CHARLES UNIVERSITY
FACULTY OF PHYSICAL EDUCATION AND SPORT

Using Virtual Reality as a Therapeutic Modality for Children with Cerebral Palsy: a Review and Synthesis

Master thesis

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Prague, April 2014

Abstract

Title: Using Virtual Reality as a Therapeutic Modality for Children with Cerebral Palsy: a Review and Synthesis

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Background: Cerebral palsy is often referred to as an" umbrella term" denoting a group of non-progressive conditions involving primarily a disorder of voluntary movement and/or co-ordination. A functional impairment is more important than diagnosis itself, due to the lifelong type of the disease. Therapy in children suffering from CP is nowadays based on individual movement therapy within a whole complex of rehabilitation programmes. The first line of treatment is building up an interdisciplinary team of professionals, led by paediatrics neurologist or neurologist who is pursuing rehabilitation.

Physical therapist should always choose an eclectic approach, knowing only too well the reasons why. Virtual reality as a therapeutic modality is standing besides classic methods according to various authors, as we know from schools and different courses. However, this kind of treatment is novel, its results are greatly promising based on current research.

Aim: The purpose of this thesis is to outline the use of virtual reality as a method of therapy in children with cerebral palsy in the main functional conditions – motor control, upper extremity dysfunction and balance. The intention is not to give a preference to this kind of treatment, but to highlight it as a possibility and a path for further procedures.

Method: This thesis is a literature review, reviewing journals, articles and books collected from the period of one year (spring 2013 to spring 2014) The collected sources are from databases (PubMed MEDLINE and CINAHL used for comparison). Other databases used as additional sources are PEDro, Academic Search Complete, Embase, ProQuest, and Cochrane. The relevant journals and reviewed books were considered.

Results: After data extraction based on the exclusion criteria, the search resulted in a total of 27 articles (in Pubmed and Cinahl), including 2 reviews. Most of the articles were pilot studies with a small sample of participants, some of them were case studies. The results were divided into three categories according to the method of therapeutic use of virtual reality intervention: motor control and overall motor performance, upper extremity dysfunction, and balance impairment. Most of the studies found and selected from the compared databases (Pubmed and Cinahl) evaluated the feasibility of virtual reality (VR) on upper extremity function, fewer of them the effect on balance function and motor control.

Conclusion: The amount of studies found is, however, very small. Few of them are novel and unusual, evaluating the customary technology focused primarily on the key functional problem, but usually at the preliminary phase of research. Most of the studies found are quite inconsistent in their methods of measurement and aim. If the criteria "adults" or "adolescents" were included, the number of results would be larger, due to a lot of articles on the usefulness of VR intervention in stroke patients. Nevertheless, in my opinion, further research is needed, focused predominantly on children's requirements and psychology combined with usefulness for functional physical impairments using custom-made games.

Keywords: computer-simulated environment, cerebral palsy, gaming systems, rehabilitation

Abstrakt

Název práce: Využití virtuální reality v terapii dětí s dětskou mozkovou obrnou: review a syntéza

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Gramatická korektura: Jan Valeška

Kontext: Dětská mozková obrna (DMO) je často označována jako skupina neprogresivních příznaků, vyznačujících se zejména poruchou volních pohybů a/nebo koordinace. Porucha funkce je důležitější než samotná diagnóza vzhledem k celoživotnímu typu onemocnění. Léčba u dětí s dětskou mozkovou obrnou je v současné době založena na individuální pohybové terapii v rámci celého komplexu rehabilitačního programu. Na začátku léčby je nutné sestavit interdisciplinární tým odborníků, v čele s neurologem nebo dětským neurologem, který se věnuje rehabilitaci. Fyzioterapeut by se měl vždy přiklánět k eklektickému přístupu a znát dobře důvody, proč ten či onen léčebný program aplikuje. Virtuální realita jako terapeutická metoda stojí vedle klasických přístupů dle nejrůznějších autorů, jak je známe z množství škol a kurzů. Ačkoliv je tento druh léčby poměrně novátorský, na základě současného výzkumu jsou výsledky velmi slibné.

Cíle: Cílem této práce je nastínit možnost terapie dětí s dětskou mozkovou obrnou s využitím virtuální reality zejména v těchto hlavních problémech – motorická kontrola a celková hrubá motorická dovednost, dysfunkce horní končetiny a porucha rovnováhy. Záměrem není upřednostňovat tento druh léčby, ale zmínit jej jako možnost a způsob, jak postupovat v terapii dětí s dětskou mozkovou obrnou.

Metody: Tato diplomová práce je rešeršního charakteru, vyhodnocující časopisy, články a knižní publikace shromážděné v období jednoho roku (od jara 2013 do jara 2014). Získané zdroje jsou z medicínských databází (PubMed MEDLINE a CINAHL použité pro srovnání). Dalšími využitými databázemi jsou PEDro, Academic Search Complete, Embase, ProQuest a Cochrane, Cochrane). Relevantní časopisy a recenzované knihy byly také zahrnuty při vyhledávání informací.

Výsledky: Po vyloučení všech irelevantních článků na základě vyřazovacích kritérií bylo detekováno 27 článků (v databázích Pubmed a Cinahl), včetně dvou studií rešeršního charakteru. Většina z nalezených studií byla studiemi pilotními s malým množstvím probandů zahrnutých do výzkumu, některé studie byly formou kazuistiky. Výsledky hledání jsou rozděleny do třech kategorií podle terapeutického využití virtuální reality: motorická kontrola a všeobecná motorická dovednost, porucha funkce horní končetiny a porucha rovnováhy. Nejvíce studí ze srovnávaných databází (Pubmed a Cinahl) hodnotily použitelnost virtuální reality u funkčních problémů horní končetiny, méně jich bylo zaměřeno na rovnovážné funkce a motorickou obratnost/kontrolu.

Závěr: Počet nalezených studií byl velmi malý. Pouze malá část nich hodnotila novátorský a netradiční postup použití individuální na míru zhotovené technologie zaměřené na klíčový funkční problém. Tyto studie byly ale spíše prvotní fází případného budoucího výzkumu. Většina nalezených článků byla relativně nejednotná v metodě měření a v cíli terapie. Pokud by byla zahrnuta kriteria výběru "dospělí" či "dospívající", množství výsledků by bylo nepochybně větší vzhledem k aktivnímu používání virtuální reality u pacientů po cévní mozkové příhodě. Nicméně dle mého názoru by byla potřeba další výzkumná intervence, zaměřením zejména na dětské pacienty, jejich potřeby a psychické faktory, v kombinaci s aplikací individuálně přizpůsobitelných herních systémů.

Klíčová slova: virtuální realita, dětská mozková obrna, herní systémy, rehabilitace

Acknowledgment

First and foremost, I would like to like to thank doc. MUDr. Staša Bartůňková, CSc., my Thesis Advisor, for giving me the opportunity to write this thesis under her guidance. The path to the creation of this thesis began in January 2013 when I arrived in Breda, the Netherlands, to study for half a year at the AVANS university. At that time I didn't know yet that future acquired knowledge and a point of view from a different perspective, can help greatly when considering the contents of the thesis and my future course.

I would like to thank the lecturers Ad van Tuijl, Els Brouwers and Rene Teunissen, who offered me insight into the practical application of motor learning theories, including the use of virtual reality as a therapeutic tool. Staying in the Netherlands has changed my life. I would like to thank all friends whom I met there, especially Raquel Santos, Tiago Eira, and Marjon van der Wansem, with whom I could discuss all kinds of new, acquired knowledge, and enjoy unforgettable moments as well. My thanks and admiration go to Thais Varella, whose courage is an inspiration for me.

Last but not least, I want to express my gratitude to my family and friends. I would especially like to thank my boyfriend, Malte Langheim, for always encouraging me to never put limits on my goals and aspirations, for all the love, and support he has given me over this year.

I dedicate this thesis to my grandfather, who has been a constant source of wisdom and kindness. He has inspired me to seek for excellence in my future endeavors, esteem the values of hard work and education.

Declaration

I hereby declare that the whole content of this thesis is my own individual work, attained with the knowledge from journals, articles, books, lectures and seminars. Any thoughts from the literature are clearly marked. Under no circumstances has this work been copied, forged or changed.

Prague, April 2014 Petra Smolová

Library records

I give consent to making this thesis available for study purposes.

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List of Abbreviations

ADHD - Attention deficit hyperactivity disorder

AHA - Assisting Hand Assessment

AMPS - Assessment of Motor and Process Skills

AROM - Active range of motion

AVG - Active Video Game

BOTMP - Bruininks-Oseretsky Test of Motor Proficiency

BRU - Balance Rehabilitation Unit

BTX-A - Botulinum toxin type A

CFCS - Communication Function Classification System

CHEQ - Children's Hand Experience Questionnaire

CIMT - Constraint-induced movement therapy

COPM - Canadian Occupational Performance Measure

CP - Cerebral Palsy

CT - Computed tomography

3D - Three-dimensional

DH - Dominant hand

DMO - Dětská mozková obrna

eBaViR - easy Balance Virtual Rehabilitation

FMA - Fugl-Meyer assessment

fMRI - Functional magnetic resonance imaging

GABA - γ-amino butyric acid

JTTHF - Jebsen-Taylor Test of Hand Function

LCD - Liquid-crystal display

MABC - Movement Assessment Battery for Children

MACS - Manual Ability Classification Scale

MAUULF - Melbourne Assessment of Unilateral Upper Limb Function

MRI - Magnetic resonance imaging

MVC - Maximum Voluntary Contraction

10MW - 10-meter walk test

N - number

NDH - non-dominant hand

NGT - NeuroGame Therapy

NJIT-RAVR - New Jersey Institute of Technology Robot- assisted Virtual Rehabilitation

Peds QL - Paediatric Quality of Life Inventory

PDMS - Peabody Developmental Motor Scale

PMAL - Paediatric Motor Activity Log

PRT - Paediatric Reach Test

QUEST - Quality of Upper Extremity Skills Test

RAGT - Robotic Assisted Gait Training

sEMG - surface electromyography

SFA - Spontaneous Functional Analysis

SHUEE - Shriner's Hospital Upper Extremity

GMFCS - Gross Motor Function Classification System

GMFM - Gross Motor Function Measure

ICF - International Classification of Functioning, Disability and Health

IREX - Interactive Rehabilitation and Exercise System

ITB - Intrathecal baclofen pumps

IVG - Interactive video gam e

Evaluation

SPPC - Self-Perception Profile for Children

TUDS - Timed Up and Down Stairs

TUI - Tangible User interface

UE - Upper extremity

VR - Virtual Reality

VRT-Home - Virtual Reality Training-Home

WE - Wrist extensores

1 Introduction

As physical therapists, we have a variety of options how to create individual rehabilitation programmes for disabled children. The actual approach varies through different countries and cultures. I spent six months at the university in Breda, the Netherlands, where I came to discover another point of view of children's therapy, different from what I used to know from my alma mater in Prague. I know methods based on neurophysiological principles, influencing the central nervous system via techniques of facilitation and inhibition on the subcortical level. These methods are widely used in the therapy of children with cerebral palsy, often combined with occupational therapy, which should be the most important and functional-based approach. Occupational therapy interventions focus on modifying the task and teaching the skill within the adapted environment, and educating the patient/family in order to increase participation in and performance of daily activities. The topic of this thesis is focused on motor performance and motor control during motivational tasks performed within virtual environment.

I decided to write my thesis in English after long reflection and thinking about my future career. I made this decision before my study stay in the Netherlands. My stay in a foreign country has only reinforced my decision to write in a foreign language. My home-faculty in Prague gave me a wide range of theoretical knowledge and practical experience, including the possibility of their application in clinical practice. I deeply appreciate the opportunity to study abroad, an opportunity that has opened up new horizons and possibilities for further self-development. I have chosen the topic of the thesis for its uniqueness and complexity, and, at the same time, I also knew that this was a topic unexplored which offers a wide opportunity for further research and study, probably in the field of postgraduate study abroad.

The very first time I saw virtual reality (VR) being applied in therapy was in the Netherlands, where I stayed for sixteen days in 2012 and then from February 2013 to July 2013 as an exchange student. Virtual reality was used in a home for seniors to improve their level of coordination, stability and manual dexterity. I could see all sorts of games requiring different movement and coordination ability. Games have always been goal-oriented and motivating, accuracy and precision of the movements was controlled by a physiotherapist. Of course, this program was only complementary to conventional physiotherapy or occupational therapy. However, it was clear that the technology used was providing a motivational and stimulating environment for the elderly in terms of overall improvement and maintaining self-sufficiency.

Using VR as a method for rehabilitation is quite new, but not futuristic. Regardless of this direction, I do hope that VR will not replace the classic and "contact" rehabilitation, including human communication and closeness between the patient and the therapist. Seen in this light, I have decided to discuss this particular topic to find different ways of treating children with cerebral palsy (CP) – while not using just the well-known methods and approaches; and I am fairly surprised, in view of the fact that these new techniques are quite commonly used in foreign countries, but not in the Czech Republic. In my opinion, there is no need to replace the established procedures with the new technologically more sophisticated concepts. However, if there is a possibility to make good use of technological advancements to influence what should be influenced, then the combination of the existing and the new processes could yield unexpected and positive results, especially in improving the functional capacity of the affected individual.

2 Thesis Structure

This master thesis begins with a front page, an abstract (both in English and Czech languages), sections of acknowledgment, declaration, and library records, followed by a table of content, list of tables, figures and abbreviations.

The first part of the thesis starts with an introduction (1) giving the reasons for the choice of this topic and an outline of the problem under scrutiny. This section is followed by a theoretical overview, chapter about cerebral palsy (3), containing information regarding CP with a description of aetiology and epidemiology, patho-physiology, classification and clinical manifestation, methods of diagnosis, and a brief outline of the selected current treatment.

The following section (4) describes objectives and research methods used for searching according to methodological rules, ending up with an overview of selected articles (5), and selected reviews (6). The first overview highlights main functional difficulties in

CP, motor control and overall motor performance, upper extremity function and balance impairment. The literature review ends with findings (7) in the form of a discussion concerning the possible future of virtual reality in the field of cerebral palsy treatment, while outlining the current use of VR intervention as a rehabilitation tool overall. General contribution of virtual reality in the therapy of various diseases is viewed with a focus on neurorehabilitation. Motor control theories are mentioned within the use of virtual reality intervention. A brief conclusion (8) at the end is followed by a list of references.

