word Recognition; Single Target	Word recognition; Dual Targets	Simultaneous Word Recognition and Mental Arithmetic	Single word recognition: continuous attention, comparison with existing knowledge.

Tracking			
Easy level	**Medium level**	**Difficult level**	**Affected attention functions**
Tracking task		–	Continuous attention, attention activation.
Word Recognition; Backwards Spelling		(target shifting interval – faster)	Continuous attention, comparison with existing knowledge.
		PASAT; Auditory Presentation PASAT; Visual presentation	Auditory / visual dividing of attention, executive function of working memory.

4.2.1.2 Evaluation and rehabilitation of social deficit

The main components of social sompetence were evaluated (see Table 4 for more details) (Study V) using the Social domain in NEPSY-II assessment battery (Korkman, Kirk, & Kemp, 2008); ToM skills were evaluated using ToM Stories test (Saltzman-Benaiah & Lalonde, 2007); social skills using two parents' questionnaires: Social Cognition Questionnaire (Saltzman-Benaiah & Lalonde, 2007) and Social Skills Rating System (Gresham & Elliott, 1990). The profile of social anxiety was evaluated with the Spence Children's Anxiety Scale (Spence, Barrett, & Turner, 2003). The Sentence Completion Test (SCT) revealed children's perception of their every-day social and emotional difficulties (Jakobson, 2014/2015). The Friendship Observation Scale (FOS) was used for paired assessments of communication and cooperation skills that children used in active interactions with each other. For measuring intervention outcome, the neuropsychological testing of social competence was used prior and after the treatment and monitoring of cardiac parameters was used during trainings.

For the social rehabilitation, two MMT interactive platforms were implemented: Multiteach (MT) platform and DiamondTouch Tabletop (DTT). The Snowflake MultiTeach Suite application (Mohi, 2016) on MT platform was used for cooperation skills and EF training, including educational (e.g., "Einstein," "Memorina") and cooperation tasks (e.g., "Bridge-Building," "Raindrop"). For social communication skills training, the "NoProblem!" application on DTT was used in different social environments: at school, at home, and after school contexts. Discussions and role-plays for starting, continuing, changing topics, and ending conversations were used. Also, children were presented with various social scenarios through the video processing task, for which we created videos that presented difficult social situations with right and wrong behaviours.

In addition, 10 social metaphors for the VR software were created and applied on the HTC Vive VR device for social skills, social anxiety, and emotion perception training. The training involved virtual solving of challenging social situations based on the development of social competence through role-play. The VR metaphors included the following situations: getting a seat back from another child in cinema, getting a cake back in cafeteria, being bullied by classmates, comforting others at school, asking the ball back from the neighbor's garden etc.

VR combined with the MMT platforms provided an engaging, realistic, flexible and safe setting for children to practice social skills (Study V).

Table 4. Tests and questionnaires used in the evaluation of social sompetence in children with ABI**.**

Test / questionnaire	Evaluated abilities / social difficulties	Scales
NEPSY-II battery ***Social Perception Scale***	Facial affect recognition, comprehending others' perspectives, intentions, and beliefs (i.e., ToM)	1. Affect Recognition 2. Theory of Mind
Theory of Mind Stories (ToM Stories)	Comprehending others' beliefs, intentions, feelings, perspectives	1. False Beliefs 2. Intentional Lying 3. Sarcasm
Friendship Observation Scale (FOS) ***Interactional coding system***	Positive social interaction and behaviour, frequency and quality of interaction	1. Positive Social Interaction 2. Global Evaluation Scale
Sentence Completion Test (SCT)	Perception of self and others, every-day social difficulties	1. Relationships 2. Behaviour 3. Self-perception 4. Emotions
Spence Children's Anxiety Scale	Severity of anxiety symptoms	1. Social Anxiety 2. Panic/agoraphobia 3. Separation anxiety 4. Obsessive compulsive problems 5. Generalized anxiety 6. Physical injury fears
Social Cognition Questionnaire	Common every-day behaviour and social interactions *(befriending, teasing, bullying, understanding jokes etc).*	*No Subscales*
Social Skills Rating System	Social skills and problematical behaviours	1. Cooperation, responsibility, assertion, self-control 2. Externalizing and internalizing problems, impulsivity
Behavior Rating Inventory of Executive Function (BRIEF)	Executive function behaviours at home and at school	1. Behavioural Regulation 2. Metacognition 3. Global Executive Composite score

4.2.2 Study designs

Cognitive rehabilitation of attention and visuospatial functions in children lasted for 6 weeks (Studies II–IV). Altogether 13 sessions were conducted twice a week: the first baseline assessment, 10 active trainings, and the second assessment with baseline tasks for primary outcome. The final follow-up assessment with baseline tasks as the secondary outcome was carried out 1.31 years (SD= 0.40, Studies III, IV) or 1.63 years (SD=0.07, Study II) after the training period (see Fig. 1).

The patients in the waiting-list control group participated in all three assessments with baseline tasks. During the five-week period between the first and the second assessment the waiting-list group received no intervention. One-time baseline assessments of the healthy control group children were performed.

The protocols for the attention and visuospatial interventions were created (see Table 3 for attention rehabilitation protocol). In the baseline assessment, all four components of attention and visuospatial functions were tested. For trainings, different tasks under the same components of functions were used, divided into three difficulty levels: easy (I), medium (II) and difficult (III). The development on difficulty levels was individual-based: if the child made no mistakes in the task, he/she advanced to the next level; if the child's response was incorrect, he/she had to stay and perform the same task level until the performance was at least 80–90% correct (depending on the task) for 3 consecutive sessions until advancing to the next level.

For the evaluation and remediation of social deficit, the structured social rehabilitation model was created (Study V). The structured three-stage model consisted of: 1. Evaluation of social competence profile pre- and post-training; 2. Individual VR training: child solved situations in VR to reduce anxiety and train new skills; 3. Multi-user (2 children) MMT training: cooperation and communication trainings with other children for social engagement and role-plays.

The intervention with children was carried out to demonstrate the effectiveness of the created model. At the first meeting, all children performed individual and paired assessments to find out their base-level social competence profiles. The intervention sessions, guided by two therapists, were performed in 1.5-hour trainings once a week for ten times according to the training protocol. Table 5 introduces the training protocol with task descriptions for every training session. The training consisted of two children practicing in pairs, who solved increasingly complicated tasks at each session (2 VR-metaphors, 1 on DTT, 2 on MT, in specified order). After the intervention period, the primary outcome was evaluated with the same baseline tests and feedback questionnaires (see Fig. 2). The healthy control group children only participated in the first baseline assessment.

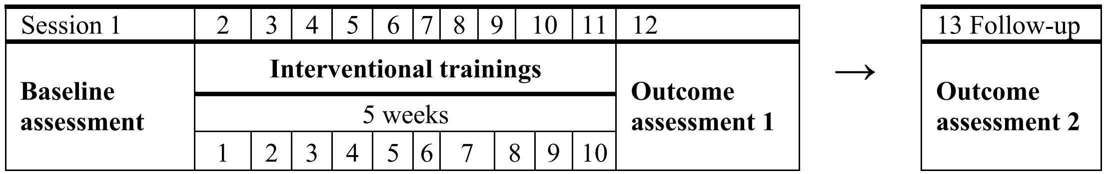

Figure 1. Intervention design for the attention and visuospatial rehabilitations.

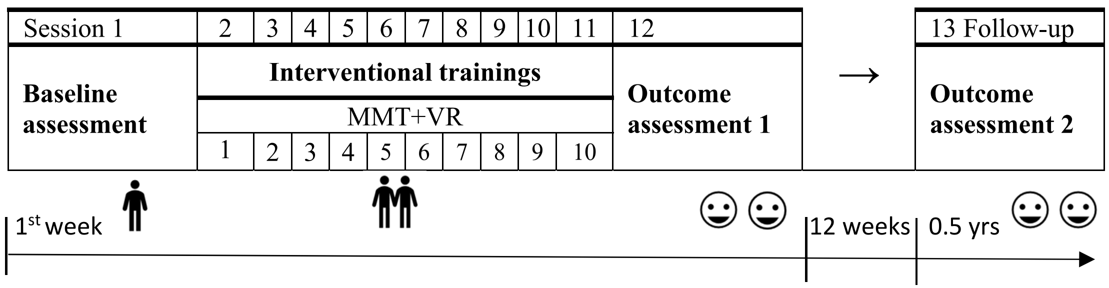

Figure 2. Intervention design for the social rehabilitation.

Table 5. Training protocol for the social rehabilitation.