3 Theoretical Overview – Cerebral Palsy

3.1 Introduction

Cerebral palsy (CP), first described as a clinical syndrome by William Little and by Sigmund Freud during the latter half of the 19th century (Korzeniewski et al., 2008), literally means brain paralysis. It can be defined as "non-progressive disorders of movement or posture" that originate in early childhood and occur as a result of interference with or a defect of the developing brain. Cerebral palsy is distinguished from other motor disorders caused by brain damage in that it relates to the developing, immature brain rather than the mature brain (Piek, 2006; Odle, 2009; Beckung & Hagberg, 2002) Neuroimpairments such as spasticity, coactivation of agonist–antagonist muscles, muscle weakness, and limited range of motion affect gross and fine motor function and lead to activity limitations. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behaviour, and/or by a seizure disorder (Bax et al., 2005). Mental disorders are quite common. These malfunctions can show up individually or in combination, and place heavy demands on health, educational, and social services as well as on the families and children themselves.

Cerebral palsy is a one-time damage and is not progressive, but the other way around, this phenomenon is called "growing into deficit" or functional deterioration. When the impairment is not severe, a child after birth does not have to show any visible symptoms because motor programme of an infant is very simple based on reflex respond to external stimuli (tactile, proprioceptive or gravity) or internal stimuli as hunger feeling (Pfeiffer, 2007). We can do little about the initial‘ disturbance’, so our multidisciplinary management should focus on the comorbidities and on minimising the impact of secondary deformities (Fairhurst, 2012).

3.2 Aetiology and Epidemiology

When Little first described CP, he attributed the cause of CP to birth trauma and this view has persisted for several decades (Sankar et al., 2005). Nowadays, the exact causes of CP are unknown, but because brain development continues during the first two years of life, they have been attributed to injuries to the foetal brain before birth (prenatal), premature birth (perinatal), and injuries occurring shortly after birth (postnatal). (Odle, 2009; Krigger, 2006).

1) **Prenatal** – Prenatal events are responsible for approximately 75% of all cases of cerebral palsy. It is usually impossible to determine the nature and the exact timing of the damaging event (Reddihough & Collins, 2003; Krigger, 2006). These factors include intrauterine infections, often represent by TORCH group, acronym for Toxoplasmosis, Rubella, Cytomegalovirus, and Herpes Simplex (Kolář, 2009). Other factors found to increase the risk of CP include maternal factors, such as maternal diabetes mellitus, threatened abortion, pre-eclampsia, and multiple pregnancy (Piek, 2006). Other causes include developmental malformations, drugs used by mother etc (Kolář, 2009).

Recently it has been argued that in the majority of cases, the pathway may begin prenatally (Piek, 2006). According to the results of the study from Soleimani et al. (2013), perinatal asphyxia, maternal age >35 years and high-risk pregnancy constitute independent factors that correlate with CP in term and near-term newborns. According to Wu et al. (2013), maternal infection of the genitourinary system during pregnancy is associated with an increased risk of cerebral palsy and epilepsy. Maternal infection before pregnancy is associated with an increased risk of epilepsy and a slightly higher risk of cerebral palsy in children. When the aetiology can be traced back to intrauterine, natal, or perinatal factors, this is referred to as congenital CP (Piek, 2006).

Ranks of factors listed above can also lead to preterm delivery of different grade. Prematureness can be one of causes of cerebral palsy for two reasons: Preterms infant's head is very fragile and alongside biological functions are not well-developed yet (Kolář, 2009). According to Sankar (2005), cerebral palsy is seen in 10 – 18 % of babies in 500–999 grams birth weight. The pathology of CP in term newborns is different from preterm infants. Brain maldevelopments are seen in 16% of term and 2.5% of preterm infants with CP and grey matter lesions are more often seen in term (33%) than preterm

(3.5%) CP infants. However, periventricular white matter lesions occur significantly more often in preterm (90%) than in term (20%) infants (Soleimani et al., 2013).
Genetic factors are nowadays still under discussion (Kolář, 2009), however they are not thought to play a major part in the aetiological pathway to CP, although ataxia has been found to have a genetic link (Piek, 2006).

2) **Perinatal** – These factors include infections, intracranial haemorrhage, seizures, hypoglycaemia, hyperbilirubinemia, significant birth asphyxia and abnormal delivery in the form of different mechanical injuries caused by pressure on brain tissue, fractures of skull bones, tear of meninges or bleeding that cause traumatic brain injuries (Sankar et al., 2005; Kolář, 2009). Ischemia and hypoxia are damaging various brain structures according to their actual maturity and vulnerability (Kolář, 2009). For the most part of the last century, asphyxia and birth trauma were cited as the primary causes of CP. Perinatal arterial ischemic stroke has been identified as another probable cause which leads to hemiplegic CP in many infants (Sankar et al., 2005).
According to Reddihough & Collins (2003), perinatal asphyxia accounts for between 6% and 8% of cerebral palsy. It now appears that only a small proportion of cases can be attributed to insult during delivery (Piek, 2006).

3) **Postnatal** – After the delivery, symptoms of cerebral palsy can be a result of infection or trauma. A haematoencephalic barrier is not fully developed yet and it can be an entrance for infections or toxic matter to the central nervous system, especially if an infant does not have enough antibody from mother (Pfeiffer, 2007). In about ten to twenty percent of patients, cerebral palsy is acquired postnatally, mainly because of brain damage from bacterial meningitis, viral encephalitis, hyperbilirubinemia, motor vehicle collisions, falls, or child abuse (Krigger, 2006). According to Kolář (2009), this group refers to infections arisen in first few month of life, most frequently bronchopneumonia and gastroenteritis. Other causes of post-neonatally acquired CP include cerebrovascular accidents and following surgery for congenital malformations. In developing countries, meningitis, septicaemia and other conditions, such as malaria, remain extremely important causes of cerebral palsy (Reddihough & Collins, 2003).

According to Nelson (2008), causative factors in cerebral palsy vary to some degree according to the gestational age group and clinical CP subtype. At the head of the list of causes of hemiplegic CP are perinatal stroke and congenital malformations. Causal factors for spastic diplegia include evidence of intrauterine infection, premature rupture of membranes, and multiple gestation. Quadriplegic CP can be caused by any pathology that inflicts bilateral and widespread damage to brain.

The reported incidence and prevalence of CP varies by region, population, age, and severity (McAdams & Juul, 2011). Overall prevalence of CP in Europe, America and Australasia is fairly stable at 2–3 per 1,000 live births, though in susceptible premature infants it rises to up to 100 per 1,000 in those born before 28 weeks gestational age (Fairhurst, 2012). According to Hurkmans et al. (2010), CP is one of the most frequently occurring conditions in childhood, with a prevalence of 0.8 to 3 per 1,000 live births in Europe and 2.0 per 1,000 live births in the United States. According to Kolář (2009) and Irwin (2011), cerebral palsy occurs in 1.5 to 2.5 per 1,000 live births.

3.3 Diagnosis and Evaluation

It is difficult to diagnose CP in infants less than 6 months, except in very severe cases. The patterns of various forms of CP emerge gradually, with the earliest clues being a delay in developmental milestones and abnormal muscle tone (Sankar et al., 2005).
Some children may not be diagnosed until three or four years of age. If CP is diagnosed in the first year of life, this often means that the case is a severe one, with major motor disability and often with other problems, such as mental retardation and sensory deficits. On the other hand, many young infants identified with abnormal motor patterns will not develop major disabilities, such as CP or mental retardation due to a large degree of individual differences in brain development, maturation, and repair (Piek, 2006). Early signs include hand preference in the first year, prominent fisting, abnormalities of tone–either spasticity or hypotonia, persistence of abnormal neonatal reflexes, delay in the emergence of protective and postural reflexes, asymmetrical movements like asymmetrical crawl and hyperreflexia (Sankar et al., 2005). Identification depends on a combination of suspicious and abnormal signs revealed during comprehensive

assessment of motor attainments, neurological signs, postural reactions and primitive reflexes. Boehme (1990) listed potential signs to watch for CP for three different age groups in the first year (Piek, 2006):

Table 1: Potential signs of Cerebral Palsy (Boehme, 1990)

Birth to 3 months	4 to 8 months	9 to 12 months
1. Limited random (spontaneous) movements	1. Hypotonia	1. Limited variety of movements
2. Easy and frequent startle responses	2. Mass patterns of movement	2. Poor trunk control
3. Poor head control	3. Limited variety of movements	3. Poor protective responses
4. Increased stiffness that may not feel like true spasticity	4. Assymetry	4. Poor balance responses
5. Reliance of head and neck hyperextension during movement	5. Limited spinal extension/ limited control in prone position	5. Poor manual skills
6. Feeding problems	6. Limited visual control	6. Hypotonicity
7. Respiratory problems	7. Limited reach and grasp/ fisted hands	7. Hypertonicity
8. Irritability		

It is impossible to find a generic patient. The outcome for a brain-damaged infant can range from normal to severely handicapped, with huge heterogeneity in terms of the sensory, motor, mental, and behavioural problems (Piek, 2006). An assessment of associated deficits like speech, hearing, vision, sensory profile, oromotor deficit, epilepsy and cognitive functioning should be included in complete evaluation of a child with CP. Last but not least, an orthopaedic evaluation as muscle imbalance and spasticity cause subluxation/dislocation of the hips, contractures, equinus deformities and scoliosis should be part of the complex diagnose (Sankar et al., 2005). The varying levels of motor impairment affecting children with CP are commonly described using two scales. Firstly, the Gross Motor Classification System (GMFCS) is used to identify children with respect to their gross motor function into 1 of 5 distinct levels. Secondly, the Manual Ability Classification System (MACS) is used to group children with CP into 1 of 5 levels with regards to their fine motor skills (Irwin, 2011).

Hidecker et. al (2012) in a recent study described and correlated GMFCS, MACS, and

CFCS (Communication Function Classification System) levels in a case series of children with CP. The CFCS has been developed to describe communication skills. They hypothesized that these classifications would not be strongly correlated, but the locations and degree of original brain injuries may overlap neural systems used in these activities, even though they are not functionally related (handling objects, mobility and communication). This could result in some correlations between the classification systems. The study shows that GMFCS levels are strongly correlated with MACS levels, and this correlation is similar across age groups. According to this research, the GMFCS–MACS relationship is strongest in children with quadriplegia, moderate in children with hemiplegia, and weakest in strength in children with diplegia, and all three classifications (GMFCS, MACS, CFCS) provide a view of overall functioning in a child with CP.

3.3.1 Gross Motor Function Classification System (GMFCS)

Classification of children with CP based on functional abilities and limitations is predictive of gross motor function, whereas age alone is a poor predictor of gross motor function (Palisano et al., 2000). The GMFCS was developed to provide a standardized classification of the patterns of motor disability and activity limitations in children with CP. This classification system is based on a five-level grading and the distinction between the different levels is focused on functional limitations and need for assistive technology, including mobility devices and wheeled mobility (Beckung and Hagberg, 2002). However, the GMFCS does not assess the quality of motor control used to accomplish the activities, which is an aspect of motor development that emerges later in childhood, nor how children apply their motor function in the context of activity or participation in daily life. Furthermore, the GMFCS assesses independent achievement of motor function tasks, but does not evaluate the ways in which children’s function is performed (the addition of augmentative and technical interventions such as aids, orthoses, or the use of powered mobility). Children may improve their gross motor performance over the years through increased stamina, balance, energy efficiency, and quality of motor control. All these features should be evaluated, but are beyond the scope of the GMFCS (Rosenbaum et al., 2007).

The GMFCS also allows to set functional rehabilitation goals for each motor level in different age groups. The treatment of a child in level I aged 0–2 aims to stimulate the child to move to and from a sitting position, crawl, move to a standing position with support, walk under supervision and use the upper limbs to handle objects. A child classified under level V, from age 0 to 2 should be stimulated to keep his head in the median line and turn it 180 degrees in a supine position, and roll over with support. Between ages 2 and 4, the treatment is focused on improving sitting position for handling objects, moving to a standing position with support, and indoors walking. Therapeutic goals should be to facilitate acquisition of basic skills for anti-gravitational positions of the head and trunk with support and moving around with support. Between ages 4 and 6, the goals are to stimulate moving from the floor and chair to a standing position, climbing up and down stairs, and jumping and running (Pfeifer et al., 2009). According to the designers of the GMFCS, most children will remain at the same level from age 2 to 12 years, which makes it possible to try to predict gross motor development (Carnahan et al., 2007).

Table 2: GMFCS I (Palisano et al., 2000)

Before 2nd Birthday	
Level I	Infants move in and out of sitting and floor sit with both hands free to manipulate objects, crawl on hands and knees, pull to stand, and take steps holding onto furniture. Infants walk between 18 months and two years of age without the need for any assistive mobility device.
Level II	Infants maintain floor sitting but may need to use their hands for support to maintain balance, creep on their stomach or crawl on hands and knees and may pull to stand and take steps holding on to furniture.
Level III	Infants maintain floor sitting when the low back is supported. They can roll and creep forward on their stomachs.
Level IV	Infants have head control but trunk support is required for floor sitting. They can roll to supine and may roll to prone.
Level V	Physical impairments limit voluntary control of movement. Infants are unable to maintain antigravity head and trunk postures in prone and sitting. Adult assistance to roll is required.

According to Pfeifer (2009), classifying children younger than 2 years old is less accurate because children at this age have a very limited amount of gross motor activities, they depend more on the quality of the movement and on how easy it is to sit, crawl, and stand up than on the ability to walk. The diagnosis of CP is typically made after the age of 2 years, but identification of the patterns of abnormal motor posture and function associated with CP can be made as early as 6 months of age (McAdams & Juul, 2011).