Session	***Evaluation and intervention tools***
1	***First individual evaluation*** 1. Tests: ToM Stories, NEPSY II, Sentence Completion, Spence Children's Anxiety Scale 2. Parents' questionnaires (3): Social Cognition, Social Skills, BRIEF
2	***First paired evaluation and training*** Video recording – MMT school situation, Drawing, Memorina, Video Discussion (later video evaluation with FOS by therapists) VR: 1. Mirror therapy 2. Social therapy: Introduction with another child (basic conversation skills) MMT: 1. **NoProblem:** School situation, role-play (starting a conversation, continuing a conversation, changing the subject of a conversation, ending a conversation). 2. Video discussion (2): situations taking place at school – taking away glasses, going to the diner. General discussion about bullying in school. 3. Memorina (8–10 yrs old: colours, animals/birds; 11–13 yrs old: fruits, jobs) 4. Drawing (8 min): children agree on what to draw, distribute tasks, name the picture
3	VR: 1. Mirror & Ball therapy 2. Social therapy: Ball in neighbour's garden-Easy (politeness, apologizing) MMT: 1. After school situation, role-play (starting a conversation, continuing a conversation, changing the subject of a conversation, ending a conversation). General discussion about politeness, rules and norms and the necessity of rules 2. Video discussion (2): finding a dog, broken phone 3. Untangle and Puzzles (giraffe, bear)
4	VR: 1. Mirror therapy 2. Social therapy: Cafeteria – Easy (politeness, assertiveness) MMT: 1. Home situation, role-play (starting a conversation, continuing a conversation, changing the subject of a conversation, ending conversation). General discussion about social anxiety, shyness, helping other shy children 2. Video discussion (3): locking to the bathroom, playing the piano, taking away hair brush 3. Planetarium; Einstein – Shapes
5	VR: 1. Mirror & Ball therapy 2. Social therapy: Bullies at school (assertiveness, emotional coping skills) MMT: 1. Video discussion (3): at the bus stop, throwing with ball, texting with other child's phone 2. Einstein – Organs, Math: prime numbers, odd numbers. 8–10 yrs: animals, residence; 11–13 yrs: countries, flags 3. Clocks; Math (easy: compounding, subtraction; difficult: multiplication, partition) 4. General discussion about rules of cooperation

Session	*Evaluation and intervention tools*
6	VR: 1. Mirror therapy 2. Social therapy: Movie theatre – Easy (convincing skills) MMT: 1. Video discussion: asking for help 2. 2 screens: drawing two separate pictures / guessing what the other drew 3. 2 screens: contest in Einstein and Memorina 4. 2 screens: contest in Word game – finding correct words
7	VR: 1. Mirror & Ball therapy 2. Social therapy: Comforting a friend (empathy) MMT: 1. Video discussion: solving a problem with a friend; apologizing 2. Puzzles 3. General discussion about non-verbal communication (emotions, gestures, eye gaze etc.) 4. Role-plays using different non-verbal communication means. Noticing own and others non-verbal communication.
8	VR: 1. Mirror therapy 2. Social therapy: Speaking in front of the classroom (anxiety, public speaking skills) MMT: 1. Video discussion: asking the teachers' help at school; asking time and directions from a stranger in the street; asking help from the clerk in the supermarket 2. Word game 3. General discussion about communication with adults 4. Role-plays about different social situations when child communicates with adults (asking help etc).
9	VR: 1. Mirror & Ball therapy 1. Social therapy: Movie theatre – Hard, Ball in neighbour's garden-Hard, Cafeteria-Hard MMT: 1. Video discussion: comforting a friend, making a compliment to a friend with a new hairstyle. 2. Math, Puzzles 3. General discussion about positive social interaction (making compliments, praising others, helping and supporting others, being thankful) 4. Role-plays about positive social interaction
10	***Second paired evaluation*** 1. Video recording – MMT school situation, Drawing, Memorina, Video Discussion (later video evaluation with FOS by therapists) 2. VR all metaphors (hard versions)
11	***Second individual evaluation*** 1. Tests: ToM Stories, Nepsy II, Sentence Completion, Spence Children's Anxiety Scale

4.2.3 Statistical analysis

The statistical data analysis was performed with the R version 3.1.2 (Studies I, III, IV) and IBM SPSS Statistics v21 (Study II). For some of the figures, the SAS data analysis package 9.2 was used. The Kolmogorov-Smirnov test was used for the assessment of normality. The Kruskal-Wallis test and Wilcoxon-Mann-Whitney test were used to compare the study group, waiting-list group and healthy control group children (Studies I, III, IV). Linear mixed models were used to assess whether longitudinal changes in groups were overall significantly different. In Study II, the independent sample t-test was used to compare the patients' and controls' performance in baseline tasks. Wilcoxon signed-rank test was mainly used to compare the patients' baseline performance to primary and secondary outcomes (Studies II–IV). Continuous outcome variables were log-transformed when necessary to satisfy model assumptions. For comparing proportions (qualitative variables) the McNemar's test was used. The confidence level was set to 5%. The false discovery rate (FDR) was controlled to be lower than 5% by using linear step-up procedure (Benjamini & Hochberg, 1995) for multiple t-tests. Benjamini-Hochberg critical values were calculated as (i/m)Q, where i is the rank in an ascending list of p values, m is the total number of tests, and Q is a false discovery rate of 0.05. The cut-off P value for significance in a single comparison for the longitudinal changes of variables in study group was 0.025. Only p-values that were below the adjusted FDR significance threshold were significant. Effect sizes for non-normal distributions were calculated using the Cliff's Delta statistic, which is a non-parametric effect size measure that quantifies the amount of difference between two groups of observations (Cliff, 1996).

5. RESULTS AND DISCUSSION

5.1 Cognitive and social profiles in children with ABI

The results from the studies showed clearly expressed impairments in attention and visuospatial functions in children with epilepsy or TBI, and social deficit in children with epilepsy, TBI, or tic disorder.

In Studies I, II and IV, the Attention and Visuospatial modules of the ForamenRehab software were adapted into Estonian and the version for children and the rehabilitation designs were created. Also, the baseline assessment levels for tasks were established, which gave the opportunity to evaluate individual cognitive profiles specifically in children. The baseline assessment with the ForamenRehab successfully distinguished patients from the healthy control group children, which gave an opportunity to use the program for screening attention and visuospatial impairments in the future and distinguish the children needing neurorehabilitation.

Study I showed that in comparison of the performances on the ForamenRehab baseline assessment tasks between children with epilepsy and healthy control group children, the patients had significantly lower results in three out of the four attention components: *sustained attention, complex attention*, and *tracking* components ($p<0.05$).

In *sustained attention* children with epilepsy were distinguished from healthy children in targeting significantly less correct stimuli and showing slower processing speed (PS) in tasks with numerous different pictures or numbers as stimuli (see Table 6). Difficulties in *sustained attention* (Baglietto et al., 2001; Semrud-Clikeman & Wical, 1999) and slower PS (Borgatti et al., 2004) in children with epilepsy have been reported before. The PS differed significantly between patients and healthy control group children even if only the children with 100% correct performance were compared. 66% of children with epilepsy and 82% of healthy children were included in this secondary analysis. Statistically significant difference still existed: the patients had slower solution time ($p=0.0086$). This was important to be analysed separately as some children with visible concentration problems rushed through tasks, quit prematurely, and although gaining faster solution times, made more mistakes.

Table 6. Comparison of performances on baseline assessment with the Attention module of the ForamenRehab between children with epilepsy and healthy control group children.

Parameters of ForamenRehab ***Attention tasks*** *Baseline assessment*	Children with epilepsy Median (Lower and Upper Quartiles)[a]	Healthy children Median (Lower and Upper Quartiles)	d[b]	Sig. P
Focused attention				
Visual reaction time (s)	0.59 (0.49…0.67)	0.53 (0.43…0.65)	0.29	0.082
Auditory reaction time (s)	0.61 (0.54…0.74)	0.62 (0.59…0.69)	-0.08	0.626
Sustained attention				
Correct responses in picture search (%)	97.44 (94.87…98.72)	98.72 (96.15…100.00)	-0.32	0.040*
Omission errors in picture search[c] (%)	2.56 (0.00…3.85)	1.28 (0.00…3.85)	0.24	0.178
Processing speed in picture search (s)	205.00 (160.50…244.00)	159.00 (140.00…215.00)	0.38	0.026*
Processing speed in numbers search (s)	709.00 (597.00…886.00)	603.00 (393.00…747.00)	0.36	0.042*
Complex attention				
Correct responses in paced search (%)	31.80 (16.15…46.06)	55.88 (38.89…74.19)	-0.57	<.001*
Omission errors in paced search (%)	68.20 (53.94…83.85)	44.12 (25.81…61.11)	0.57	<.001*
Total errors in paced search[d] (nr)	32.00 (26.00…35.00)	22.00 (12.00…27.00)	0.58	<.001*
Correct responses in word recognition (%)	41.67 (25.00…66.66)	80.13 (50.00…90.91)	-0.66	0.0001*
Omission errors in word recognition (%)	58.33 (33.33…75.00)	19.87 (9.09…50.00)	0.66	0.0001*
Commission errors in word recognition[e] (nr)	1.00 (1.00…2.00)	2.00 (1.00…3.00)	-0.16	0.335
Correct responses in addition (%)	30.00 (15.00…65.00)	80.00 (70.00…90.00)	-0.77	<.0001*
Tracking				
Correct responses in PASAT (%)	22.50 (10.00…30.00)	65.00 (45.00…95.00)	-0.82	<.0001*
Omission errors in PASAT (%)	50.00 (27.50…65.00)	17.50 (5.00…20.00)	0.63	0.0003*
Commission errors in PASAT (%)	22.50 (15.00…47.50)	12.50 (0.00…30.00)	0.43	0.013*
Commission errors in tracking task (nr)	1.0 (0.00…2.00)	0.00 (0.00…0.00)	0.40	0.013*

a Median (Lower 25%ile and Upper 75%ile)
b Effect size index Cliff's delta
c Omission errors–missed responses to target stimuli
d Total errors–sum of omission and commission errors
e Commission errors–responses to nontarget stimuli
* $P<0.05$

In *complex attention*, the children with epilepsy performed significantly worse than healthy children in every aspect: they gave significantly less correct responses, had more omission errors and more total errors (see Table 6). The same results – difficulties dividing attention between two or more stimuli at the same time – have previously been reported (Ceminara et al., 2013; Ceminara et al., 2010). Significant deficits existed in tasks under *complex attention* that demanded word recognition and calculation skills, which required working memory involvement. Impairments in working memory have been previously described for children with epilepsy, with similar difficulties existing at school for these children, as was reported by their parents (Sherman, Brooks, Fay-McClymont, & MacAllister, 2012). Furthermore, previous studies have shown specific learning difficulties in children with epilepsy (Pavlou & Gkampeta, 2011; Piccinelli et al., 2008). Overall lower educational outcome and need for special education for children with epilepsy have been reported over time (Berg et al., 2005; Pastor, Reuben, Kobau, Helmers, & Lukacs, 2015; Sillanpää, 1992).

In *tracking component,* the Paced Auditory Serial Addition Test (PASAT) revealed that the patients' group had significantly worse results in every aspect of the test compared to healthy control group children: less correct responses, more commission and omission errors. Also, the percent of commission errors was significantly higher for children with epilepsy compared to healthy children (Table 6). Therefore, in tasks that required continuous tracking of stimuli, they detected less correct stimuli and committed or reacted to wrong stimuli more often. They would therefore have problems with tasks requiring intact working memory, which enables prolonged information processing and considers the data acquired moments earlier. In general, our data confirmed the previous findings (Cerminara et al., 2013; Mitchell, Zhou, Chavez, & Guzman, 1992) that children with epilepsy make more omission errors compared to healthy children.

The patients performed as good as healthy control group children only in one component – *focused attention*. There were no statistically significant differences in the visual or auditory reaction times, or the percent of correct responses measured in these reaction time tasks between the children with epilepsy and their healthy peers.

The results from Study II also expressed impairments in attention components in children with ABI (epilepsy and mTBI) (see Fig. 3).

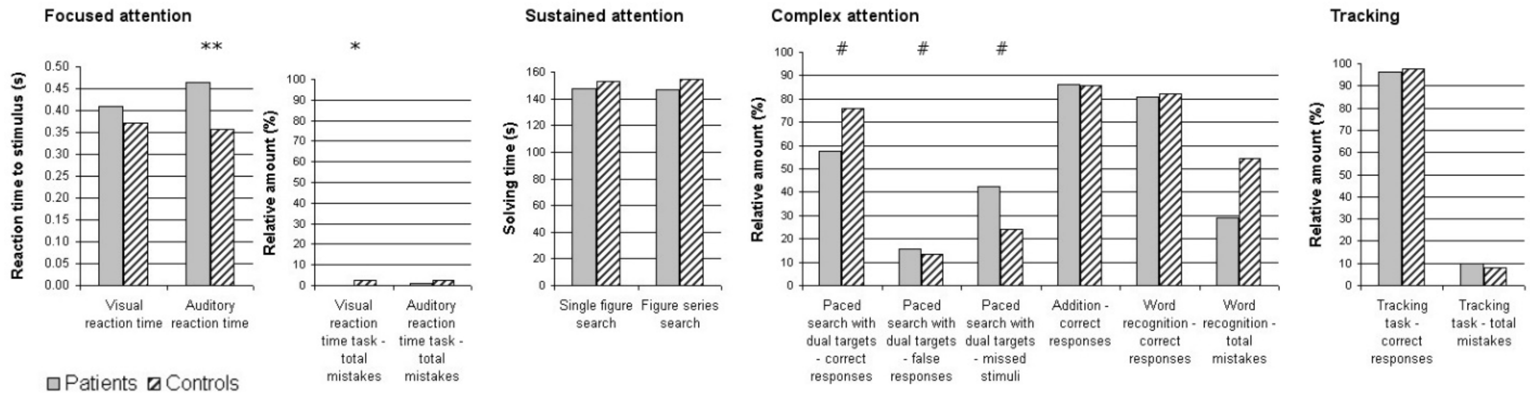

Figure. 3. Comparison of baseline performances in children with ABI and healthy control group children.
*Note. ** p<0.001; * p<0.05; # p<0.08)*

Study IV expressed visuospatial impairments in children with epilepsy aged 8–12 years as they showed significant deficits in all 4 of the visuospatial components compared to the healthy control group children (Table 7). Impairments in visuospatial functions have often been present in children with ABI (Groffman, 2016; Parisi et al., 2012). These difficulties are particularly important to be assessed and remediated in children in this age range (Tonks et al., 2009).

Firstly, deficits in *visual recognition* component with additional spatial awareness and EF were observed on baseline level. Previously, lesions in anterior regions of the right temporal lobe in epilepsy have been found to impair recognition of the identities of familiar faces, as well as the learning of new faces (Glosser, Salvucci, & Chiaravalloti, 2003). Deficits in EF in children with epilepsy have also often been reported before (Bender, Marks, Brown, Zach, & Zaroff, 2007; Max et al., 2004; Zilli, Zanini, Conte, Borgatti, & Urgesi, 2015; Riccio, Pliego, Cohen, & Park, 2015). In *visual organization* component the children with epilepsy gave significantly less correct answers, although the solving time of tasks did not differ from the healthy children. This result could in part show that the children with epilepsy rushed through the tasks with less concentration, and therefore making more errors. The tasks in this category also showed that the patients had deficits in visuospatial memory and construction abilities. Our results were in line with Danielsson & Petermann (2009) who found deficits in visual-constructive skills in children with BECTS and with Deonna et al. (2000) who reported deficits in visuospatial memory and visuospatial organization in children with benign FE. This adds an important basis for CR as a significant positive association has been demonstrated between visuospatial working memory and mathematical performance (Allen, Higgins, & Adams, 2019). Formerly, an alteration of functional connectivity within visuospatial working memory-related brain network in patients with right temporal lobe epilepsy has been found with fMRI (Lv et al., 2014). Rehabilitation would help to better the connectivity by training specific functions. Also, the activation of mesiotemporal structures during visuospatial memory retrieval has been found to be asymmetrical in patients with medial temporal lobe epilepsy. The activation of the mesiotemporal structures is usually reduced ipsilateral to the epileptogenic region (Jokeit, Okujava, & Woermann, 2001).

The children with epilepsy also showed deficits in *visual attention* component, which have been reported before in children with BECTS and in children with both, BECTS and migraine (Parisi et al., 2012). Newly-diagnosed children with BECTS have displayed brain activity alterations in the ventral and dorsal attention networks with fMRI (Xiao et al., 2015), which also impact visual attention. Furthermore, in the current study, the children with epilepsy showed deficits in *visuospatial perception* component. In epilepsy, the right lateral temporal cortex is associated with inhibited neuronal activity during short-term visuospatial memory in contrast to excitation activity during other functions, particularly figure matching and perception (Holmes, Ojemann, & Lettich, 1996).

Table 7. Comparison of results on the first baseline assessment with the Visuospatial module of the ForamenRehab program between training group, waiting-list group and healthy control group children.

Parameters of ForamenRehab Visuospatial tasks	Training group (T)	Waiting-list group (W)	Healthy control group (H)	T vs W vs H	T vs H	W vs H	T vs W
	Median (Lower and Upper Quartiles)[a]	Median (Lower and Upper Quartiles)[a]	Median (Lower and Upper Quartiles)[a]	*p*	*p*	*p*	*p*
Visual Recognition							
Circle Following (%)	30.81 (21.69...57.44)	28.89 (16.18...39.85)	71.58 (50.10…93.07)	0.1061	0.1626	0.0470	0.3958
Line Orientation Judgement (°)	5.83 (4.75...16.92)	8.92 (6.13...21.58)	2.92 (1.67...3.75)	<.0001	0.0003**	<.0001**	0.2999
Visual Organization							
Geometric Pattern Recognition (nr)	14.35 (13.34...15.36)*	14.60 (13.63...15.57)*	14.06 (12.90...15.22)*	0.7865	0.8473	0.5050	0.6741
Geometric Pattern Recognition (%)	61.54 (53.33…71.43)	64.10 (51.67...73.61)	73.33 (71.43...81.82)	0.0140	0.0101**	0.0134**	0.9029
Visual Attention							
Spatial Attention (%)	80.00(50.00...90.00)	70.00 (67.50...81.67)	95.00 (90.00...100.00)	<.0001	0.0003**	<.0001**	0.8055
Spatial Attention (s)[b]	8.50 (7.00...14.86)	8.82 (6.74...11.97)	6.15 (5.04...7.47)	0.0015	0.0034**	0.0010**	0.7722
Visuospatial Perception							
Cubes (%)	20.00 (0.00...40.00)	20.00 (0.00...50.00)	80.00 (40.00...80.00)	0.0006	0.0007**	0.0011**	0.6585
Cubes (s)[b]	37.43 (30.04...44.81)*	38.67 (31.46...42.87)	48.15 (25.56...61.40)	0.6087	0.4694	0.3370	0.9393
Construction (%)	66.67 (33.33...100.00)	66.67 (33.33...100.00)	100.00 (100.00...100.00)	0.0007	0.0005**	0.0008**	0.6382
Construction (s)[b]	243.17 (148.31...311.24)	221.93 (160.25...321.04)	103.16 (74.00...198.50)	0.0027	0.0030**	0.0030**	0.9878
Maze (nr)	6.00 (4.00...9.00)	6.00 (2.50...16.50)	1.00 (1.00...3.00)	0.0002	0.0002**	0.0008**	0.8306
Maze (%)	32.87 (27.62...36.96)	24.62 (11.98...38.48)	8.53 (0.45...12.11)	<.0001	<.0001**	0.0008**	0.2171
Maze (s)[b]	54.83 (46.16...84.60)	63.18 (56.87...75.81)	42.46 (37.37…51.35)	0.0004	0.0047**	0.0001**	0.4929

[a]Median (Lower 25%ile and Upper 75%ile)
[b]seconds
* Mean (95% confidence intervals)
** We controlled the FDR to be lower than 5% by using linear step-up procedure for multiple t-tests.

To attain the results of the *social competence* profile in children with ABI, the baseline assessment was carried out prior to the intervention (Study V). At baseline assessment, the children with epilepsy, TBI or tic disorder demonstrated social incompetence compared to healthy control group children, which is frequent in children with ABI (Anderson et al., 2017). They had noticeably higher deficits in EF (M=117, SD=23.59) compared to healthy children (M=22, SD=18.39), and social perception and social skills deficit (see Table 8). The individual assessments revealed that the most impaired components of social competence were *emotion recognition, ToM abilities,* and *low cooperation skills*. Specifically, inability to start and end conversations, deficient cooperation behaviours (accepting rules, waiting for turn, interrupting conversations), and lower perception of communication norms were revealed.

Table 8. Pre-training scores of patients' individual social competence assessments.