Table 3: GMFCS II (Palisano et al., 2000)

Between 2nd and 4th Birthday	
Level I	Children sit on the floor with both hands free to manipulate objects. Movements in and out of floor sitting and standing are performed without adult assistance. Walking is the preferred method of mobility without the need for any assistive mobility device.
Level II	Children sit on the floor but may have difficulty with balance when both hands are free to manipulate objects. Movements in and out of sitting are performed without adult assistance. They can pull to stand on stable surface, crawl on hands and knees with a reciprocal pattern, cruise holding onto furniture, and walk using an assistive mobility device as preferred methods of mobility.
Level III	Children maintain floor sitting often by “W-sitting” (sitting between flexed and internally rotated hips and knees) and may require adult assistance to assume sitting. They creep on the stomach or crawl on hands and knees (often without reciprocal leg movements) as their primary methods of self-mobility. They may pull to stand on a stable surface and cruise short distances. Walking short distances indoors is possible using an assistive mobility device and adult assistance for steering and turning.
Level IV	Children sit on the floor when placed, but are unable to maintain alignment and balance without use of their hands for support. Adaptive equipment for sitting and standing is required. Self-mobility for short distances (within a room) is achieved through rolling, creeping on stomach, or crawling on hands and knees without reciprocal leg movement.
Level V	Physical impairments restrict voluntary control of movement and the ability to maintain antigravity head and trunk postures. All areas of motor function are limited. Functional limitations in sitting and standing are not fully compensated for through the use of adaptive equipment and assistive technology. Children at this level have no means of independent mobility and are transported. Some children achieve self-mobility using a power wheelchair with extensive adaptations.

Table 4: GMFCS III (Palisano et al., 2000)

Between 4th and 6th Birthday	
Level I	Children get into and out of, and sit in, a chair without the need for hand support, and move from the floor and from chair sitting to standing without the need for objects for support. They walk indoors and outdoors, and climb stairs. Emerging ability to run and jump.
Level II	Children sit in a chair with both hands free to manipulate objects. They can move from the floor to standing and from chair sitting to standing but a stable surface to push or pull up on with their arms is often required. Walking is possible without the need for any assistive mobility device indoors and for short distances on level surfaces outdoors. They climb stairs holding onto a railing but are unable to run or jump.

Level III	Children sit on a regular chair but may require pelvic or trunk support to maximize hand function. They can move in and out of chair sitting using a stable surface to push or pull up on with their arms. Walking is possible with an assistive mobility device on level surfaces and climbing stairs with assistance from an adult. They are usually transported when travelling for long distances or outdoors on uneven terrain.
Level IV	Children sit on a chair but need adaptive seating for trunk control and to maximize hand function. Moving in and out of chair sitting is possible with assistance from an adult or a stable surface to push or pull up on with their arms. They may at best walk short distances with a walker and adult supervision but have difficulty turning and maintaining balance on uneven surfaces. Self-mobility can be achieved by using a power wheelchair.
Level V	Physical impairments restrict voluntary control of movement and the ability to maintain antigravity head and trunk postures. All areas of motor function are limited. Functional limitations in sitting and standing are not fully compensated for through the use of adaptive equipment and assistive technology. Children at this level have no means of independent mobility and are transported. Some children achieve self-mobility using a power wheelchair with extensive adaptations.

Table 5: GMFCS IV (Palisano et al., 2000; Beckung & Hagberg, 2002)

Between 6th and 12th Birthday	
Level I	Children walk indoors and outdoors without restrictions, and climb stairs without limitations. Gross motor skills including running and jumping are performed but speed, balance, and coordination are reduced. Limitations are apparent in more advanced gross motor skills.
Level II	Children walk indoors and outdoors without restrictions, and climb stairs holding onto a railing but experience limitations walking on uneven surfaces and inclines, and walking in crowds or confined spaces. They have at best only minimal ability to perform gross motor skills such as running and jumping.
Level III	Children walk indoors or outdoors on a level surface with an assistive mobility device, may climb stairs holding onto a railing. Depending on upper limb function, they propel a wheelchair manually or are transported when travelling for long distances or outdoors on uneven terrain.
Level IV	Children may maintain levels of function achieved before age 6 or rely more on wheeled mobility at home, school, and in the community. They may achieve self-mobility using a power wheelchair.
Level V	Physical impairments restrict voluntary control of movement and the ability to maintain antigravity head and trunk postures. All areas of motor function are limited. Functional limitations in sitting and standing are not fully compensated for through the use of adaptive equipment and assistive technology. Children at this level have no means of independent mobility and are transported. Self-mobility is severely limited even with use of assistive technology, but some children achieve partial self-mobility using a power wheelchair with extensive adaptations. Limitations in mobility necessitate adaptations to enable participation in physical activities and sports including physical assistance and using powered mobility.

Table 6: GMFCS V (Palisano et al., 2008)

Between 12th and 18th Birthday	
Level I	Youth walk at home, school, outdoors, and in the community. They are able to walk up and down curbs without physical assistance and stairs without the use of a railing. The performation of gross motor skills such as running and jumping is limited in speed, balance, and coordination.
Level II	Environmental factors (such as uneven terrain, inclines, long distances, time demands, weather, and peer acceptability) influence mobility choices. At school or work, youth may walk using a hand-held mobility device for safety, and wheeled mobility when travelling long distances outdoors or in the community. They walk up and down stairs holding a railing or with physical assistance. Limitations in performance of gross motor skills may necessitate adaptations to enable participation in physical activities and sports.
Level III	Youth are capable of walking using a hand-held mobility device. They may require a seat belt for pelvic alignment and balance when seated. Sit-to-stand and floor-to-stand transfers require physical assistance from a person or support surface. At school, youth may self-propel a manual wheelchair or use powered mobility. They are transported in a wheelchair or use powered mobility outdoors and in the community. Walking up and down stairs is possible holding onto a railing with supervision or physical assistance. Limitations in walking may necessitate adaptations to enable participation in physical activities and sports including self-propelling a manual wheelchair or powered mobility
Level IV	Wheeled mobility is used in most settings. Youth require adaptive seating for pelvic and trunk control. Physical assistance is required for transfers. They may support weight with their legs to assist with standing transfers. Walking short distances is possible indoors with physical assistance, using wheeled mobility, or, when positioned, using a body support walker. Youth are physically capable of operating a powered wheelchair. Limitations in mobility necessitate adaptations to enable participation in physical activities and sports, including physical assistance and/or powered mobility.
Level V	Youth are transported in a manual wheelchair in all settings. Their ability to maintain antigravity head and trunk postures and control arm and leg movements is limited. Assistive technology is used to improve head alignment, seating, standing, and mobility but limitations are not fully compensated. Physical assistance or a mechanical lift is required for transfers. They may achieve self-mobility using powered mobility with extensive adaptations for seating and control access. Limitations in mobility necessitate adaptations to enable participation in physical activities and sports including physical assistance and using powered mobility.

3.3.2 Manual Ability Classification System (MACS)

Complementing the GMFCS is the MACS for upper extremity function (Hidecker et al., 2012). This system classifies how well children aged 4–18 years with CP use their hands when handling objects in daily activities (Carnahan et al., 2007). These activities should be age appropriate and relevant, such as eating, dressing, and playing, and should not include activities that need advanced skills training, such as playing a musical instrument (Kuijper et al., 2010). The focus is on manual ability, as defined in the International Classification of Functioning, Disability and Health (ICF). The MACS is a five-level system influenced by environmental and personal factor, and similar to the GMFCS where level I represents the best manual ability (Carnahan et al., 2007). It has been stated that there is moderate reliability of the MACS in children 1–5 years of age, though reliability in infants (less than 2 years old) is lower than in children aged 2–5 years (Plasschaert et al., 2009).

Table 7: Manual Ability Classification System (Hidecker et al., 2012)

MACS Level	Expected manual ability
1	Handles objects easily and successfully. At most, limitations in the ease of performing manual tasks requiring speed and accuracy. However, any limitations in manual abilities do not restrict independence in daily activities.
2	Handles most objects but with somewhat reduced quality and/or speed of achievement. Certain activities may be avoided or be achieved with some difficulty; alternative ways of performance might be used but manual abilities do not usually restrict independence in daily activities.
3	Handles objects with difficulty; needs help to prepare and/or modify activities. The performance is slow and achieved with limited success regarding quality and quantity. Activities are performed independently if they have been set up or adapted.
4	Handles a limited selection of easily managed objects in adapted situations. Performs parts of activities with effort and with limited success. Requires continuous support and assistance and/or adapted equipment, for even partial achievement of the activity.
5	Does not handle objects and has severely limited ability to perform even simple actions. Requires total assistance.

3.3.3 Neuroimaging

Neuroimaging (magnetic resonance imaging (MRI), computed tomography (CT)) is not necessarily required for diagnosis of CP because the disorder is based on clinical findings (Korzeniewski et al., 2008). According to Fairhurst (2012), as all clinical problems are individual, total reliance of neuroimaging for diagnosis is not entirely reliable. However, according to Hnatyszyn (2010), MRI plays an especially important role for prediction of CP due to its extremely high sensitivity resulting from correlation between MRI hypoxic-ischemic findings and further progression to CP in neonates with perinatal asphyxia. Neuropathology identified by MRI corresponds well to clinical descriptions of motor impairment in children who have CP (McAdams & Juul, 2011).

Most (83%) children with cerebral palsy have abnormal neuroradiological findings, with white matter damage the most common abnormality. Combined grey and white matter abnormalities are more common among children with hemiplegia. Isolated white matter abnormalities are more common with bilateral spasticity or athetosis, and with ataxia. Isolated grey matter damage is the least common finding (Korzeniewski et al., 2008). Wu et al. (2006) collected records of 273 children with CP that received a head CT or MRI. Most common neuroimaging findings was focal arterial infarction (22%), brain malformation (14%), and periventricular white matter abnormalities (12%).

3.4 Classification

Cerebral palsy depends on several pre-, peri- and postnatal aspects. From one year of age and in pre-school age cerebral palsy symptoms are occurring differently from infant age. Different levels of motor damage (topography) and changes in tonus are observed (motor type) according to the kind of cerebral injuries (Pfeifer et al., 2009). From clinical and didactical point of view, these symptoms are classified into several forms and types that are usually overlapping each other and can demonstrate themselves from light to severe (Pfeiffer, 2007). Not only is movement affected in different ways, but the degree of involvement of body and limbs also differs (Piek, 2006).

Severity and pattern of clinical involvement varies widely, dependent on the area of the central nervous system compromised (Fairhurst, 2012). The lesions that produce CP influence many different motor pathways, so the resulting movement difficulties are quite complex (Piek, 2006). Because the diagnosis of CP does not specify a particular aetiology or pathology, epidemiologic studies of CP have traditionally grouped children with CP into phenotypic subtypes based on the distribution of limb weakness and type of tone abnormality (Wu et al., 2006). It generally includes a combination of the following: the degree of disability (mild, moderate, or severe), the location of the primary motor disability (e.g., monoplegia or hemiplegia) and the type of motor disability (e.g., spasticity, dyskinesia). Five broad categories of CP can be distinguished: hemiplegia, spastic and ataxic diplegia, tetraplegia/quadriplegia, athetoid CP, and ataxic CP (Piek, 2006).

Bax et al. (2005) proposed a different system, the four major dimensions of classification that would meet the needs of clinicians, investigators, and health officials, and provide a common language for improved communication. Components of CP classification include motor abnormalities (nature and typology of the motor disorder; functional motor abilities), associated impairments (seizures, hearing or vision impairments, or attentional, behavioural, communicative, and/or cognitive deficits), anatomic and radiological findings, causation and the presumed time frame during which the injury occurred.

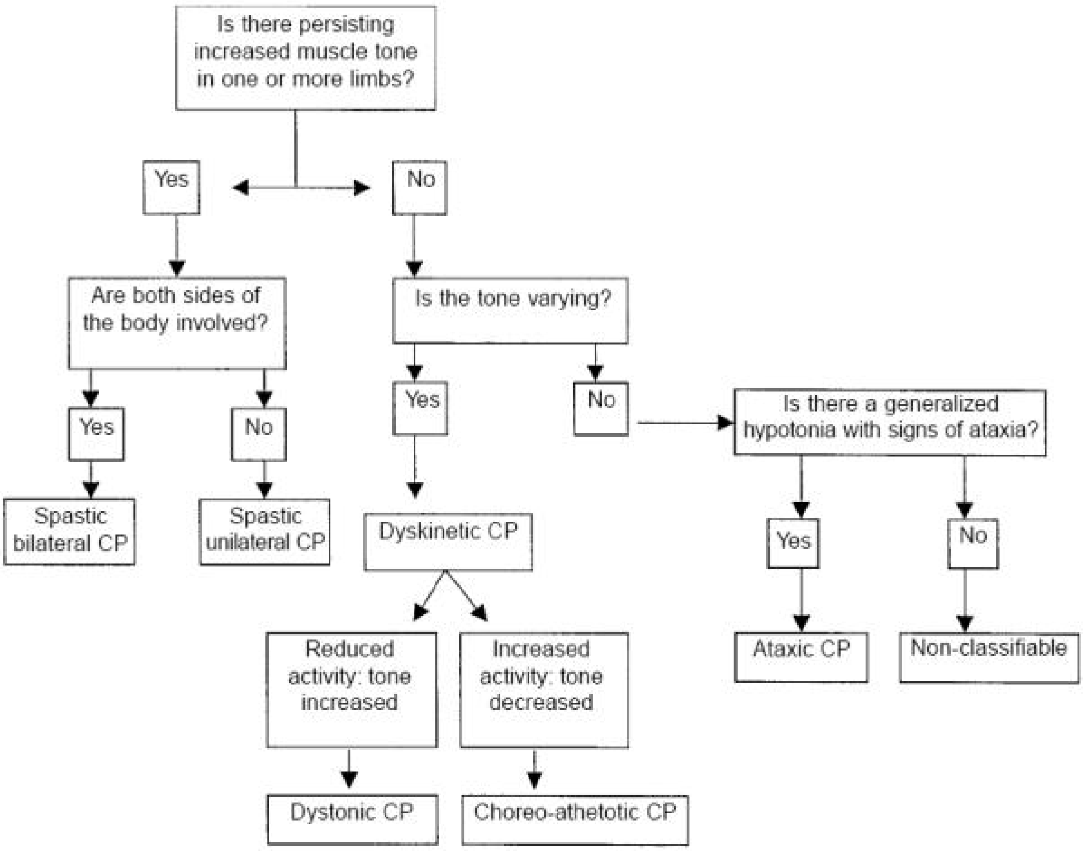

Figure 1: Hierarchical classification tree of cerebral palsy sub-types (O'Shea, 2008)

3.4.1 Categorization by Affected Body Part

Terminology used to describe the areas affected by CP has been defined by Scherzer and Tscharnuter (1990) as follows (Piek, 2006):

- Monoplegia - only one limb is affected
- Hemiplegia - both the arm and leg of one side are affected
- Paraplegia - both legs are affected
- Quadriplegia - all limbs are equally involved
- Diplegia - all limbs are unequally involved, arms have only mild difficulties

In-term and near-term infants, hemiparetic (1-sided) and quadriparetic (4-limb) CP are the most common clinical subtypes, whereas in preterm and very preterm infants spastic diplegia (legs affected more than arms) is the predominant form of spastic involvement (Nelson, 2008). Monoplegia and triplegia are relatively uncommon (Sankar et al., 2005).