	Pre-training scores	
	Mean (SD)	Min/max
NEPSY-II (normal range 8–12)		
Affect Recognition	7 (5.01)	1/12
Verbal ToM	8 (3.06)	4/13
Contextual ToM	8 (3.15)	5/13
ToM stories		
False Beliefs	15 (2.14)	11/16
Intentional Lying	7 (2.20)	4/10
Sarcasm	6 (2.20)	2/10

The children with ABI used less non-verbal communication, had more inadequate social responses, and presented remarkable problems with understanding social scenarios. Observation with FOS revealed scores approximately 25–50% out of 100 (Table 9).

Table 9. Mean FOS subscale scores (% of social skill observed) pre-training.

FOS scale	%
1. General communication skills	**50**
Interest: Listening	50
Interest: Looking	25
2. Friendship and cooperation skills	**25**
Coping with criticism	25
Patience	25
Accepting rules of the game	25
3. Pragmatics	**25**
Avoids monologue	10
4. Empathy	**75**

SCT revealed that patients struggled with lack of friends, behavioural problems, bullying, teasing, and social anxiety. Girls reported more intrinsic problems, like regrets related to their behaviour, fears related to new social situations, and the need for help in difficult conditions. Boys recognized the need to improve their external behaviour, but they disliked rules and authority.

Taken together, the need for revealing and targeting specific problematic components of the impaired cognitive functions and social competence was evident.

5.2 Attention rehabilitation

Study II and III demonstrated that the Attention module of the ForamenRehab program is a suitable method for attention rehabilitation in children with epilepsy and TBI. The rehabilitation design successfully supported the children's continuous progress during the intervention process in different attention components. One of the strengths of this method was that it was tailored to follow each child's individual abilities and attention impairment profile. Amonn et al. (2013) have stated that in order to prove clinical value, the cognitive training programs should "focus more strongly on individually existing neuropsychological deficits". Still, the strict training protocol allowed the objective observation of progress in each child as well as the children's overall progress within attention components.

In Study III the effects of rehabilitation were measured by comparing the performances in baseline tasks (used only for baseline and outcome evaluation) before and after the intervention period. After the active training for five weeks, the study group children's performance improved significantly in two attention components: *complex attention* and *tracking*, which showed significant improvement in various aspects (see Table 10).

Table 10. Primary and secondary outcomes of attention function training with the ForamenRehab program in children with epilepsy.

Parameters of ForamenRehab Attention tasks	Baseline B1 Mean (95%CI)[a]	Primary outcome B2 Mean (95%CI)	Secondary outcome B3 Mean (95%CI)	B1-B2-B3 Sig P [#]	B1 vs B2 Sig P	B1 vs B3 Sig P
Focused attention						
Visual reaction time (s)	0.64 (0.57…0.71)	0.67 (0.58…0.76)	0.51 (0.43…0.60)	0.0071	0.5715	0.0047**
Auditory reaction time (s)	0.66 (0.59…0.73)	0.67 (0.58…0.75)	0.58 (0.50…0.65)	0.1297	0.9115	0.0869
Sustained attention						
Correct responses in picture search (%)	96.15 (93.59…100.00)*	98.72 (96.15…100.00)*	99.36 (97.44…100.00)*	0.1530	0.1864	0.0930
Omission errors in picture search[b] (%)	3.85 (0.00… 6.41)*	1.28 (0.00…3.85)*	0.64 (0.00…2.56)*	0.1578	0.1922	0.0966
Processing speed in picture search (s)	185.71 (165.54…205.87)	210.94 (161.77…260.12)	182.10 (148.09…216.11)	0.4384	0.2927	0.2160
Processing speed in numbers search (s)	738.94 (588.32…889.56)	854.65 (675.19…1034.10)	575.00 (459.70…690.30)	0.0770	0.2783	0.1677
Complex attention						
Omission errors in paced search (%)	66.74 (57.79…75.68)	41.99 (30.96…53.03)	33.94 (26.56…41.31)	<.0001	<.0001**	<.0001**
Total errors in paced search[c] (nr)	32.19 (27.37…37.00)	18.35 (13.51…23.20)	17.67 (13.60…21.73)	<.0001	0.0002**	<.0001**
Omission errors in word recognition (%)	56.15 (41.70…70.60)	38.78 (25.59…51.97)	20.76 (5.27…36.26)	0.0003	0.0028**	0.0002**
Commission errors in word recognition[d] (nr)	2.00 (1.00…2.00)*	1.00 (0.00…2.00)*	0.00 (0.00…2.00)*	0.1081	0.0744	0.0741
Correct responses in addition (%)	41.76 (26.75…56.78)	63.53 (49.57…77.49)	80.00 (68.82…91.18)	0.0002	0.0007**	0.0002**
Tracking						
Correct responses in PASAT (%)	25.88 (17.79…33.97)	55.29 (38.70…71.89)	67.00 (49.71…84.29)	0.0001	0.0002**	0.0002**
Omission errors in PASAT (%)	36.80 (23.97…49.62)	29.70 (15.70…43.71)	17.00 (5.66…28.34)	0.1877	0.3600	0.0710
Commission errors in PASAT (%)	34.12 (20.51…47.73)	15.00 (8.08…21.92)	16.00 (4.71…27.29)	0.0164	0.0049**	0.0475
Commission errors in tracking task (nr)	1.00 (0.00…1.50)*	1.00 (1.00…2.00)*	0.50 (0.00…1.00)*	0.4045	0. 2526	0. 2624

a Mean score (95% confidence intervals)
b Omission errors–missed responses to target stimuli
c Total errors–omission and commission errors
d Commission errors–responses to nontarget stimuli
* Median score (Lower 25%ile and Upper 75%ile), *non-normal distribution*
** Cut-off P value for significance in single comparison for longitudinal changes of attention variables is 0.023
[#] Mixed models method

Van't Hooft et al. (2007) have also described positive change in children with ABI after rehabilitation in *complex attention* tasks, in contrast to the simpler reaction time tests. A better outcome in *complex attention* could show improved abilities to concentrate on tasks, and to divide and shift attention between stimuli. Less commission errors may also suggest improvement in impulse control and behaviour regulation, as commissions in tasks have been described as indicating impulsivity by rapid, but incorrect responses (Halperin, Wolf, Greenblatt, & Young, 1991). Also, the *tracking component* of attention (tracking the processes of a task) improved significantly during the training. This improved the ability to process new information.

In *focused* attention, no significant change was discovered when measuring visual and auditory reaction times. Similar results have been reported by Cicerone (2002) and van't Hooft et al. (2007), who have stated that although training might not improve reaction times, it still provides the children with valuable solution techniques and strategies.

Furthermore, in the current study, distinctive differences in the more complicated attention components were revealed by measuring children's individual progress at each difficulty level. A slower rehabilitation effect out of the four attention components occurred in two: *complex attention* and *tracking* – where children's average attained level at the end of training was only 1.55 (95% CI: 1.36…1.74) out of a maximum of 4 and 1.31 out of a maximum of 3, respectively (see Table 11). Even though significant improvements in *complex attention* and *tracking* were revealed after training, these components would need longer training.

Table 11. Average attained difficulty levels at the end of intervention in all four attention components.

Attention component	Nr of task	Mean level	95% confidence intervals	
Focused attention	1	3.88	3.69	4.06
	2	4	–	
Sustained attention	1	3.31	2.94	3.69
	2	3	2.81	3.19
	3	3.56	3.23	3.9
Complex attention	1	1.19*	0.97	1.4
	2	1.62*	1.3	1.95
	3	1.88*	1.61	2.14
Tracking	1	1.31*	0.99	1.63

* Tasks with slower progress.

All children had positive individual progress throughout the intervention as they gradually reached higher difficulty levels. Still, the speed of progress was different for each child. At the end of training, children with faster progress had attained approximately 1.5–2 times higher difficulty levels compared to the children with slower progress (see Fig. 4).

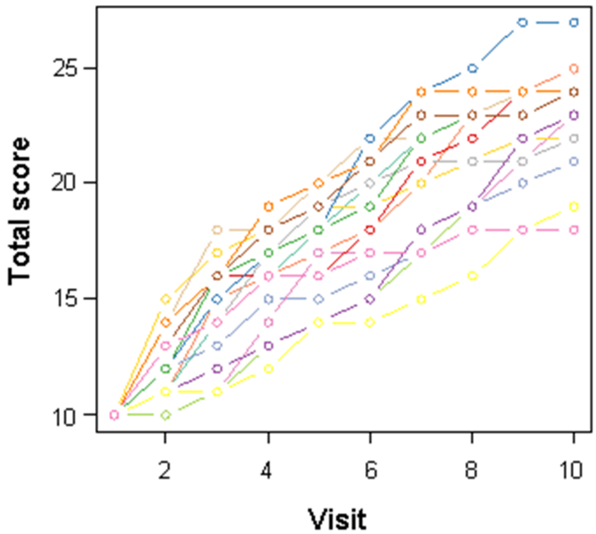

Figure 4. Children's individual progress trajectories for 10 sessions of attention training (summary score per visit).

The significant positive rehabilitation effect in the intervention group was further confirmed in comparison with the waiting-list group. After the 5-week period without intervention, the children with epilepsy in the waiting-list group demonstrated no change between the first and second assessment with the baseline tasks. Furthermore, the follow-up assessment after 1.31 years showed the sustained, positive long-term effect of the rehabilitation in the patients in the study group, in contrast to the children in the waiting-list group, who demonstrated remarkably fewer positive dynamics over time (aside from the developmental curve). This emphasizes the effectiveness of the intervention and diminishes the chance of a positive outcome solely due to normal developmental processes. Thereafter, the parents conclusively confirmed the preserved positive effect and reported noticeable positive changes in their children's everyday life. The generalized rehabilitation effect was expressed in the children's behaviour and overall performance in school. Notably, full compliance and positive feedback from children showed that the computer-based attention rehabilitation was pleasing for the children.

The previous pilot study (Study II) had also confirmed positive effects of the attention rehabilitation with the ForamenRehab program in children with epilepsy and TBI. After the training, the patients were faster in completing a *sustained attention* task than before the training ($Z=-2.37$, $p<0.05$). They also performed significantly better in outcome assessment with a *complex attention* task: they gave more correct responses ($Z=-2.20$, $p<0.05$) and made fewer mistakes ($Z=-1.99$, $p<0.05$). An important finding was that children with epilepsy needed a longer training period compared to the children with TBI. Diagnosis-specific profiles were assessed by progressing on difficulty levels of tasks: TBI group reached higher levels in *complex, sustained* and *tracking functions* faster (Saard et al., 2014). The long-term follow-up revealed persistent positive rehabilitation effects after 1.63 years and the 100% compliance suggested that the used method was attractive to children. The current thesis adds to the knowledge about positive effects of attention training in children with ABI (Bogdanova et al., 2016; Cernich et al., 2010; Rohling et al., 2009) and the importance of therapists in developing strategies (Cicerone et al. 2011; Slomine & Locascio, 2009).

5.3 Visuospatial rehabilitation

Study IV demonstrated that the Visuospatial module of the ForamenRehab program is a suitable method for visuospatial rehabilitation in children with epilepsy. After the five-week training period, the training group showed a positive rehabilitation effect in 3 out of the 4 visuospatial components: *visual organization*, *visual attention* and *visuospatial perception*. The effect was seen in all parameters of *visual organization* (see Fig. 5 as an example) and *visual attention*. In *visuospatial perception*, the number of correct responses increased, but no significant improvements in reaction time were observed (Table 12). This could indicate that the rehabilitation helped the children find better strategies to solve the tasks, without quickening in reactions.

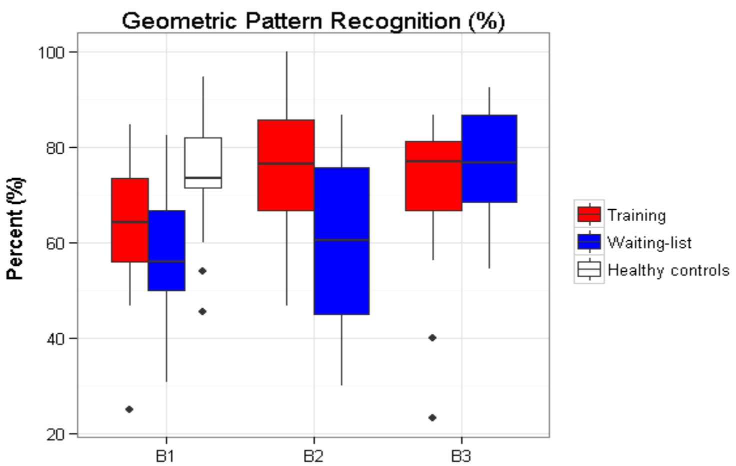

Figure 5. Longitudinal changes in the percentage of correct responses in visual organization task at three assessment points with baseline tasks (B1–baseline, B2–primary outcome, B3–secondary outcome).

Table 12. Comparison of performances on three assessments with the Visuospatial module of the ForamenRehab program within training and waiting-list groups.

Tasks of FORAMENREHAB Visuospatial module		Training group Mean (95% CI)[b]	Waiting-list group Mean (95% CI)	B1 vs B2 *p*	B1 vs B3 *p*	B2 vs B3 *p*
Visual recognition	B1[a]	9.38 (4.98...17.65)**	13.26 (6.11...28.78)**	n. s.	T=0.0007***	n. s.
Line Orientation Judgement (degree	B2	3.83(1.67...8.80)**	10.76 (4.90...23.61)**			
of deviation)	B3	2.67 (1.42...5.0298)**	5.63 (3.02...10.49)**			
Visual organization	B1	14.23 (13.07...15.39)	13.80 (12.34...15.26)	T=0.0371	n. s.	n. s.
Geometric Pattern Recognition (nr of	B2	15.62 (14.61...16.62)	14.00 (11.57...16.43)			
solved tasks)	B3	14.31 (12.97...15.65)	15.10 (13.58...16.62)			
	B1	64.29 (56.00...73.33)*	55.83 (50.00...66.67)*	T=0.0327	T=0.0002***	n. s.
Geometric Pattern Recognition (% of	B2	76.47 (66.67...85.57)*	60.48 (44.44...78.57)*		W=0.0020***	
correct answers)	B3	76.92 (66.67...81.25)*	76.79 (66.67...88.89)*			
Visual attention	B1	80.00 (45.00...90.00)*	70.00 (65.00...80.00)*	T=0.0054***	T=0.0059***	n. s.
Spatial Attention (% of correct	B2	95.00 (85.00...100.00)*	67.50 (60.00...80.00)*		W=0.0313	
answers)	B3	97.50 (85.00...100.00)*	90 (65.00...100.00)*			
	B1	9.38 (7.03...12.51)**	9.76 (7.63...12.49)**	T=0.0005***	T=0.0134***	n. s.
Spatial Attention (reaction time)	B2	5.67 (4.72...6.80)**	9.11 (7.15...11.60)**			
	B3	6.53 (5.56...7.68)**	7.51 (5.85...9.65)**			
Visuospatial perception	B1	24.62 (9.69...39.54)	26.00 (9.41...42.59)	T=0.0469	n. s.	n. s.
Cubes (% of correct answers)	B2	36.92 (17.28...56.56)	62.00 (39.18...84.82)			
	B3	43.08 (24.07...62.09)	48.00 (29.90...66.10)			
	B1	33.66 (24.30...39.03)*	41.27 (32.49...41.92)*	n. s.	n. s.	n. s.
Cubes (reaction time)	B2	26.86 (23.06...35.72)*	39.85 (30.22...46.05)*			
	B3	26.51 (24.02...35.76)*	36.62 (29.27...47.52)*			
	B1	50.00 (0.00...83.34)*	66.67 (66.67...100.00)*	T=0.0098***	T=0.0313***	n. s.
Construction (% of correct answers)	B2	100.00 (83.34...100.00)*	83.34 (33.33...100.00)*			
	B3	83.34 (66.67...100.00)*	100.00 (66.67...100.00)*			
	B1	243.59 (166.21...320.96)	218.95 (153.71...284.19)	W=0.0234	T=0.0479	n. s.
Construction (reaction time)	B2	195.58 (126.72...264.45)	193.87 (126.38...261.37)*			
	B3	159.97 (110.52...209.41)	174.06 (116.32...231.79)*			
	B1	7.04 (4.82...10.26)**	7.85 (2.93...21.01)**	n. s.	n. s.	W=0.0391

Tasks of FORAMENREHAB		Training group	Waiting-list group	B1 vs B2	B1 vs B3	B2 vs B3
Visuospatial module		Mean (95% CI)[b]	Mean (95% CI)	*p*	*p*	*p*
Maze (nr of wrong moves)	B2	4.15 (1.54...11.20)**	8.22 (3.83...17.69)**			
	B3	4.25 (1.63...11.07)**	3.29 (1.87...5.79)**			
	B1	30.59 (25.79...36.29)**	23.96 (15.53...36.99)**	n. s.	T=0.0105***	n. s.
Maze (% of navigation errors)	B2	12.31 (5.61...27.02)**	27.99 (18.74...41.80)**			
	B3	8.62 (3.58...20.80)**	12.62 (5.67...28.07)**			
	B1	61.30 (48.38...77.67)**	72.21 (57.68...90.41)**	n. s.	W=0.0371	n. s.
Maze (solving speed)	B2	55.92 (43.77...71.45)**	74.46 (57.83...95.87)**			
	B3	52.60 (39.69...69.71)**	52.44 (36.96...74.40)**			

[a] B1–first baseline assessment, B2–primary outcome assessment, B3–secondary outcome assessment (follow-up), T–training group, W–waiting-list group, n. s.–not significant

[b] Mean score (95% confidence intervals for Mean)

* Median (Lower 25%ile and Upper 75%ile)

** Geometric Mean (95% confidence intervals)

*** We controlled the FDR to be lower than 5% by using linear step-up procedure for multiple t-tests.

Still, a positive long-term rehabilitation effect was seen 1.31 years after the rehabilitation in *visual recognition*, even though no immediate rehabilitation effect was found. This may suggest that the positive effects were observable not immediately, but more than a year later, since the waiting-list control group did not show any improvements. In *visual organization,* the percentage of correct responses improved also in the secondary outcome. The strategies learned during active training were maintained, but regular training would be required to keep up the solving speed. In *visual attention,* and *visuospatial perception* the positive rehabilitation effects in most of the parameters had preserved (Table 12). To sum up, the children with epilepsy in the training group showed a positive long-term rehabilitation effect in all 4 visuospatial components.

In contrast, the children with epilepsy in the waiting-list control group improved their performance only in reaction time of one *visuospatial perception* task in primary outcome and had improved in a few parameters under two components in long-term outcome. The normal developmental processes again do not explain the immediate and long-term positive rehabilitation effects in the training group, since there was a noticeable difference in performances between the two groups (Table 12).

When analysing the individual improvements on levels in children with epilepsy, the slowest advancements were seen in *visual recognition* and *visuospatial perception* tasks (Table 13)–these components required longer training on easier levels. In contrast, higher difficulty levels were achieved in all *visual organization* and *visual attention* tasks. Furthermore, both components also demonstrated a significant improvement in outcome assessments.

Table 13. Mean difficulty levels achieved by the end of intervention and average number of completed sessions before moving from 1st to 2nd difficulty level.