Spastic Diplegia

This type is the most common form of cerebral palsy. The incidence is reported variously between authors and ranges from 41% to 65%. Syndrome of spastic diplegia affects patients who achieve self-bipedal locomotion without support, but also patients who are unable to walk independently (Kolář, 2009). This form is often related to low--birth-term infants and preterm infants (delivered in the 7th month of gestational age) (Piek, 2006). Its main causes are cerebral ischemic and haemorrhagic phenomena and foetal or post-natal hydrocephaly especially in preterm newborn children (Pfeifer et al., 2009). Characteristic sign is impairment of lower extremities, as the lesions are generally located along the outer angle of the lateral ventricles and subcortical white matter (Piek, 2006; Pfeifer et al., 2009). Upper extremities are often affected lightly as well. During growth, lower part of the body stays less developed (Pfeiffer, 2007). Mild cases may present with toe walking due to impaired dorsiflexion of the feet with increased tone of the ankles (Sankar et al., 2005). In children able to walk with this form of CP, typical gait named "scissors gait" can be observed. This gait is caused by spasticity of adductors and internal rotators of lower extremities (Pfeiffer, 2007). Hips cannot achieve full extension and are flexed in the stance position, while knees may be either hyperextended or flexed (Piek, 2006). Feet are usually held in the equinovarus position (club foot) (Pfeiffer, 2007). A major problem for infants with diplegia is the inability to sit, as they have difficulty opening their legs wide enough to provide a stable base of support (Piek, 2006). Disabled child has usually accentuated thoracical kyphosis and Babinski-like responses are positive (Rossolimo sign and Bekhterev-Mendel reflex). Bilateral CP is usually accompanied by strabismus, deteriorated perception of high tones, unusual stretch reflexes on m. triceps surae and some others symptoms (Pfeiffer, 2007). Epilepsy occurs in half of the affected children and only a third of them have normal intellect (Kolář, 2009).

Hemiplegia

This category is also termed hemiparesis or unilateral spastic paresis, often referred to spastic hempilegia because it is mostly spastic in type of motor disorder (Piek, 2006). Disability is on one entire side of the body, including the involvement of the facial nerve and the hypoglossal nerve (Kolář, 2009). Upper limbs are more severely affected than the lower limbs. It is seen in 56% of term infants and 17% of preterm infants (Sankar et al., 2005). Malfunction is located in one of the hemispheres contralateral to the affected side in the form of atrophy, porencephalic cavity, enlargement of lateral ventricle. Upper extremity is more affected than in the bilateral form of CP, held in flexed position, whilst lower extremity is extended with tendency to equinovarus position of foot and ankle (Pfeiffer, 2007). Pincer grasp of the thumb, extension of the wrist and supination of the forearm are affected. In the lower limb, dorsiflexion and aversion of the foot are most impaired (Sankar et al., 2005). C-shaped scoliosis arises. Higher muscle tone in arm flexors and hypotone of hand can be found on upper extremity. A hand is highly paretic or plegic. Lower muscle tone of hand can be tested by flexion of a wrist – palm is in contact with forearm. Hyperextension of interphalangeal joints can be made passively. Very common is impairment of proprioception, touch sense, feeling of temperature and pressure, mostly on hand, palm and first two fingers. Grasping is highly immature, with flexed wrist, remains of grasp reflex (Pfeiffer, 2007). Asymmetrical gait is one of the most common features of a child with spastic hemiplegia. During walking, most of the body weight is on the unaffected leg, and appropriate arm swing is observable only on the unaffected side, as the shoulder of the affected arm is generally hyperextended and the elbow flexed. There is also evidence that the right side of the body is more often affected than the left, although there appear to be similar clinical patterns for right and left hemiparetic CP (Piek, 2006). More than a third of patients suffers from epilepsy and mental retardation (Kolář, 2009).

Tetraplegia

This form is also termed spastic quadriplegia or bilateral hemiplegia (Piek, 2006) and is the most severe form of CP with damage of both hemispheres (Pfeiffer, 2007). Tetraplegia results from its location associated with the cause (the most frequent is hypoxic-ischemic encephalopathy) followed by defects of cortical cerebral development

(Pfeifer et al., 2009). This disorder involves the whole body and occurs in only 5% cases, including the spasticity of the four limbs, associated with problems including feeding and absence of speech due to oral difficulties (Piek, 2006). The upper extremities are involved more than the lower extremities (Bialik & Givon, 2004). Clinical manifestation is similar to pseudobulbar syndrome (Pfeiffer, 2007) and accompanying problems, such as epilepsy and severe mental retardation, are often also present (Piek, 2006). Voluntary movements are few; vasomotor changes of the extremities are common. Half the patients have optic atrophy and seizures. Intellectual impairment is severe in all cases (Sankar et al., 2005).

3.4.2 Categorization by Movement Type

This categorization is based on four main types of motor involvement: spasticity, ataxia, dyskinesia and hypotonia (Piek, 2006). Evans and Alberman (1985) classified CP likewise according to the type of neuromuscular deficit and motor involvement into spastic, dyskinetic (choreo-athetoid and dystonic), ataxic, hypotonic and mixed (Sankar et al., 2005).

Spasticity

Spastic CP is the most common and accounts for 60%-75% of all cases (Sankar et al., 2005; Hurkmans et al., 2010) This motor problem is characterized by rigidity, which occurs as a result of hypertonia with abnormal resistance to passive movement. As this resistance builds up, there is rapid release of tension with exaggerated stretch reflexes and increased deep tendon reflexes. Contractures are a major problem for children with this type of CP. Spasticity produces shortened muscles that lead eventually to contractures affecting joint function. The ankle is particularly vulnerable, leading to foot deformities. Also, abnormalities of the hip joint may occur as a result of internal rotation and adduction at the hips (Piek, 2006). The descending cortico-spinal tracts normally stimulate release of the inhibitor neurotransmitter γ-amino butyric acid (GABA) at the spinal level. Lesions lead to dysinhibition of the spinal reflex arc and muscle over activation (Fairhurst, 2012). In severe cases, the child may be fixed in a few specific position patterns as a result of the strong co-contraction of muscles.

Spasticity has been associated with damage involving the motor portion of the cerebral cortex and pyramidal tracts (Piek, 2006). Performance of daily activities is challenging for persons with spastic CP because of paresis, increased muscle tone, involuntary movements, and postural instability (Hurkmans et al., 2010).

Ataxia

Ataxia is described as excessive incoordination and difficulty with balance. It has been associated with damage of cerebellum. Ataxis CP is distinct from ataxic diplegia in that the former refers only to individuals who demonstrate cerebellar symptoms and signs most prominently. The arms are particularly affected, with signs of overreaching (overshooting) and underreaching (undershooting) and intention tremors are also sometimes evident. Eye movements independent of head movements can be difficult and as a result visually tracking object might be a problem. Motor milestones are frequently delayed, with infants often being unable to sit until 15 to 18 months, and they may not stand or walk until two or three years of age or older (Piek, 2006). This form is associated with less than 5% of CP (Sankar et al., 2005).

Dyskinesia

Dykinesia has been linked with damage to the extrapyramidal pathways. Evans and Alberman (1985) divide dyskinesia into two types:

Chorea-athetoid type is a manifestation of involuntary movements described as swiping, jerky and rotary patterns, unnecessary and purposeless, often slow and writhing in character. Athetoid movements result from the recruitment of inappropriate muscle groups, and affects mainly the proximal part of the limbs. Choreatic form is characterized by impairments mainly affecting acral parts of the extremities (Kolář, 2009).

Dystonia is characterized by changing muscle tone during the movement. Generally, these changes occur from normal to increased tone (Piek, 2006). Damage to the basal ganglia leads to patterns of sustained muscle contraction causing abnormal postures that are frequently associated with involuntary movements (Fairhurst, 2012).

Both athetosis and dystonia may be evident in the same individual. Bobath (1980) categorized this "athetoid group" into three different subgroups: the first group involved

dystonia and dyskinesia; the second group was a mixed group with spasticity and ataxia or athetosis; the third group involved athetosis, floppy infant, ataxia (Piek, 2006).
The diagnosis of athetoid CP covers the dyskinetic movement problems and includes a variety of terminology, such as athetosis, chorea, dystonia and dyskinesia. The pathology of athetoid type of CP is well defined, with selective involvement of the central grey nuclei (Piek, 2006). Dyskinetic CP is presented in 10% to 15% of all cases (Sankar et al., 2005). According to Pfeifer et al. (2009) spasticity occurs during the first three months and dyskinesia occurs in up to three years in most of the cases. One of the common symptoms is vegetative lability (hyperhidrosis), and emotional imbalance. Mental abilities are normal. Some of the children are of above average intelligence (Kolář, 2009).

Hypotonia

Hypotonia is characterized by decreased muscle tone that usually results in increased joint range (Piek, 2006). Hypotonic CP is characterized by generalized muscular hypotonia that persists beyond 2 to 3 yrs of age that does not result from a primary disorder of muscle or peripheral nerve (Sankar et al., 2005). All muscles are feeble and joints can be bent to large angles passively (Kolář, 2009). The deep tendon reflexes are normal or hyperactive, and the electrical reactions of muscle and nerve are normal (Sankar et al., 2005). The hypotonic group is usually found among children under the age of 2 and the dyskinetic group is identified later in life. Only few children stay hypotonic (Pfeifer et al., 2009). Epilepsy occurs in 30% of children with this form of CP (Kolář, 2009).

3.5 Manifestation

Although CP is a non-progressive disorder in that neurological impairment does not progress, the problems associated with the disorder frequently become more complex with age. This phenomenon is called "growing into deficit" (Piek, 2006). Despite the static nature of the brain damage in CP, the clinical manifestations of the disorder may change, as the child grows older. Although movement demands increase with age, the child’s motor abilities may not change quickly enough to meet these demands (Akbari et al., 2009). If the upper limbs are affected, this will result in difficulties with manual dexterity. If the lower limbs are affected, the first signs may become clear when the child is delayed in walking or develops an unusual gait (Piek, 2006).

Bobath (1980) highlighted the problems faced by children with CP when he stated: *"A child, whether normal or abnormal, can only use what he has experienced before. The normal child will use and modify his normal motor patterns by practice, repetition and adaptation. The child with cerebral palsy will continue to use and, by repetition, to reinforce abnormal patterns."* (Piek, 2006).

3.5.1 Hand Impairments

Cerebral palsy (CP) commonly affects the brain structures responsible for skilled hand movements (Arnould et al., 2008). About half of the children diagnosed with CP have upper extremity dysfunction, which makes activities involving reaching, grasping, and manipulation a challenge (Odle, 2009). The severity and type of hand impairments (i.e. motor or sensory impairments) vary widely according to the time of appearance, the location and the degree of cerebral damage. There is, therefore, a need to quantify hand impairments in the various types of children with CP (i.e. hemi-, di-, and tetra-plegics) (Arnould et al., 2008). When compared to their typically developing peers, children with spastic CP exhibit reaching patterns that are jerkier, slower, and less forceful (Odle, 2009). Hand sensorimotor impairments are generally thought to be largely responsible for the difficulty experienced in daily activities. The International Classification of Functioning, Disability and Health (ICF) conceptualizes hand impairments and manual ability as different dimensions of functioning that are not necessarily related. While most hand impairments can be measured with physical units (e.g. grip strength can be measured in Newtons), manual ability is a capacity concealed within a person or a child and cannot be directly measured (Arnould et al., 2008). Lemmens et al. (2014) defined arm movement components based on functional goals as follows:

Table 8: Movement components of arm and their definition (Lemmens et al., 2014)

Movement component	Definition
Positioning the upper extremity	Maintaining a fixed position of the shoulder, arm and/or hand in space.
Reach	Intentional movement of the arm towards an object

Grasp	To make a motion of seizing, snatching or clutching
Hold	Keep an object in a fixed position in the hand without external support
Release	To free an object from grip
Manipulate	To skilfully control the position of an object using the fingers
Push/Pull/Shove	To apply force against an object with the intention to move or stabilize
Displace/Lift	Moving an object without the object being in contact with a surface in the environment
Fixate	To stabilize an object against a surface
Other	Other movement components not covered by the above mentioned movement components

In children with CP, the domain of self-care in daily life is closely related with their hand fine motor function (Kwon et al., 2013), and according to Speth et al. (2013), evaluation of hand function over time or after treatment should focus on the actual use of the affected hand in bimanual activities of daily life.

3.5.2 Proprioception

Proprioception is a complex somatosensory modality that utilizes inputs from muscle, joint, and cutaneous afferent fibres, and consists of two components, the sense of limb movement (kinesthesia) and static limb position (joint-position sense) (Wingert et al., 2009). CP could be associated with somatosensory alterations, including abnormal perception of touch, altered pain sensitivity, poor stereognosis and proprioception, as well as increased pain and abnormal activation of cortical somatosensory areas (Riquelme et al., 2014). Proprioceptive deficits in the upper limbs in children with CP are greater on the non-dominant side. Joint-position sense worsens especially in pronation, and passive movements are significantly less accurately detected (Wingert et al., 2009).

According to Wingert et al. (2009), visual adaptation to proprioception deficits in CP is a probable compensatory and results in improved performance accuracy when seeing the affected limb during the task. Therefore, optimization of vision is essential for people with CP and should be engaged and relied upon while learning and practicing movements (e.g., using mirrors, video, virtual reality), especially in early stages of the rehabilitation process until accurate perception of body movements is presented. This visual input can be gradually decreasing to improve perception. The same applies in the case of focusing on proprioceptive information from the lower limbs. While visual, somatosensory and vestibular inputs are each important for maintaining balance, their contribution varies by task. Due to diminished proprioception, individuals with unilateral and bilateral CP demonstrate balance deficits when attempting to stand still, walk slowlier and have a bigger postural sway (Damiano et al., 2013).

3.5.3 Other Impairments

Children with CP have a higher incidence of obesity and physical inactivity compared to the general population. Therefore, they tend to have lower endurance, muscular strength, and cardiorespiratory fitness. Children, particularly those with CP, face many barriers to physical activity. Some of the mainstream barriers to physical activity for children include: lack of interest, preference for indoor activities, low energy levels, time constraints, unsafe neighbourhoods, self-consciousness, lack of motivation, and insufficient social support from parents and peers. Children with CP face additional barriers to physical activity including: weakness, muscle spasticity, imbalance, poor accessibility, lack of transportation, equipment, and resources, parental restrictions, and learned helplessness (Irwin, 2011).