Visuospatial	**Nr of**	**Mean level**	**Mean sessions**
		Mean (95% CI)	Mean (95% CI)
Visual Recognition	1	1.56 (1.29...1.84)*	4.69 (3.3...6.07)
	2	1.81 (1.33...2.3)	5.06 (3.99...6.14)
	3	2.19 (1.74...2.63)*	2.38 (1.35...3.4)
Visual Organization	1	3.25 (2.84...3.66)	1.62 (1.08...2.17)
	2	3.12 (2.55...3.7)	1.5 (1.02...1.98)
Visual Attention	1	3.31 (2.89...3.74)	2 (1.25...2.75)
Visuospatial Perception	1	1.38 (0.99...1.76)	6.25 (5.35...7.15)
	2	2.12 (1.7...2.55)*	3 (2.13...3.87)
	3	3.31 (2.81...3.82)	1.88 (1.26...2.49)
	4	1.62 (1.3...1.95)*	3.94 (3.04...4.84)
	5	1.25 (1.01...1.49)	3.94 (2.98...4.9)

* Tasks with a maximum difficulty level of 3.

All children showed positive individual advancement on the visuospatial tasks during the training. Still, all the study group children with epilepsy had individually different progress trajectories (see Fig. 6). The difference between the difficulty levels reached at the end of the intervention was up to 2 times higher for the children with the quickest improvements compared to the children with the slowest improvements.

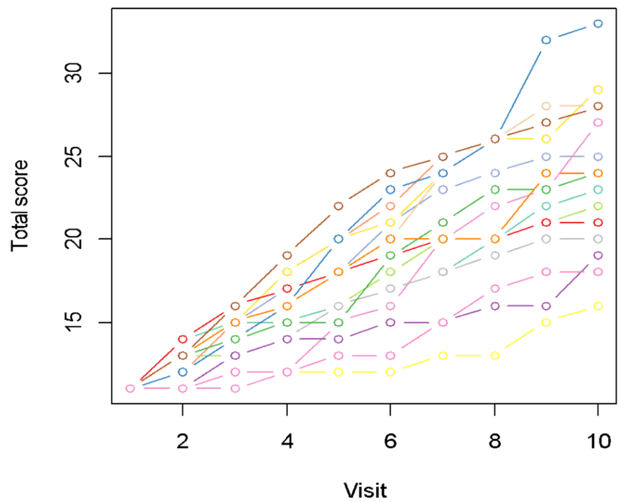

Figure 6. Each patient's individual progress trajectories for 10 sessions of visuospatial training (total score achieved per visit).

Better visuospatial skills may also lower the children's psychosocial risk in the future as visual-spatial performance has been found to be correlated with reported social difficulties in children with ABI (Tonks et al., 2009).

5.4 Social rehabilitation

5.4.1 Structured social rehabilitation model

Based on our findings, we created a structured social rehabilitation model for the practical intervention of social deficit in children. The evaluation and rehabilitation tools for different aspects of the *social competence* domain were depicted in the model (see Fig. 7).

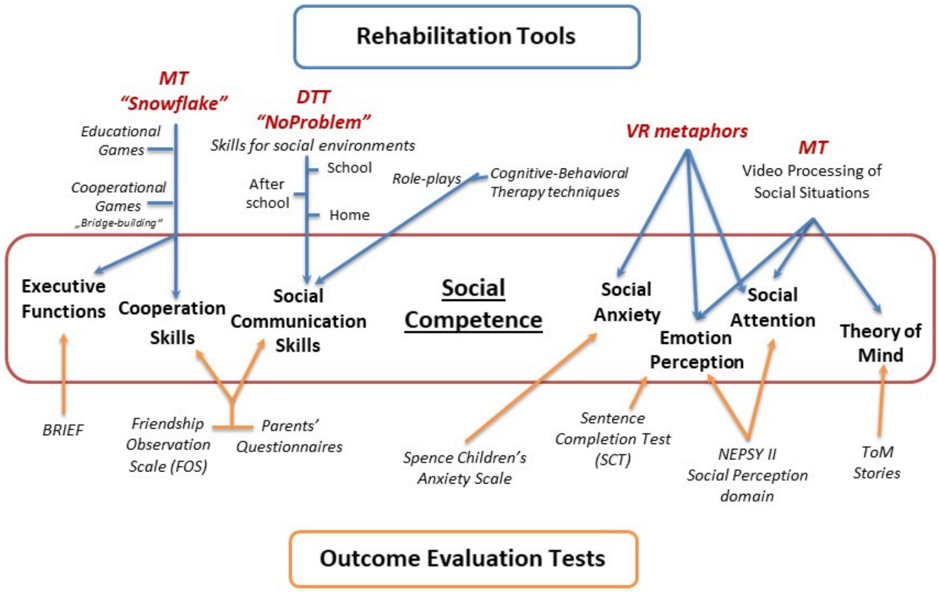

Figure 7. Structured model of the main components of social competence with evaluation and rehabilitation tools (two MMT platforms: MT and DTT, and VR plaform).

The algorithm introduced the social competence components (cooperation and communication skills, social anxiety and attention, emotion recognition, ToM abilities, and EF) and the following software platforms: MT, DTT, and VR, expressing the relationship between social skills and, multiuser and virtual rehabilitation techniques. The intervention design combines MMT and VR platforms for the remediation of social impairment in children to support the transfer of learned skills to real life experiences through role-plays.

Overall, the structured social rehabilitation model that we developed helps therapists to understand the objectives and tools for paediatric neurorehabilitation and theoretical connections between components of social competence and modern intervention with computerized platforms. Trainings based on this model were promising in paediatric social deficit remediation.

5.4.2 Effectiveness of social rehabilitation tools

The results of the Study V showed positive effect of the intervention using the MMT and VR platforms in children with ABI following the structured model and protocol. The patients' compliance was 100% and feedback was encouraging. The objective assessment measures showed positive outcome in various aspects of social competence after the intervention period. After paired collaboration, everyday social skills benefitted, and children were easily motivated and engaged into the rehabilitation process.

Post-training evaluations showed that the MT platform helped the children to acquire executive and cooperation skills (e.g., the Finger Paint program trained cooperation), negotiation, and manual skills. The training on DTT developed new communication and language skills, metacognitive skills, and coping in social situations. Using video modelling to teach individual verbal and non-verbal skills of interacting, and role-plays improved natural communication, verbal and non-verbal social skills, and gestural behaviours. The VR training improved social attention, emotional attitude, and decreased social anxiety (see Tables 14 and 15).

NEPSY-II showed improvement in Affect Recognition (mean assessment results at B1=7, SD=5.01 vs B2=10, SD=5.85), Verbal ToM (B1=8, SD=3.06 vs B2=10, SD=4.08), and Contextual ToM (B1=8, SD=3.15 vs B2=11, SD=2.87). Also, ToM Stories test showed improved understanding of Intentional Lying (B1=7, SD=2.20 vs B2=10, SD=0.50), and Sarcasm (B1=6, SD=2.20 vs B2=7, SD=2.50). Better affect recognition could additionally prevent further behavioural problems and increase children's self-awareness (Spikman, et al., 2013).

Table 14. Pre- and post-training scores of patients' individual social competence assessments.

	Pre-training		**Post-training**	
	Mean (SD)	Min/max	Mean (SD)	Min/max
NEPSY-II				
(normal range 8–12)				
Affect Recognition	7 (5.01)	1/12	10 (5.85)	1/13
Verbal ToM	8 (3.06)	4/13	10 (4.08)	4/13
Contextual ToM	8 (3.15)	5/13	11 (2.87)	7/13
ToM stories				
False Beliefs	15 (2.14)	11/16	15 (3.00)	10/16
Intentional Lying	7 (2.20)	4/10	10 (0.50)	9/10
Sarcasm	6 (2.20)	2/10	7 (2.50)	4/10

Table 15. Samples of mean FOS subscale scores (% of social skill observed) pre- and post-training.

FOS subscale	%
1. General communication skills	**50/75**
Interest: Listening	50/75
Interest: Looking	25/50
2. Friendship and cooperation skills	**25/75**
Coping with criticism	25/25
Patience	25/50
Accepting rules of the game	25/75
3. Pragmatics	**25/50**
Avoids monologue	10/50
4. Empathy	**75/75**

Previously, Beauchamp & Anderson (2010) have presented the model of interaction between cognitive and social development: The Socio-Cognitive Integration of Abilities Model (SOCIAL). This model demonstrates how cognitive, socio-emotional, communicative, biological, and environmental dimensions interact predicting social functioning within a developmental framework. The authors have also underlined increasing social problems throughout childhood, including few friendships, rejection by peers, and lack of guilt or empathy (Anderson, Beauchamp, Rosema, & Soo, 2014). However, research into the interventional models of social functioning in children is still very limited. In study V, we found that children with ABI had deficits in social communication and cooperation skills. Children with ABI made insufficient or excessive attempts towards collaborating with each other. After paired neurorehabilitation, a noticeable increase in ToM abilities, communication skills, and *cooperation behaviours* was revealed. Improving social skills is crucial for children to feel competent in everyday social interactions. Saltzman-Benaiah & Lalonde (2007) pointed out that the ability to interpret social situations was associated with good social competence. A more focused study in children with epilepsy have shown affected ToM skills consisting of significantly lower ability to understand other people's mental states (false belief, intentional lying, sarcasm) (Raud, Kaldoja, & Kolk, 2015). By interpreting the findings of previously performed studies we considered societal and neuropsychological aspects of social life in children to develop the structured model for social competence rehabilitation. The algorithm consisted of three new intervention platforms–MMT, DTT, and VR, which were specially selected to train certain components of social competence and to explain the relationship between social skills and new-age rehabilitation techniques, which facilitate better cooperation (Boydell et al., 2014; Corti et al., 2019; Howard, 2017).

We also found that MMT/VR interfaces are motivating and interesting for children with ABI, ensuring good compliance. After the trainings, the children reported that starting conversations with other children had become easier, they had made new friends and experienced less bullying in school. This is important as peer bullying and conduct behaviours could considerably worsen the cognitive and emotional problems that children with ABI experience due to injury (e.g., trouble focusing and paying attention to details) (Ilie et al., 2014).

Taken together, Study V provided the structured rehabilitation model, intervention protocol and practical recommendations in the field of paediatric social rehabilitation using next-generation devices.

5.5 Clinical implications for paediatric rehabilitation

The rehabilitation of children is different from interventions for adults, because children do not enter the process through their own initiative. Therefore, they need continuous guidance and motivation throughout the rehabilitation period. According to Cicerone et al. (2011/2000) active therapist involvement enhances the overall effectiveness of rehabilitation. The designs described in the current thesis involve therapists to help make individual plans by tracking each child's progress and follow the training protocol. The therapist motivates the child and supports the use of acquired skills in everyday life situations. Charvátová et al. (2012) have pointed out that children do not make a strict distinction between games, work, leisure and educational activities, but the crucial characteristics are motivation, competitiveness, emotions, and natural curiosity. This emphasizes the importance of therapists' guidance in the rehabilitation process. Children with epilepsy have previously shown improved behavioural performance when presented with rewards, which could significantly benefit in cognitive and social interventions (Triplett et al., 2014). The studies of the current thesis imply that guided intervention is especially valuable for children with attention impairment, as they continually need extra help in directing attention to tasks. It leads the child to become more aware of different options for solutions and to learn to compensate for cognitive weaknesses. Therefore, it could help them to become more independent in the general learning process. If the child understands the solution process by using a specific strategy, he/she has a successful experience, and could gain motivation and self-confidence. As a result of the interventions, the children were more attentive in classes and in solving homework assignments–they improved in pinpointing mistakes, revising work, finding solutions to problems etc. Therefore, the support from the therapist could also contribute to the effect of the training.

The Neuropsychology Task Force of the ILAE has stated the importance of providing the patients' families with implications of assessment results and clinical recommendations regarding what can be done for cognitive improvement (Wilson et al., 2015). In the current studies, the parents received personal feedback about their child's cognitive and social profile, progress throughout the trainings, and suggestions for future training possibilities at home (e.g., via the Internet). They were also provided with additional advice for supporting their child's general learning abilities and for considering the child's individual differences.

Developing an intervention design with a specific protocol and well-defined instructions for therapists is recommended. In a review by Sohlberg, Ehlhardt & Kennedy (2005) the importance of giving systematic instructions in CR was emphasized. These should consist of "simple, consistent instructional wording and scripts to reduce confusion and focus the learner on relevant content". With the studies of this thesis, specific baseline assessment tasks and strict intervention protocols for the rehabilitation of cognitive and social functions were created, which could be used in the future for hospitals, outpatient clinics or rehabilitation centres. Furthermore, the programs could be adapted to be used in children with different ABI diagnosis. The studies provide everyday practical recommendations and guidance in paediatric neurorehabilitation and encourage therapists to use these novel techniques. Well-controlled studies have been much needed in the field of paediatric CR (Limond & Leeke, 2014; Lindsay et al., 2015; Shaw, 2014).

The results revealed that for cognitive functions like attention and visuospatial abilities, individual interventions were most effective, where the therapist could help to follow the progress based on each child separately. To achieve the effect of intervention, 10 sessions tailored to individual levels of ability were the minimum. Still, some components–*sustained attention, complex attention, tracking* and *visual recognition*–need selective and longer training for more effective remediation. In social rehabilitation, trainings with two children and two therapists were effective to best facilitate communication skills and cooperation behaviours. In these paired trainings, the best suitability occurred between children with same sex, same diagnosis, without previous acquaintance to each other, and up to one-year age difference.

In addition, based on the qualitative feedback, we noted that an important task for the therapist was to find specific motifs for each individual child (e.g., some children preferred joking, some needed breaks, and others frequent appraisal and endorsement). Yet, some children also required more specific boundaries to keep them on track. In some cases, children preferred the therapist to be of the same gender as themselves. This might have contributed to making a better connection and feeling of companionship between the child and the therapist. Ultimately, an individual approach to motivation was essential to enhance the best possible improvement levels. Furthermore, the children's motivation was also influenced by their parents' attitude toward the training sessions. If parents had low interest to participate in the regular meetings and verbally explained their lack of motivation, their children also showed less acceptance with trainings. Educating parents about the importance and outcome of rehabilitation facilitated better cooperation and compliance.

Taken together, multicomponent paediatric intervention programs should address the individual difficulties of children as the effects of ABI are complex and affect several areas of functioning (Lindsay & Edwards, 2013). The present thesis showed that the cognitive rehabilitation design with the FORAMEN-

Rehab program, and the structured social rehabilitation with MMT and VR techniques were effective for children with ABI. Training specific components of a function combined with individually tailored motivation and teaching meta-cognitive strategies improved attention and visuospatial functions, and social competence in children with epilepsy, TBI or tic disorder. The modern technology-based methods were suitable for children. The intervention designs combined principles of computer assisted neurocognitive rehabilitation and an individualized approach, and hold practical future benefits as effective interventions, which is a prerequisite for outpatient training sessions in clinical settings. Children's individual improvement was important to follow as complicated tasks were associated with slower progress and thus, need longer training periods.

Limitations and future directions

The present thesis (Studies I–V) has some limitations that must be acknowledged. Firstly, the samples were biased as the patients were self-selected, and the patients and families were not blinded to the treatment. Secondly, the information about the patients belonging either to the study group or waiting-list group was known to the therapist. Thirdly, most of the children with ABI and the healthy control group children lived in Tartu city or near Tartu, which means that the group was not randomly chosen. Other limitations were relatively small sample sizes (with low statistical power) and linguistically-restricted sample, which may limit the generalizability of the studies to broader samples. Therefore, continued research is recommended with a larger sample size. Still, it should be noted that an intervention is a time-consuming and long-lasting process and therefore, resources may be limited for conducting research with substantial sample sizes.

6. CONCLUSIONS

1. Children with ABI aged 8–12 years showed significant impairments in all the visuospatial function components, most components of attention function, and social competence performances compared to healthy control group children. The results emphasize the need for neurorehabilitation in children with ABI and the importance of focusing on specific components of the impaired functions in planning the interventions. Therefore, assessing cognitive profiles prior to rehabilitation is crucial, especially focusing on diagnosis-specific vulnerabilities, e.g., attention impairment in epilepsy.
2. The neurorehabilitation design with the Attention module of the Foramen-Rehab computer program was effective for children with ABI. Training specific attention components combined with individually guided strategies and metacognition significantly improved attention function in children with epilepsy and TBI compared to their baseline performances and the patients in waiting-list group. The long-term outcome assessments (after 1.3 yrs) revealed persisted improvements in *complex attention* and *tracking* components.
3. Neurorehabilitation with the Visuospatial module of the FORAMENRehab software was effective for children with epilepsy. The patients showed a positive immediate rehabilitation effect in three components and a positive long-term effect in all four visuospatial components. This suggests that in *visual recognition* the positive effect was observable more than a year later, since the waiting-list group did not show improvements over time. *Visual recognition* and *visuospatial perception* components need longer active training periods or re-training.
4. Improving social skills is crucial for children to feel competent in everyday interactions and better QoL. The structured social rehabilitation model helps therapists to understand the objectives and tools for improving social skills in children with ABI. We recommend paired social rehabilitation based on this model to increase the patients' ToM and communication skills, and to improve cooperation.
5. Positive generalized effects of the interventions were confirmed by the parents' and children's qualitative feedback with learned skills transferring to everyday life. The effects were revealed in the children's behaviour and overall performance in school. The 100% compliance showed that modern neurocognitive rehabilitation is an efficient way to guide children towards their full potential. Individual improvement trajectories are important to follow as they point out the need for individualized approach for cognitive rehabilitation. At least 10 intervention sessions were needed to notice significant improvements in cognitive and social functions. The active role of the therapists is important as they help to make individual plans based on each child's progress, follow the training protocol and motivate the children.

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SUMMARY IN ESTONIAN

Kaasaegsete kognitiivsete ja sotsiaalsete sekkumistehnikate loomine pediaatrilises neurorehabilitatsioonis ajukahjustusega lastel

Omandatud ajukahjustusega lapsed vajavad võimaliku kaasuva kognitiivse ja sotsiaalse defitsiidi diagnostikat ja häire(te)-põhist neuropsühholoogilist rehabilitatsiooni. Siiani on uuringud ja ravi keskendunud põhiliselt motoorikahäiretele, kuid lapse edasise akadeemilise edukuse ja elukvaliteedi seisukohast on ülioluline roll kahjustatud kognitiivsete ja sotsiaalsete funktsioonide arendamisel. Neurorehabilitatsioon on plaanipärane sekkumine, mille eesmärk on kompenseerida või kergendada ajukahjustusest tingitud kognitiivset ja/või käitumuslikku defitsiiti, parandada igapäevaeluga toimetulekut, suurendada oskusi teha seda, mis meeldib ja vajalik, kuid mida on raske sooritada kahjustusest põhjustatud häire(te) tõttu. Neurorehabilitatsiooni alustamise eelduseks on põhjaliku neuropsühholoogilise hindamise läbiviimine kognitiivse ja sotsiaalse profiili kaardistamiseks. Epilepsiaga lastel esineb kognitiivseid probleeme ligi 57%-l (Pavlovic et al, 2006) ja ajutrauma järgselt 46%-l (Yeates et al, 2005). Lapseea epilepsia ja ajutraumaga kaasnevad tihti häired tähelepanus ja visuaal-ruumilistes võimetes. Varasemad uuringud on näidanud neurorehabilitatsiooni positiivset efekti ajukahjustusega laste kognitiivsete häirete ravis (Bangirana et al, 2011; Kerns et al., 2010; van't Hooft, 2007).