Associated deficits, such as mental retardation, are common in CP in up to 60% of the cases. Children with spastic quadriplegia have a higher degree of cognitive impairment than children with spastic hemiplegia. Visual impairments and disorders of ocular motility are common (28%) in children with CP (strabismus, amblyopia, nystagmus, optic atrophy, and refractive errors). Hearing impairment occurs in approximately 12% of children with CP. 35% to 62% of children develop epilepsy. Children with spastic quadriplegia or hemiplegia have a higher incidence of epilepsy than patients with diplegia or ataxic CP (Sankar et al., 2005). Beckung and Hagberg (2002) were investigating a series of 176 children with cerebral palsy (CP), aged 5 to 8 years. Learning disability occurred in 40%, epilepsy in 35%, visual impairment in 20%, and infantile hydrocephalus in 9% of the children. Articulation disorders and impaired speech are present in 38% children with CP and go hand in hand with mental retardation (Sankar et al., 2005).

McAdams & Juul (2011) made a list of impairments associated with cerebral palsy.

Table 9: Morbidities Associated with Cerebral Palsy (McAdams & Juul, 2011)

• Cognitive impairments
• Epilepsy: 20% to 40% of patients
• Behavior problems: 5 times more likely in children who have CP
• Pain
• Weakness
• Speech impairment: up to 80% of patients
• Low visual acuity: up to 75% of all children who have CP
• Gastrointestinal and feeding problems: 50% of children who have CP
• Dental caries
• Developmental enamel defects
• Gingival health, tooth wear, oral mucosal health, and malocclusion problems
• Swallowing dysfunctions and dysarthria symptoms
• Stunted growth: 25% of children who have CP
• Under- or overweight problems: 50% of children

3.6 Treatment

The goal of management of cerebral palsy is not to cure or to achieve normalcy but to increase functionality, improve capabilities, and sustain health in terms of locomotion, cognitive development, social interaction, and independence (Krigger, 2006). The problems associated with the disability tend to be progressive. Appropriate early intervention is, therefore, essential to ensure the best possible outcome for children with cerebral palsy (Piek, 2006). Optimal treatment in children requires a team approach focused on total patient development, not just on improvement of a single symptom (Krigger, 2006). There are two approaches used. First, focus on clinical and developmental comorbidities, such as behaviour, communication, epilepsy, feeding problems, gastro-oesophageal reflux and infections. The second approach is focused on specifics of muscle tone, motor control and posture (Fairhurst, 2012).

Table 10: Multispecialty Management Team for Children with Cerebral Palsy (Krigger, 2006)

Physician	Team leader; synthesizes long-term, comprehensive plans and treatments
Orthopedist	Focuses on preventing contractures, hip dislocations, and spinal curvatures
Physical therapist	Develops and implements care plans to improve movement and strength, and administers formal gait analyses
Occupational therapist	Develops and implements care plans focused on activities of daily living
Speech and language pathologist	Develops and implements care plans to optimize the patient's capacity for communication
Social worker	Assists the patient's family in identifying community assistance programmes
Psychologist	Assists the patient and patient's family to cope with the stress and demands of the disability
Educator	Develops strategies to address cognitive or learning disabilities

Close collaboration between the members of the specialized teams and fluent care coordination are considered crucial to the quality of children's healthcare (Nijhuis et al., 2008). Home therapy by parents and caregivers is an important factor in treatment, because infants must be viewed in the context of their environment to understand developmental and maturational processes.

3.6.1 Medical movement therapies

Progressive casting is considered to increase muscle length, and benefits from serial casting can be improved with use of the drug botulinum toxin type A (BTX-A) (Piek, 2006). Botulinum toxin (Botox) is a formulation of botulinum toxin type A, derived from the bacterium Clostridium botulinum. This bacterium produces a protein that blocks the release of acetylcholine and relaxes muscles (Krigger, 2006). This produces partial denervation of the muscle, causing a period of muscle weakness that can last around four months. This can result in reduced spasticity and improved functional performance (Piek, 2006). It is licensed in America only for use in children over the age of 2 for dynamic equinus foot deformity caused by spasticity in ambulant paediatric CP. However, there is a good level of evidence for its use at calf, hip adductor, hamstring and upper limb levels (Fairhurst, 2012). Degelaen et al. (2013) analyzed the effect of lower limb botulinum toxin injections on trunk postural control and lower limb intersegmental coordination in children with spastic CP (GMFCS I or II). They stated that this intervention leads to changes in motor planning, and influencing trunk control during gait in children with spastic CP.

Intrathecal baclofen pumps (ITB) have similar effects as BTX-A. Their aim is to maximize antispasticity benefits of baclofen and minimize the cerebral side effects, by using an implantable pump (Fairhurst, 2012). Candidates for ITB have severe, generalized tone that has not been successfully managed with oral medications and other more conservative methods. Baclofen is delivered directly to the cerebrospinal fluid via a catheter connected to an implanted device in the abdomen. The device contains a peristaltic pump, a battery, a reservoir for baclofen, and electronic controls that allow regulation of the pump by telemetry (Matthews & Balaban, 2004). However, ITB therapy does carry the risk for significant complications, such as infection, pump malfunction, catheter kinking or withdrawal, and Baclofen overdose, because of programming error (Tilton, 2006).

Selective dorsal rhizotomy is a procedure intended to minimize or eliminate spasticity by selectively cutting dorsal rootlets from spinal cord segments L1 to S2 (Krigger, 2006). It can reduce the stimulation of the spinal reflex arc, as the motor and sensory nerves are separated and then the sensory fibres are blunt dissected into a series of rootlets (Fairhurst, 2012). According to Rosenbaum et al. (2002), after selective dorsal rhizotomy the improvements in gross motor function are significantly greater than those seen with physical therapy alone, but the actual measured changes in Gross Motor Function Measurement are quite modest. This intervention affects mainly the lower limbs although beneficial changes are sometimes found in the upper limbs (Rodda & Graham, 2001).

Orthopaedic surgical intervention is frequently indicated for spastic type of CP. The ultimate goal is to enable verticalization, standing, walking and self-care. Therefore, most operations are performed on the lower extremities (Kolář, 2009). Common surgical options are lengthening shortened muscle–tendon complexes, moving awkward muscles, bio-mechanically improving lever arms or providing a stable base for standing and/or walking, and vertebral fusion in scoliosis (Fairhurst, 2012). Muscle imbalance caused by spasticity can lead to complete dislocation of hips. The incidence of hip dislocation in children with CP has been reported to be as high as 59%. A common surgical procedure for the subluxated hip is the proximal femoral varus-producing osteotomy in combination with appropriate soft-tissue release (Krigger, 2006).

3.6.2 Early Intervention Approaches

Given that the indicated physiotherapy treatment is symptomatic, it should begin even before the diagnosis has been established. More serious deviations from the physiological motor development are the indication for treatment (Kolář, 2009). A major aim of early intervention is to ensure that the pathological movement patterns do not become habit, therefore reducing the likelihood of contractures and the subsequent need for orthopaedic intervention (Piek, 2006). Late initiation of physiotherapy also means fixing developmentally older motor patterns through which the child moves (Kolář, 2009).

Around the middle of 20th century, neurophysiological theories, based on the reflex theory, were proposed to account for CP. Some of the methods developed around this time were Bobath concept according to Karel and Berta Bobath, who targeted the inhibition of postures and patterns, and the method devised by Václav Vojta, who aimed at provoking or eliciting reflex locomotor patterns. Theories highlighting the importance of sensory information were developed by Ayres in the 1970s and this approach became popular with occupational therapists (Piek, 2006).

Neurodevelopmental Therapy (Bobath Concept)

The neurodevelopmental therapy (NDT) was developed by Bobath (1980), and originally focused on improving motor control by inhibiting abnormal automatic reactions and reflexes. This approach is based on the early hierarchical reflex theories arguing that reflexes were the basis of later movement (Piek, 2006). A child is positioned in reflex-inhibiting postures to reduce spasticity. Then, specific reflexes and reactions are stimulated to improve normal movement sense (Yalcinkaya et al., 2014). Another important component of this approach is the acknowledgment of the importance of posture in motor development. Specific handling techniques were developed to influence sensorimotor components of muscle tone, reflexes, abnormal movement patterns, postural control, sensation, perception, and memory. Adequate postural tone exists when the body has a sufficiently high muscle activation to maintain a posture against gravity and yet low enough activation to allow the body to move through gravity (Piek, 2006; Krigger, 2006). As the child gains postural control, the therapist gradually withdraws support. Handling techniques and treatment activities undergo continual change, as they are adapted to the responses of a particular child (Fetters & Kluzik, 1996).

Nowadays the neurodevelopmental therapy takes into account the importance of the practice of functional skills, and although this method is based on an outdated theory, continues to be applied and is popular because its procedures appear to follow recent motor control approaches (Piek, 2006). The goal of the therapy is to enhance self--sufficiency and independence of the child. Exercises are applied throughout the day within daily activities, whose implementations are adapted to the specific therapeutic target. To prevent deformity, to provide external support and facilitate the activity, assistive devices are used. Of greatest importance for a younger child is learning spontaneous movements, while efforts should be made in the pre-school and school child to actively control voluntary movements (Kolář, 2009).

Vojta Method

The Vojta treatment is based on a maturational perspective, as it aims to activate normal muscle responses ("postural ontogenesis") that will then provide the child with proprioceptive information that can be utilized by the CNS (Piek, 2006). According to Professor Vojta, the persistence of the newborn reflex patterns in a child with CP interferes with postural development. It is postulated that with appropriate stimulation, the newborn reflex pattern can be provoked and activated in a child with CP, thereby facilitating the development of reflex locomotion (Patel, 2005). This method uses isometric strengthening techniques and normal movement patterns are encouraged through application of tactile stimulation (Piek, 2006). Two global patterns of locomotion are used within this technique - reflex creeping and reflex rolling. In these models, the activation occurs throughout the striated musculature in certain coordination contexts (Vojta & Annegret, 2010). These patterns can be retrieved at predetermined positions of the body by stimulating ten available zones on the trunk and on the arms and legs. Using the technique by Professor Vojta it is possible to enter into a genetically encoded human motion programme and its control. An accurate intervention from the periphery (afferent stimulus) elicits exact motor reaction (efferent response) (Kolář, 2009).

Sensory-Integration Approach

The sensory-integration approach emphasizes sensory processing and movement planning due to organization and integration of different sensory inputs as an important component of motor control. This approach, developed by Ayres (1972), highlighted poor visual-spatial organization as the key problem in children with movement problems, such as developmental coordination disorder. Sensory-integrative abilities in children with CP are disrupted as a result of neurological dysfunction, or because poor motor ability reduces the sensory experiences of the infants and children (Piek, 2006). The sensory integration theory is based on the hypothesis that in order to develop and execute a normal adaptive behavioural response, the child must be able to optimally receive, interpret, modulate, and integrate the sensory information (Patel, 2005).

This method involves the stimulation of vestibular, kinesthetic, and tactile senses through a variety of equipment such as swings and balls to lie on and materials of different textures such as sand and water. This equipment is used to train the child to be able to appropriately process different sensory stimuli (Piek, 2006). Nowadays, this method is widely used among occupational therapists working with various children with developmental, learning, and behavioural problems (Parham et al., 2007).

3.6.3 Virtual Reality

The use of VR as an intervention to improve motor learning and performance of motor skills in children with neurological impairments is an active area of rehabilitation. These systems utilize hardware and software options to create interactive simulations that engage the user in virtual environments (Galvin & Levac, 2011b). Patients are motivated by seeing themselves engaging in various sports and games, which may improve focus and adherence (Moffat, 2004) and thus shorten the time needed for motor skill recovery (Brütsch et al., 2014). Goals change as rehabilitation progresses over long periods of time. Therefore, VR system choice should also evolve in tandem with the child's changing abilities (Levac & Galvin, 2011). Nevertheless, supportive evidence for the application of VR in the rehabilitation of children with neurological disorders is still poor since most of the studies are uncontrolled trials with only a small number of cases and case series (Brütsch et al., 2014).

The aim of this study was to explore the available information about the possibilities of application of virtual reality as a therapeutic intervention for children with cerebral palsy. The following part of the thesis evaluates the collected data on the use of virtual reality in the form of gaming systems. In the discussion and conclusion at the end of the thesis, virtual reality is considered as a therapeutic tool also for other disabilities, mentioned in context of motor learning theories, including consideration of its future applicability.

4 Objectives and Research Method

4.1 Research Questions

1) How big is the evidence within Pubmed and Cinahl search of virtual reality used as a rehabilitation tool in children with cerebral palsy?
2) What are the main outcomes of measurements in the articles found in the databases?
3) How extensive is the applicability of the study results?

4.2 Literature Search

The literature search in the databases started in March 2013 and ended in March 2014. The databases that are used for comparison are PubMed MEDLINE and CINAHL. Other databases used as additional sources are PEDro, Academic Search Complete, Embase, ProQuest, and Cochrane. The search was based on the following MeSH-terms: "Cerebral Palsy", "Video Games" and "Rehabilitation". When no MeSH-term was available, the following Key-terms/Text-words were used: "virtual", "virtual reality", "virtual environment", "virtual rehabilitation", and "gaming".
In the databases (PubMed/CINAHL), "Cerebral Palsy" and "Rehabilitation" were combined with the remaining MeSH- and Key-terms using AND. Double articles were excluded. The remaining articles were screened, based on the title and abstract. When the abstract was not available or when there was not enough information to include or exclude the article, then the full text was screened. In the first instance, I looked for articles that measured functional parameters. Because the amount of relevant articles found was limited, I also included case studies and only used LIMITS based on the language English.

4.3 Selection Criteria

During the screening of the articles, the following inclusion and exclusion criteria were used:

Inclusion Criteria

- Language: articles in English
- Population: cerebral palsy children
- Intervention: use of virtual reality in movement rehabilitation/physical therapy
- Outcome/measurements: effect of virtual reality intervention on functional movement parameters

Exclusion Criteria

- Based on population:
  - no children
  - not focused on cerebral palsy primarily
- Based on the intervention:
  - no use of VR as a tool for rehabilitation
  - different system as a main intervention
- Based on the measurements:
  - no functional movement parameters
  - other perspective
- Based on the topic:
  - article non-related with the objectives
- Based on the article type
  - short articles – editorials, pictorials, brief items, comments

Because a lot of articles found were also case studies, I did not use "case study" as an exclusion criteria, otherwise the amount of articles would be relatively limited. The following data were extracted from the included articles: type of article, sample size, population characteristics (age), intervention (type of virtual rehabilitation, combination with other techniques (robotics), measured functional parameters related to movement, and method of measurement.

4.4 Methodology of Searching

When combining MeSH- and Key-terms, this resulted in a total of 154 articles, of which 77 were founded in PubMed (Table 11) and 77 in CINAHL (Table 12). With the different combinations of Mesh- and Key-terms, a lot of double articles were found. In PubMed there were 17, in CINAHL 18 and in PubMed, compared to CINAHL, 36 double articles. The total after exclusion of the double articles was 83. These 83 articles were screened on relevance based on the inclusion criteria: articles in English, cerebral palsy children, use of virtual reality as a rehabilitation tool, study the effect of virtual reality intervention on the functional movement parameters. This resulted in 27 articles, 2 reviews included. Because of poor evidence about VR used in rehabilitation in children with CP, "case studies" were also included. Articles were not included when: no cerebral palsy cases (n= 5) and no children (n = 15), no use of virtual reality for therapy/rehabilitation predominantly (n= 4), no functional movement parameters measured (n = 20), no relevant topic (n = 1), and article type (n = 9) (table XY).

Table 11: Overview of results in PubMed

Search	Query	Items found
# 1	Search **cerebral palsy [MeSH Terms]**	12,274
# 2	Search **virtual [Title/Abstract]**	27,994
# 3	Search **video games [MeSH Terms]**	1,835
# 4	Search **gaming [Title/Abstract]**	962
# 5	Search **virtual reality [Title/Abstract]**	4,064
# 6	Search **virtual environment [Title/Abstract]**	1,174
# 7	Search **virtual rehabilitation [Title/Abstract]**	48
# 8	Search **(#1) AND #2**	44
# 9	Search **(#1) AND #3**	22
# 10	Search **(#1) AND #4**	11
N = 77		

Table 12: Overview of results in CINAHL

Search	Query	Items found
# 1	Search **cerebral palsy [MeSH Headings]**	12,395
# 2	Search **virtual [Title/Abstract]**	9,360
# 3	Search **video games [MeSH Headings]**	3,000
# 4	Search **gaming [Title/Abstract]**	853
# 5	Search **virtual reality [Title/Abstract]**	2,013
# 6	Search **virtual environment [Title/Abstract]**	686
# 7	Search **virtual rehabilitation [Title/Abstract]**	245
# 8	Search **(#1) AND #2**	37
# 9	Search **(#1) AND #3**	29
# 10	Search **(#1) AND #4**	11
N = 77		

Table 13: Exclusion procedure

Articles in **PubMed**
(n = 77)

Total articles when combining
MeSH- and Key-terms
(n = 154)

Articles in **CINAHL**
(n = 77)

Articles in **PubMed**
(n = 60)

Double articles in:
PubMed **(n = 17)**
CINAHL **(n = 18)**

Articles in **CINAHL**
(n = 59)

Double articles:
PubMed compared with CINAHL
(n = 36)

Total after exclusion of double articles
(n = 83)
PubMed (n = 24)
CINAHL (n = 23)
PubMed/CINAHL (n = 36)

Table 14: Selection Criteria Overview

Inclusion Criteria:
1) Articles in English
2) Population: cerebral palsy children
3) Intervention: use of virtual reality as a tool for rehabilitation
4) Outcome: effect of virtual reality intervention on functional movement parameters
Exclusion Criteria:
1) Based on population (n = 20)
- no children
- not focused on cerebral palsy predominantly
2) Based on the intervention (n = 6)
- no use of VR as a tool for rehabilitation
- robotic rehabilitation as a main topic
3) Based on the measurements (n = 20)
- no functional movement parameters
- description of VR system
- other perspective
4) Based on the topic (n = 1)
- article non-related with the objectives
5) Based on the article type (n = 9)
- short articles - editorials, pictorials, brief items, comments

Table 15: Overview of excluded articles and reason for exclusion

Reason	**Total articles**	**References**
Exclusion based on **POPULATION**	**(n = 20)**	
No children - Adult - Adolescent - Different age groups	 6 8 1	 (Slaboda, Lauer, Keshner, 2013) (Mawase, Bar-Haim, Karniel, 2011) (Feasel et al., 2011) (Hurkmans, van den Berg-Emons, Stam, 2010) (Rowland, Rimmer, 2012) (Szturm et al., 2008) (Huber et al., 2010) (Leung, Yates, Duez, Chau, 2010) (Wann, Turnbull, 1993) (Brien, Sveistrup, 2011) (Golomb et al., 2010) (Deutsch, 2008) (Golomb et al., 2011) (Dinomais et al., 2013) (Unknown, Paediatric PT, 2011)
No (only) Cerebral Palsy - Review of gaming systems - Review of sensorimotoric training in VR - Musculoskeletal and neuromuscular conditions - Stroke	 2 1 1 1	 (Taylor et al., 2011) (Gordon, Okita,2010) (Adamovich, Fluet, Tunik, Merians, 2009) (Deutsch, 2009) (Merians, Tunik, Adamovich, 2009)

Exclusion based on **INTERVENTION**	**(n = 6)**	
No use of VR as a tool for rehabilitation - Investigating the sense of agency - Assistive device for wheelchair with virtual paths in software Robotic rehabilitation (main topic)	 1 3 2	 (Ritterb et al., 2011) (Guir, Dicianno, Mahajan, Cooper, 2011) (Dicianno et al., 2012) (Zeng, Burdet, Teo, 2009) (Wu et al., 2010) (Meyer-Heim, van Hedel, 2013)
Exclusion based on the **MEASUREMENTS**	**(n = 20)**	
No functional parameters - Bone mineral density and muscle strength - Exercise intensity levels, physical activity - Spatial orientation/cognitive ability - Competency, control, expression - Playfulness - Motivation - Self-efficacy - Person-environment experience, active participation - Post-surgical rehabilitation - VR as a pain modulation technique - Wheelchair driving skills Verifying the task difficulty, summarizing the design of VR intervention Other perspective - Parents perceptions of VR	 2 2 1 1 1 2 1 2 2 1 1 3 1	 (Chen et al., 2013) (Chen et al., 2012) (Robert, Ballaz, Hart, Lemay, 2013) (Mitchell, Ziviani, Oftedal, Boyd, 2012) (Akhutina et al., 2003) (Miller, Reid, 2003) (Reid, 2004) (Harris, Reid, 2005) (Tatla et al., 2013) (Reid, 2002a) (Reid, 2002c) (Brütsch et al., 2011) (Kane, Dannemiller, Roberts, 2011) (Sharan et al., 2012) (Steele et al., 2003) (Secoli, Zondervan, Reinkensmeyer, 2011) (Koenig et al. 2007) (Riener et al., 2012) (Dunne et al., 2010) (Sandlund, Dock, Häger, Waterworth, 2012)
Exclusion based on different **TOPIC**	**(n = 1)**	
No VR - Periventricular leukomalacia - mechanism of injury	 1	 (Haynes et al., 2003)
Exclusion based on **ARTICLE TYPE**	**(n = 9)**	
No valid article - Editorial - Comment - Brief item, pictorial	 1 1 7	 (Snider, Majnemer, 2010a) (Yu, Fetters L, 2011) (Unknown, Nursing Times, 2008) (Unknown, Today in PT, 2012) (Glomstad, 2010) (Golumb et al., 2011) (Lewis, 2010) (Westby, 2013) (Unknown, Paediatric Physical Therapy, 2012)

Table 16: Overview of included articles I

Art.	Article type	Population	Intervention	Measurements	Method of measurements
(Barton et al., 2013)	Case study	N = 1 age 10 years	Computer game driven by pelvic rotations	Pelvis to trunk coupling	Vicon 612 optoelectronic system measuring the pelvis and trunk motion
(Bryanton et al., 2006)	Clinical trial/ Comparative Study	N = 10 age 7-17 years	IREX VR therapy system (television monitor, a video camera, cyber gloves, virtual objects, and a large screen)	Selective control of muscle activity - ankle movements Perceptions of exercise programs	Electrogoniometer Visual analog scale
(Burdea et al., 2013)	Case study series	N = 3 age 7-12 years	Game-based robotic training of the ankle (Rutgers Ankle CP system - playing two custom VR games)	Impairment Overall function/gait function Quality of life Game performance	Dorsiflexion/plantarflexion torques, dorsiflexion initial contact angle and gait speed The Gross Motor Function Measure (GMFM) Paediatric Quality of Life Inventory (Peds QL) Game score
(Chen et al., 2007)	A single -subject study	N = 4 mean age 6.3 years	VR-based hand rehabilitation training system (with sensor glove) EyeToy-Play System	Reaching performance - movement time - path length, peak velocity - movement units Upper extremity function	Reaching kinematics - using video taping Peabody Developmental Motor Scales-Second Edition (PDMS-2)

Table 17: Overview of included articles II

Art.	Article type	Population	Intervention	Measurements	Method of measurements
(Choi & Lo, 2010)	Two case studies	N = 2 age 7 years	The provision of force feedback as guidance in a computer-assisted training environment	Handwriting ability - average writing time, path length of 10 test character, the trajectory of the pen tip	Paper test with video taping
(Fluet et al., 2010)	Pilot study	N = 9 mean age 9 years	New Jersey Institute of Technology Robot- assisted Virtual Rehabilitation (NJIT-RAVR) system - combination of three dimensional virtual environments and robotics	Upper extremity function - speed and accuracy of shoulder and elbow movements - reaching toward a moving object - forearm supination/pronation	Melbourne Assessment of Unilateral Upper Limb Function Test Active range of motion (AROM) Grip and pinch dynamometry
(Gordon et al., 2012)	A pilot study	N = 6 age 6-12 years	Using the Nintendo Wii™ (Boxing, Baseball and Tennis) in a developing country	Gross motor function	Gross Motor Function Measure (GMFM)
(Green & Wilson,2012)	A multiple case study	N = 4 age 3-14 years	VR tabletop workspace (large horizontally-mounted LCD panel, tracking camera, graspable objects)	Functional grasp and release Functional manipulation of objects Manual ability Participation and engagement	Box & Blocks test Jebsen-Taylor Test of Hand Function (JTTHF) ABILHAND-Kids Children's Hand Experience Questionnaire (CHEQ) Feedback questionnaire

Table 18: Overview of included articles III

Art.	Article type	Population	Intervention	Measurements	Method of measurements
(Howcroft et al., 2012)	Single -group experimental study	N = 17 age 7-10 years	Four Active Video Games (AVG) - bowling, tennis, boxing, and a dance game	Energy expenditure Upper limb muscle activations Upper limb kinematics Self-reported enjoyment	Portable cardiopulmonary testing unit Surface electromyography Optical motion capture system Physical Activity Enjoyment Scale
(Jannink et al., 2008)	A Pilot study	N = 12 mean age 11 years 9 months	The EyeToy-Play	User satisfaction Upper limb function	User satisfaction questionnaire The Melbourne Assessment of Unilateral Upper Limb Function
(Jelsma et al., 2013)	A single -subject single blinded study	N = 14 age 6-12 years	Playing Interactive video gaming (IVG) - Nintendo Wii Fit	Balance Running speed and agility	Bruininks-Oseretsky Test of Motor Proficiency-2 (BOTMP-2) Timed Up and Down Stairs (TUDS)
(Li et al., 2009)	Feasibility study	N = 10 age 6-8 years	A virtual reality therapy home-based system using a Sony PlayStation 2 equipped with an "EyeToy" video camera	Hand/arm movements: effectiveness (the extent to which the task is achieved), efficiency (the rate at which the targeted movements were achieved) Satisfaction (the attitudes toward the use of the system)	Quality of Upper Extremity Skills Test (QUEST) Questionnaire

Table 19: Overview of included articles IV

Art.	Article type	Population	Intervention	Measurements	Method of measurements
(Luna-Oliva et al., 2013)	A preliminary study	N = 11 age unknown	A videogame system based on non-immersive virtual reality technology (Xbox 360 Kinect™)	Motor and the process skills, balance, gait speed, running and jumping and fine and manual finger dexterity	Gross Motor Function Measure (GMFM) Assessment of Motor and Process Skills (AMPS) Gross Motor Function Classification System (GMFCS) Paediatric Reach Test (PRT) Jebsen Taylor Test of Hand Function (JHFT) 10-meter walk test (10MW)
(Peper et al., 2013)	A single-subject study	N = 6 age 7-12 years	Computer games involving simple perceptual goals, based on Lissajous feedback. Such feedback implicitly facilitates the performance of complex rhythmic bimanual coordination patterns.	Functional bimanual performance	Assisting Hand Assessment (AHA) Manual Ability Classification Scale (MACS)
(Qiu et al., 2009)	Clinical trial	N = 2 age 10 and 7 years	The NJIT-RAVR system - Integration of virtual reality (VR) with robot-assisted rehabilitation	Speed and accuracy of shoulder and elbow movements General upper extremity strength and reaching accuracy Upper extremity reaching towards a moving object Forearm pronation and supination during shoulder flexion and elbow extension in a three-dimensional space Upper extremity active range of motion and strength	Melbourne Assessment of Unilateral Upper Limb Function (MAUULF)

Table 20: Overview of included articles V

Art.	Article type	Population	Intervention	Measurements	Method of measurements
(Ramstrand, 2012)	A randomized cross-over study	N = 18 age 8-17 years	Nintendo Wii Fit (activity promoting computer game)	Standing balance Reactive balance Weight shifting ability (directional control and synchronization of movement)	The modified sensory organization test Reactive balance test Rhythmic weight shift test
(Reid, 2002b)	A pilot study	N = 4 age 8-12 years	Mandala gesture Xtreme technology - uses a video camera as a capturing and tracking device	Upper extremity control	Upper Extremity Skills Test (QUEST) Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) Average percent accuracy score
(Reid & Campbell, 2006)	A pilot randomized controlled trial	N = 31 age 8-12 years	Video camera tracking movements when playing different games	Quality of upper-extremity movement - dissociated movements Self-concept Functional self-efficacy	Quality of Upper-Extremity Skills Test (QUEST) Gross Motor Function Classification System for children with CP (GMFCS) Self-Perception Profile for Children (SPPC) Canadian Occupational Performance Measure (COPM)
(Rios et al., 2013)	Multiple case study	N = 4 age 8-13 years	NeuroGame Therapy using surface electromyographic (sEMG) signals routed through motivating computer games to improve motor control (visual/augmented feedback of sEMG provided through computer game)	Feasibility (hours of play) Specificity (changes in sEMG activity during game play) Changes in co-contraction Range of motion, segmental alignment, and spontaneous upper extremity function	Spontaneous Functional Analysis (SFA) Shriner's Hospital Upper Extremity Evaluation (SHUEE) Maximum Voluntary Contraction (MVC)