Arvutipõhise keskkonna kasutamine on pediaatrilises neurorehabilitatsioonis uus kiiresti arenev valdkond. See on ohutu ja huvitav ning võimaldab lastel praktiseerida vajalikke oskusi, alates tähelepanust, ruumitajust ja mälust kuni käelise tegevuseni ning suhtlemisoskuse arendamiseni. Cicerone ja kolleegid (2000) on leidnud, et tõenduspõhised uurimused soovitavad kasutada just arvutipõhist sekkumist, millele kaasneb aktiivne terapeudi osalus. Terapeudi ülesandeks on laste kognitiivsete tugevuste ja nõrkuste hindamine ning kompensatoorsete strateegiate arendamine.

Sageli lisanduvad ajukahjustusega laste kognitiivsele defitsiidile ja õpiraskustele ka käitumis- ja suhtlemisprobleemid. Selle tulemusena ei leia lapsed sõpru ning satuvad koolikiusamise ohvriteks, mis omakorda võib viia psüühiliste häirete väljakujunemisele. Uuteks vahendiks suhtlemisoskuste ja koostöö rehabilitatsioonis on puutetundlikud lauad, mis võimaldavad korraga koos treenida kahel lapsel, ning virtuaalreaalsuse platvormid. Väljatöötatud virtuaalsed situatsioonid ja mängud arendavad sotsiaalset kompetentsi ning on näidustatud suhtlemisraskuste, meeleoluhäirete, käitumisprobleemide ja kognitiivsete häirete korral. Varasemalt on puutetundlikke vahendeid kasutatud põhiliselt autismispektri häiretega lastel (Zancanaro, 2014, Weiss et al., 2011).

Hetkel leidub vähe lastele suunatud kaasaegseid neurorehabilitatsiooni-alaseid sekkumisuuringuid. Seetõttu on oluline uute teaduspõhiste uuringute läbiviimine laste neurorehabilitatsiooni valdkonnas, mida on rõhutanud mitmed erinevad autorid (Limond & Leeke, 2005; Prigatano, 2000; Slomine & Locascio, 2009). Antud doktoritöö kajastab esimest omandatud ajukahjustusega laste kognitiivse ja sotsiaalse rehabilitatsiooni alast longituuduuringut Eestis.

Uuringu eesmärgid

Doktoritöö keskendub uute arvutipõhiste puutetundlike ja virtuaalreaalsuse programmide kasutuselevõtmisele 8–12 aastaste omandatud ajukahjustusega laste kognitiivses ja sotsiaalses neurorehabilitatioonis. Uuringud keskenduvad laste rehabilitatsioonidisainide arendamisele ja hindamisele järgmiste funktsioonide ravis: tähelepanu, ruumitaju ja sotsiaalne kompetents.

Täpsemad eesmärgid:

1. Hinnata kognitiivset ja sotsiaalset profiili omandatud ajukahjustusega lastel.
2. Hinnata kognitiivse rehabilitatsiooni meetodi–ForamenRehab programmi tähelepanumooduli efektiivsust tähelepanu funktiooni ravis epilepsia ja ajutraumaga lastel.
3. Hinnata arvutipõhise kognitiivse rehabilitatsiooni meetodi ForamenRehab ruumitaju-mooduli efektiivsust ruumitaju funktsiooni ravis epilepsiaga lastel.
4. Luua struktureeritud sotsiaalse rehabilitatsiooni mudel hindamis- ja sekkumisvahenditega sotsiaalsete häirete raviks ajukahjustusega lastel.
5. Luua teaduspõhised soovitused laste arvutipõhiseks neurorehabilitatiooniks.

Uuringu meetodid

Pilootuuringus osales kaheksa 9–12 aasta vanust ajukahjustusega last (viis kerge ajutrauma ja kolm epilepsia diagnoosiga) ning 18 samaealist normaalse arenguga last. Järgnevates uuringutes osales tähelepanu ja ruumitaju rehabilitatsioonis 29 8–12 aasta vanust fokaalse epilepsia diagnoosiga last ning 19 samaealist tervet last kontrollgrupis. Sotsiaalsete oskuste treeningus osales 22 8–13 aasta vanust epilepsia, ajutrauma või tikkide diagnoosiga patsienti ja 10 samaealist tervet last. Uuringugrupi patsiendid läbisid 10 treeningkorda, koos eelneva baastaseme ja treeningujärgsete testimistega.

Tähelepanu ja ruumitaju rehabilitatsiooniks loodi sekkumisprotokollid ForamenRehab'i arvutipõhise programmi põhjal. Tähelepanufunktsioone arendavad ülesanded jaotati neljaks komponendiks: *tähelepanu keskendamine, tähelepanu säilitamine, tähelepanu jagamine* ja *seiramine*. Ruumitaju funktsiooni komponendid olid *visuaalse materjali äratundmine*, *visuaal-konstruktiivsed võimed*, *visuaalne tähelepanu* ja *nägemis-ruumitaju*.

Sotsiaalsete häirete raviks lastel loodi struktureeritud sotsiaalse rehabilitatsiooni mudel, mis koosneb sotsiaalse kompetentsi komponentidest ning nende hindamis- ja rehabilitatsiooni vahenditest. Mudeli efektiivsuse hindamiseks viidi läbi rehabilitatsiooniprotsess (10 treeningkorda) kahel puutetundlikul laual – *Snowflake Multiteach Tabletop* ja *DiamondTouch Tabletop*, ning virtuaalreaalsuse keskkonnas. Treeningu käigus toimus koostööoskuste arendamisele põhinev keeruliste olukordade virtuaalne lahendamine ja sotsiaalsete oskuste parandamine läbi analüüsi ja rollimängude.

Tulemused ja järeldused

Uuringu tulemused näitasid, et omandatud ajukahjutusega lastel esineb väljendunud tähelepanu ja ruumitaju funktsioonide defitsiit. Olulise tulemusena selgus, et ForamenRehab tarkvara on lastele kohandatuna efektiivne kognitiivsete häirete ravis. Patsientidel esines treeningute järgselt statistiliselt oluline paranemine kahes tähelepanu funktsiooni komponendis (*tähelepanu jagamine* ja *seiramine*) ja kolmes ruumitaju funktsiooni komponendis (*visuaal-konstruktiivsed võimed, visuaalne tähelepanu* ja *nägemis-ruumitaju*). Positiivne treeninguefekt oli säilinud ka 1,3 aastat hiljem läbi viidud järeltestimisel. Lisaks kirjeldasid ForamenRehab tähelepanu ja ruumitaju baastasemete põhjal leitud testitulemused hästi laste esialgse kahjustuse spetsiifilist profiili ja ulatust, mis on kasulik edasise raviprotsessi planeerimisel. Samuti tulid rehabilitatsiooniprotsessi jälgides välja indiviidipõhised spetsiifilised erinevused raviprogressi osas – raskustasemetel edasiliikumisel jõudsid kiirema progressiga patsiendid treeningu lõpuks kuni kaks korda kõrgematele tasemetele.

Uuringu teises osas loodi struktureeritud neurorehabilitatsiooni mudel sotsiaalse defitsiidi raviks lastel. Baastaseme testimiste tulemusena selgus, et omandatud ajukahjustusega lastel on oluliselt häiritud sotsiaalne taju, emotsioonide äratundmine ja praktilised sotsiaalsed ning koostöö oskused. Treeningueelsel testimisel kasutasid patsiendid ainult 25–50% sotsiaalse koostöö ja suhtlusoskustest normiga võrreldes (FOS). Peale väljatöötatud sekkumisprotokolli põhjal läbi viidud raviprotsessi paranesid oluliselt patsientide oskused vaimuteoorias (*Theory of Mind*) ja emotsioonide äratundmisel. Patsiendid kasutasid rohkem koostööoskuseid (reeglite järgimine, oma korra ootamine), verbaalset ja mitteverbaalset sotsiaalset kommunikatsiooni ning pragmaatika oskuseid.

Uuringute tugevuseks oli ka sajaprotsendiline patsientide ravisoostumus ning laste ja vanemate positiivne tagasiside. See tõestab, et arvutipõhised ja virtuaalreaalsuse meetodid on lastele atraktiivsed ning nende kasutamine aitab arendada praktilisi oskusi toetavas kontrollitud keskkonnas. Vanematele oli treeningu jooksul oluline uus informatsioon lapse kognitiivsete ja sotsiaalsete funktsioonide tasemest ja edasiminekust treeningu jooksul ning samuti soovitused lapse motiveerimiseks ja õpetamiseks edaspidiselt.

Kokkuvõttes, doktoritöö käigus loodi teaduspõhised protokollid ja praktilised juhised kaasaegsete tehnoloogiapõhiste rehabilitatsiooni meetodite kasutamiseks laste kognitiivse ja sotsiaalse defitsiidi kliinilises ravis. Rehabilitatsioonile eelneval hindamisel olid omandatud ajukahjustusega lastel häiritud kõik ruumitaju komponendid ning enamus tähelepanu ja sotsiaalse kompetentsi komponentidest. Tulemused näitasid lastele loodud rehabilitatsiooni meetodite vajadust, mis keskenduvad spetsiifilistele häiritud funktsiooni komponentidele.

Neurorehabilitatsioon ForamenRehab programmiga oli efektiivne ja püsivate positiivsete kaugtulemustega tähelepanu ning ruumitaju funktsioonide ravis. Suhtlemis- ja koostöö oskuste ravis oli oluline töö käigus loodud struktureeritud sotsiaalse rehabilitatsiooni mudel, mille põhjal läbi viidud sekkumised aitavad parandada laste igapäevast suhtlemist ning elukvaliteeti. Samuti annab mudel juhised ja vahendid terapeutidele sotsiaalsete häirete struktureeritud hindamiseks ning treenimiseks lastel, kasutades kaasaegseid tehnoloogiaid. Tagasiside näitas, et treenitud oskused kandusid üle igapäevaellu – laste õppeedukus ning käitumine paranesid. 100% ravisoostumus näitas, et lapsed olid motiveeritud treeningutes osalema ning arvutipõhine rehabilitatsioon on sobilik laste kognitiivse ja sotsiaalse defitsiidi ravis.

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