Table 21: Overview of included articles VI

Art.	Article type	Population	Intervention	Measurements	Method of measurements
(Rostami et al., 2012)	Single -blinded, randomized, controlled trial	N = 32 age 6-11 years	E-Link Upper Limb Exerciser System in the form of games such as soccer, hitting walls, space shooting, driving, and throwing balls into a bucket (modified constraint-induced movement therapy in a virtual environment)	Upper limb function	Paediatric Motor Activity Log (PMAL) Bruininks-Oseretsky Test of Motor Proficiency (BOTMP)
(Sandlund et al., 2011)	Feasibility study	N = 14 age 6-16 years	Eye Toy for Playstation 2	General motor performance Intensity of practice	Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) Movement Assessment Battery for Children-2 (Movement ABC-2) One Minute Walk Test Gaming diaries
(Tarakci et al., 2013)	Pilot study	N = 14 age 5-17 years	Nintendo Wii Fit	Postural stability The margin of stability Speed during functional tasks that potentially threaten balance Functional status	One leg standing test The functional reach test The Timed Up and Go test The 6-minute walking test
(Wade, 2012)	A randomized cross-over trial	N = 13 age 7-16 years	Computer games controlled using a sitting platform that can detect changes in the distribution of pressure	Sitting ability - shifting the centre of pressure	Chailey Levels of Ability (levels relating to box sitting) Sitting Assessment for Children with Neuromotor Dysfunction

Table 22: Overview of included articles VII

Art.	Article type	Population	Intervention	Measurements	Method of measurements
(Winkels et al., 2013)	An explorative study	N = 15 age 6-12 years	Nintendo Wii™ training	Upper extremity function Enjoyment in gaming	Melbourne Assessment of Upper Limb Function ABILHAND-Kids Visual analogue scale
(You et al., 2005)	Case study	N = 1 age 8 years	IREX VR therapy system (television monitor, a video camera, cyber gloves, virtual objects, and a large screen)	Cortical activation Upper limb coordination The amount of use and quality of movement of the affected upper limb during ADL Sensation, range of motion, reflexes, synergy, muscle strength, and movement speed	Functional magnetic resonance imaging (fMRI) Bruininks–Oseretsky Test of Motor Proficiency (BOTMP) The modified Paediatric Motor Activity Log (PMAL) questionnaire The upper limb subtest of the Fugl-Meyer assessment (FMA)

5 Findings

5.1 Motor Control and Motor Performance

Children with cerebral palsy (CP) have difficulty controlling and coordinating selective muscle activity. The incorrect phasing in and out of muscle activation, co-activation of agonists, and limited co-activation of antagonists is disrupted and leads to coordination, balance, and transfer deficits.

Howcroft et al. (2012) evaluated the potential of active video game (AVG) play for rehabilitation therapies in children with cerebral palsy (CP) through the level of muscle activation (quantifying upper limb kinematics) and quality of movement. 17 children with diplegia and hemiplegia in the mean age of 9,43 years played 4 AVGs (bowling, tennis, boxing, and a dance game). Only children who were categorized as level I or II on the Gross Motor Function Classification System (GMFCS) were eligible to participate to ensure standing position during play. The main outcome measure was the activity of wrist bundle. Wii bowling required the least wrist activity with lower degrees of extension, flexion, and lateral deviation than in Wii tennis and DDR. Wii boxing elicited higher angular velocities and accelerations for wrist movements compared with the other games. Elbow extension (of the dominant limb) was greatest during Wii bowling. Muscle activations did not exceed maximum voluntary contractions and were greatest for the boxing AVG and for the wrist extensor (WE) muscle group. Angular velocities and accelerations were significantly larger in the dominant arm than in the hemiplegic arm during bilateral play.

Table 23: Summary of AVG characteristics (Howcroft et al., 2012)

Game	Intensity of Physical Activity	Nature of Movements	Most Active Muscles (upper limb)	Movement Frequency	Therapeutic Goals
Boxing	Moderate	Bilateral	WE	High	- Wrist extension/flexion - Wrist medial/lateral deviation - High velocity movements - Hand-eye coordination
DDR	Moderate	Quadrilateral	WE	Low* to medium	- Primarily lower body (balance, strength) - Whole body coordination
Tennis	Light	Unilateral	WE	Medium	- Shoulder abduction/adduction - Wrist extension/flexion - Wrist medial/lateral deviation - Hand-eye coordination
Bowling	Light	Unilateral	WE	Low	- Shoulder flexion/extension - Elbow flexion/extension

*Low frequency is associated with beginner levels similar to those tested in this study.

The pelvis and trunk play an active role in gait and the good control of the movement of the core is a requirement for well controlled use of the legs and carry out activities of daily living. According to Barton et al. (2013), children with cerebral palsy often have reduced ability to modulate coupling between the trunk and pelvis. The study made in Liverpool, 2013 by Barton and colleagues was evaluating how pelvis to trunk coupling changed while playing a computer game driven by pelvic rotations. The participant was one 10-year-old boy with spastic diplegia, who trained for 6 weeks, twice a week for 30 minutes (13 sessions in total) on custom-made computer game. His GMFCS score of 1 indicates no limitations in transfers but speed, balance and coordination may be reduced. The aim of the game was to navigate a flying dragon in a virtual cave towards randomly appearing targets by rotating the pelvis around a vertical axis. Motion of the pelvis and trunk was captured in real-time by an optoelectronic system tracking three markers attached to the sacrum and thoracic spine. The results of measurements showed that coupling between the trunk and pelvis increased over game training and reaching to targets far from the midline required tighter coupling.

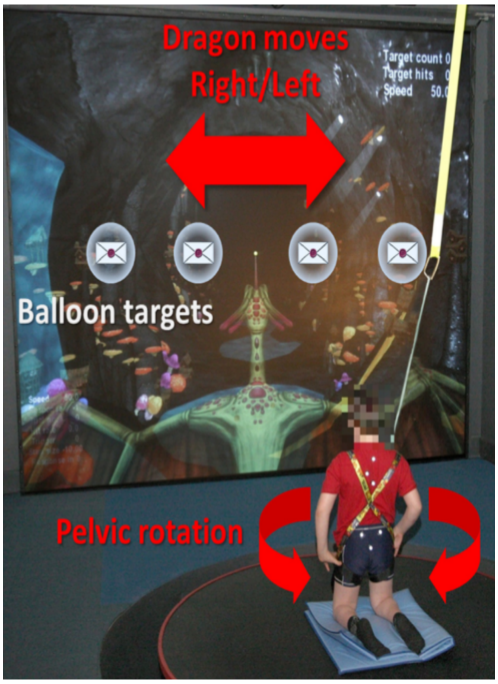

Figure 2: The Goblin Post Office Game (Barton et al., 2013)

The study made in Ottawa, 2006 by Bryanton et al. is focused on motor control and kinematics of ankle movement. The child with CP cannot appropriately contract the tibialis anterior muscle, creating functional problems such as the inability to achieve heel strike during gait. Ten children with CP (four male, six female; 7–17 years old), included eight children with spastic hemiplegia and two with spastic diplegia with Gross Motor Functional Classification System (GMFCS) scores of 1 or 2 were involved in this study. They were asked to complete ankle selective motor control exercises in a conventional manner and using a virtual reality system. Each participant completed one 90-min exercise session. The movement kinematics was recorded next to evaluation of the level of interaction with the system and interest or fun expressed during game play. The VR system, called IREX, consisted of a large television monitor, camera, and computer. The child saw his or her image as part of the virtual scenario on the large monitor and could interact with virtual objects in the environment. Two specific applications were created to elicit the ankle movements (dorsiflexion) in the virtual environment. During VR exercises, the children had to maintain ankle dorsiflexion at the maximal position in order to generate an action. Considering the conventional exercise, there was no task-oriented stimulus other than verbal instruction to hold the extreme position. The results of measurements using an electrogoniometer showed significantly greater mean ankle active ranges of motion into dorsiflexion during VR versus conventional exercise. With the VR exercises, the children had a goal to score, whereas with the conventional exercises, children received no feedback on ankle range.

One study found went further in exercising the ankle of children with CP. Burdea et al. (2013) combined robotics and gaming to improve ankle strength, motor control, and coordination in children with cerebral palsy. The design was a case study with 12 weeks of intervention (3 times/week = 36 rehabilitation sessions). The participants were 3 children with cerebral palsy, age 7-12 years. All children trained on the Rutgers Ankle CP system, playing two custom virtual reality games in sitting position. The Rutgers Ankle CP robot represents the interface that allows the patient to interact with the virtual environment by using the ankle movements. This study provides evidence that game focused on lower extremities improved gait function substantially in ankle kinematics, speed and endurance. Overall function (Gross Motor Function Classification Measure) showed improvements typical of other ankle strength training programmes.

Sandlund et al. (2011) investigated physical activity and motor performance during playing Sony EyeToy at home. The EyeToy for Sony's PlayStation is based on a video--capture technique that allows the child to watch himself/herself on the screen and interact with the virtual environment without having to wear any technical equipment. Whole body movements are involved with elements of hitting or avoiding virtual objects displayed on the screen but can also require the user to balance, jump or run on the spot. The games in general are enhancing overall gross motor physical abilities such as arm and leg coordination, eye–hand coordination, range of movement and balance.

Fourteen children with cerebral palsy (spastic, dykinetic and ataxic), age 6-16, were recruited for the study. The intervention lasted 4 weeks, playing at least 20 minutes/day. The children's physical activity increased during the game-play and according to Movement Assessment Battery for Children-2 (mABC-2) the children's motor performance improved. If the test scores were divided into sub-tests, however, only improvements in the sub-test' Manual dexterity' reached significance.

Luna-Oliva et al. (2013) made a study providing evidence about the usefulness of Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment. Eleven children with cerebral palsy were included in this preliminary study. The aim of the study was to evaluate motor and the process skills, balance, gait speed, running and jumping and fine and manual finger dexterity after 8 weeks of intervention, added to the participant's conventional physiotherapy treatment. The outcome measures showed improvements in balance and ADL within the Gross Motor Function Measure (GMFM) and Assessment of Motor and Process Skills (AMPS) test.

In addition, Gordon et al. (2012) were exploring the possibility of using the Nintendo Wii in rehabilitation process for children with cerebral palsy in a developing country (Jamaica, West Indies). The potential for an impact on their gross motor function was measured using the Gross Motor Function Measure (GMFM). Seven children, aged 6 to 12 years, with dyskinetic CP trained with the Nintendo Wii twice weekly for 6 weeks. The games used were Wii Sports Baseball, Boxing and Tennis. Results showed the improvement in the mean GMFM score that increased from 62.83 to 70.17.

5.2 Upper Extremity Motor Function

Cerebral palsy produces non-progressive motor dysfunction and multi-joint incoordination in both upper and lower extremities. An impaired upper extremity (UE) significantly affects activities of daily living such as eating, dressing and play in disabled children.

The basis of a larger scale randomized clinical trial was the pilot study made by Reid (2002b) in Canada. The author was investigating the feasibility of the Mandala Gesture Xtreme technology on 4 children aged 8 to 12 years with cerebral palsy (3 children with spastic quadriplegia, 1 child with spastic diplegia). The VR system used consists of a video camera as a capturing and tracking device to put the user inside VR experiences. One session a week was provided for 8 weeks. Each intervention session lasted 1.5 hours. The main outcome measure used was the Quality of Upper Extremity Skills Test (QUEST), and two other outcome measures were used: item #6 "touching a swinging ball with preferred hand" from the subtest #5 of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) and a measure of accuracy. Three participants demonstrated an improvement on the QUEST, and all the participants showed an improvement on the BOTMP item“ touching a swinging ball” at post-test.

The following 2-years study made by Reid and Campbell (2006) reports the use of virtual reality in changes of the quality of upper-extremity movement. Nineteen experimental and 12 control subjects at the age of 8-13 years with different muscle tone and GMFCS level were involved in 8 weeks of VR intervention (one session a week) – the Mandala Gesture Xtreme technology. Each intervention session was approximately 1.5 hours long. The dissociated movement domain of the Quality of Upper-Extremity Skills Test (QUEST) was used for measurement of motor performance. The trend was towards improvement, however the only significant change was for the social acceptance subscale as the part of self-efficacy investigation. The results did not suggest that VR is more effective for the quality of upper extremity function than regular intervention for children with cerebral palsy. The lack of findings could be due to the fact that the intensity of the VR intervention was not sufficiently powerful.

Hemiplegic cerebral palsy often results in impaired bimanual coordination, partially due to strong coupling between the arms. Peper et al. (2013) aimed at inducing more flexibility in this coupling, in a bid to improve bimanual coordination. Six children with spastic unilateral CP at age 7-12 years received 9 hours of computer training over a 6-weeks period. The authors designed computer games involving simultaneous asymmetrical movements of both arms, based on Lissajous feedback. Such feedback presents the relation between the movements of the arms in a single plot by displaying the oscillations of one arm along the horizontal axis and the oscillations of the second arm along the vertical axis. The author's final assumption was that training improves bimanual coordination even when feedback is removed and results in positive transfer to functional bimanual task. The transfer effects of the training were analyzed within the performance of rhythmic coordination patterns without the support of the Lissajous feedback. Both in-phase and antiphase coordination were examined. Moving with the maximum amplitude resulted in a clear improvement in antiphase performance of the upper extremities after the training, whereas this improvement was not observed for the trials oriented on performing the coordination patterns as fast as possible. The children also performed the antiphase pattern less stably than the in-phase pattern when moving fast. In addition, their arms were desynchronized, with the non-impaired arm moving faster than the affected arm, especially during antiphase performance. The Assisting Hand Assessment (AHA) was used to measure how effectively the children used their affected upper extremity while performing functional bimanual activities. Just two children showed significant improvements in AHA scores after the training period.

The feasibility study made by Qiu et al. (2009) provides evidence about the integration of virtual reality (VR) with robot-assisted rehabilitation in children with hemiparetic CP. Two children, a ten-year-old boy and a seven-year-old girl, both with spastic hemiplegia trained with the New Jersey Institute of Technology Robot-Assisted Virtual Rehabilitation (NJIT-RAVR) system for one hour, 3 days a week for three weeks. One participant demonstrated improvements in overall performance on the functional aspects of the Melbourne Assessment tool. The second participant showed improvements in upper extremity active range of motion and in kinematics of reaching movements.

A more recent study made by Fluet et al., 2010, at New Jersey Institute of Technology is suggesting the use of virtual reality in the form of virtual environment combined with an admittance-controlled robotic system that provides haptically rendered obstacles and spatial constraints such as floors and walls which allow for force and tactile feedback. This system elicits more complex, three-dimensional movements of the shoulder, elbow and forearm. The authors of the simulations focused on purposeful nature of activities utilized. Participants control a moving car, hammer pegs, transport objects, blow up moving targets etc. The study presented several activities aiming on different upper extremity functions such as speed and accuracy of shoulder and elbow movements, reaching toward a moving object, and quality of forearm supination/pronation. Nine children with hemiplegia were using the NJIT-RAVR System for 1 hour, 3 days a week for 3 weeks. This resulted in significant increases in active supination, which carried over into improvements in an active range of motion. Motor performance and motor control, measured using The Melbourne Assessment of Unilateral Upper Limb Function

Test, demonstrated statistically significant improvements. Grip and pinch strength increased, measured by dynamometry.

Green & Wilson (2012) were evaluating the use of tabletop workspace designed to improve upper-limb function. Four children aged 3 to 15 with hemiplegia participated in VR-based training, 30-minute sessions each week, over a period of three to four weeks. The task environment consists of a large horizontally-mounted LCD panel, a camera for visual tracking, graspable objects (or tangible user interfaces, TUIs, with passive marker, tracked by the stereocamera in 3D space). The child interacts with this system by moving the objects (the TUIs – graspable object) over and on the LCD surface. There were two main modes of user interaction: The first mode was goal-directed with tasks of graded complexity (placing the graspable object on a target). The second mode of user interaction was exploratory, using of abstract tools for individual composition with sounds and visual feedback ("painting"). This study provides some support for use of the RE-ACTION system in movement rehabilitation with children. Two children made progress across the system variables with some translation to daily activities. Results showed improvements in reaching and targeting, and grasp control (ability to grasp and release a block) which translated into daily activities, such as being able to open a door with hemiplegic hand, and increased independence and use of affected hand in bimanual activities. However, without more detailed motion analysis, it is unclear to which improvements in motor actions specifically. Performance of the other two children was more variable, depending on their cognitive disability.

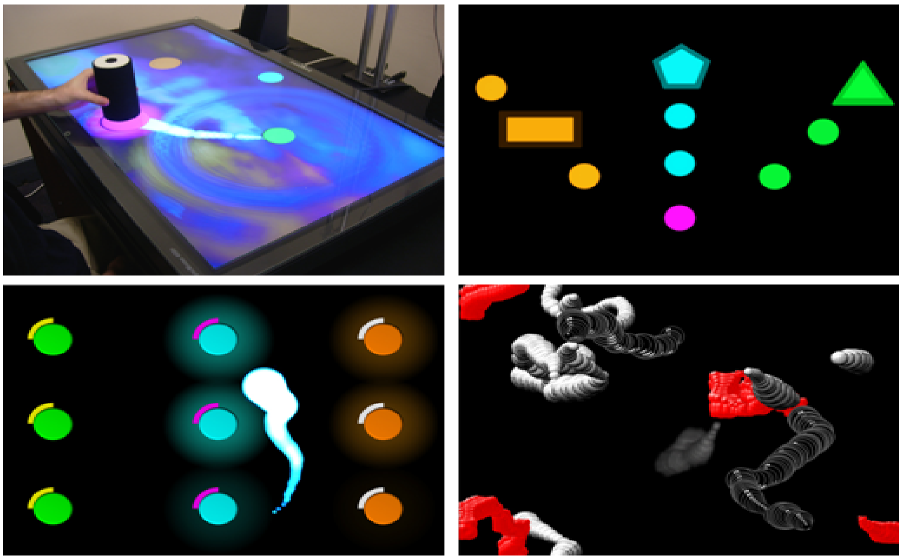

Figure 3: Tabletop Game (Re-Action System) (Green & Wilson, 2012)

Many children with CP may sustain dysfunctions in upper-extremity activities such as reaching, grasping, and manipulation. Reaching in children with CP is jerkier, slower, less forceful, and less straight, compared to children who are developing typically. Chen et al. (2007) investigated the training effects of a VR intervention on reaching behaviours in four children with spastic cerebral palsy (mean age was 6,3 years). The participants trained for 4 weeks (2 hours per week) with two virtual reality systems. The 2-hour intervention time was divided into 45 minutes for the VR-based hand rehabilitation training system and 75 minutes for the commercial VR system (Sony EyeToy). The VR-based hand rehabilitation training system consisted of a sensor glove and a 3-dimensional virtual environment with a corresponding hand displayed on the screen. This VR system could provide both auditory and visual feedback to the children. The commercial VR- system, called EyeToy, consisted of a camera tracking a whole--body movement. The authors picked games for EyeToy enhancing the goal-directed reaching behaviour. Measurements used in this study were reaching kinematics assessing mail-delivery activities in 3 directions, and a standardized fine motor assessment tool in the form of Fine Motor Domain (grasping and visual-motor integration) of the Peabody Developmental Motor Scales-Second Edition (PDMS-2). The training objective was to improve the qualities of reaching behaviours: to move in a faster, smoother, and straighter manner. The results demonstrated that 3 of the 4 children showed some improvement in the different kinematic parameters of reaching performance during the VR intervention. The VR systems used in the study allowed the children to practice reaching repeatedly in various directions and contexts, which resulted in improved quality of their reaching. Improvements on the PDMS-2 occurred in the visual-motor integration subtest. The items included in this subtest were activities related to eye-hand coordination.

Handwriting is a demonstration of fine motor skills that requires delicate motor control of small muscles of the fingers and accurate hand–eye coordination. One of the uncommon selected studies made in 2010 by Choi & Lo in Hong Kong was investigating the feasibility of force feedback as a guidance in computer-assisted training environment for improving Chinese handwriting ability of children with CP. Participants were two children at the age of 7 diagnosed with dystonia and dyskinesia, who took part in a 2-week study, two times a week. The training system provided visual and haptic cues during training session. Chinese handwriting is characteristic with different kind of strokes, more similar to little sketches or drawings. The subjects were able to reduce the writing time through repeated practice. The study showed promising results in decreased path length, improvement in fine motor control ability and handwriting accuracy. One subject showed slight progress in legibility, while both of them developed a better sense of the proper ways of handwriting.

Figure 4: The virtual hand rehabilitation system (Choi & Lo, 2010)

Jannink et al. (2008) measured the effect of the EyeToy training method on the upper limb function, as an additional measurement, next to the user satisfaction during the game play. Ten children with spastic CP (7 children with tetraplegia, 2 children with diplegia, 1 child with hemiplegia) in the mean age of 11 years and 9 months were randomly assigned to the intervention. Half of these children were in the control group. Functional outcome was measured using the Melbourne Assessment of Unilateral Upper Limb Function. Within different EyeToy minigames selected, patients had to make gross elbow and shoulder movements to“ touch” and manipulate the virtual objects on the television screen. The study showed that the EyeToy has the potential to improve arm function in children with CP. Of the five children in the intervention group, two children improved considerably on the Melbourne Assessment score after following only 6 weeks of EyeToy training with moderate intensity.

Another study focused on the feasibility of EyeToy-Play and its use for improvement in upper-extremity function was made in Canada by Li et al. (2009). The authors provide evidence about home-usability of the system. All the participants (mean age of 8 years) had hempilegic CP with varying fine motor skills. Supervised test sessions with five participants found that the system elicited targeted movements of the hemiplegic upper extremity, especially reaching activities. A further home-usability study with additional five participants showed that the intervention was an enjoyable way to practise hemiplegic arm movements at home. The participants were using the VRT-Home for 30 minutes per day for 10 days. As a result, the VRT-Home effectively provoked movements of the proximal hemiplegic upper extremity, including shoulder abduction and flexion, reach across midline, and elbow extension. Fewer targeted movements of the wrist, fingers, and thumb were observed.

The usability of the Nintendo Wii system on upper extremity function was investigated by Winkels et al. (2013) in the Netherlands. Fifteen children with hemiplegic cerebral palsy (age range 6-12 years) participated in this study. During six weeks, all the children trained twice a week with the Wii system, using their most affected arm. The results showed no significant change in the quality of upper extremity movements, while a significant increase of convenience in using hands/arms during performance of daily activities.

A highly unique research was recently carried out by Rios et al. (2013). The authors were examining the feasibility, specificity, and preliminary effectiveness of the NeuroGame Therapy (NGT) for improving wrist control in four children (aged 8-13 years) with hemiplegic cerebral palsy. Children completed a mean of 8.8 hours of NGT over 5–6 weeks. This novel approach uses surface electromyographic (sEMG) signals routed through motivating computer games to improve motor control of upper extremity. Augmented feedback was provided on appropriate selective muscle control. The amount of muscle activity necessary to control the game was manipulated by adjusting the amplifier gain of each muscle group in order to individualize treatment. Functional outcomes were measured secondary as follows: changes in co-contraction, range of motion, segmental alignment, and spontaneous upper extremity function following intervention. The data during game play show that the participants improved independent activation of their wrist flexors and extensors with an increase of the maximum voluntary contraction of wrist extensors. The intervention led to substantial increases in active wrist extension for 2 participants. The Shriner's Hospital Upper Extremity Evaluation (SHUEE) reflected improvements in alignment of the involved upper extremity and spontaneous upper extremity use for three of the participants.

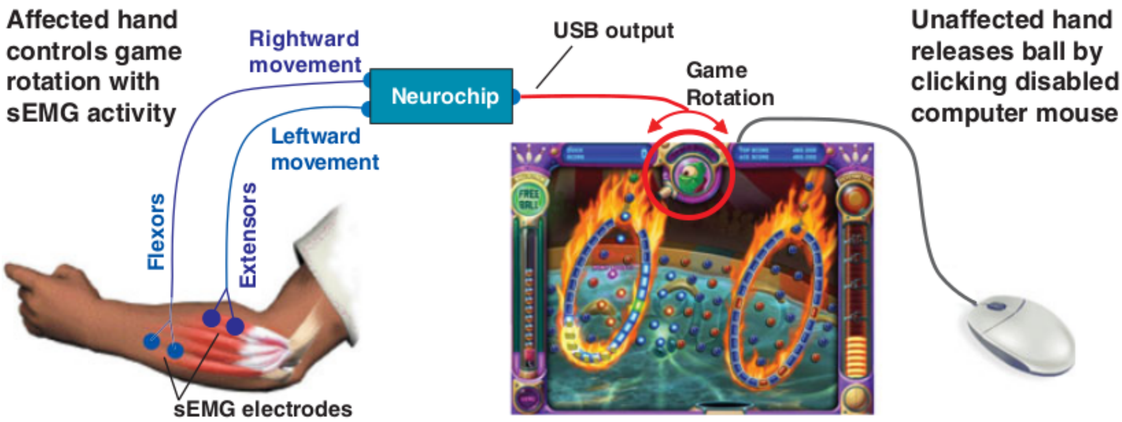

Figure 5: NGT interface (Rios et al., 2013)

The modified constraint-induced movement therapy (CIMT) uses massed repetitive practice and immediate rewards and feedbacks as positive reinforcement of the impaired upper extremity, and by negative experiences of the unaffected hand through immobilization tries to improve developmental disregard in children. Effect of the modified constraint-induced movement therapy in virtual environment on upper-limb function in children with cerebral palsy was investigated by Rostami et al. (2012). VR is capable to integrate the benefits of mass repetitive practice, motor imagery, and imitation learning. Thirty-two participants with spastic hemiparetic CP (age range 6-11 years) received 18 hours training in 3 different groups (virtual reality, the modified constraint-induced movement therapy, and a combination group). The fourth group was a control group. Training sessions were 3 times per week (lasting 1.5 hours) for 4 weeks. The intervention within the combination group (VR + CIMT) programme began with immobilization of the non-impaired hand one day before intervention to prevent performing daily activities with the involved side. Practice period was performed in the virtual environment similar to the VR group, but their unaffected hand was immobilized. The results showed improvements in the combination therapy group for the amount of limb use, quality of movement, and speed and dexterity of the affected limb in comparison with children who received the VR, the modified CIMT, or conventional movement therapies. The training effects were preserved after a 3-month follow-up period.

One selected study by You et al. (2005) investigated cortical reorganization and associated motor function of upper limb induced by the virtual reality therapy. The study is in the form of case report with an 8-year-old child with hemiparetic CP. The outcomes were measured before and after the VR therapy using functional magnetic resonance imaging (fMRI) and standardized motor tests. The IREX VR therapy system used as an intervention tool consists of a television monitor, a video camera to capture and track movement, cyber gloves, virtual objects, and a large screen. The intervention was given for 60 minutes a day, five times a week for 4 weeks. The child had no functional use of the affected hand before the VR therapy (according to the modified Paediatric Motor Activity Log – PMAL test score). The modified PMAL showed that the amount of use of the affected limb increased with improved quality of movement during functional motor skills (i.e. holding a book or shirt, washing face, and carrying an object). Fugl-Meyer assessment (FMA) showed improvement in active movement control, reflex activity, and coordination in the upper extremity motor performance. After the VR therapy, the Bruininks–Oseretsky Test of Motor Proficiency (BOTMP) item score improved from 1 to 5. Before the intervention, the bilateral primary sensorimotor cortices and ipsilateral supplementary motor area were predominantly activated during affected elbow movement. After the VR therapy, the altered activations disappeared and the contralateral sensorimotor cortex was activated. This neuroplastic change was associated with functional motor skills including reaching, self-feeding, and dressing. These findings suggest that the VR therapy could improve neuroplasticity by facilitating the neural motor pathways that have never been utilized.

Manual activities typically require co-operation of both hands, which tend to be specialized for different functions. Usually the non-dominant hand (NDH) holds the object in a stable position while the dominant hand (DH) acts upon it. In other words, the achievement of manual activities requires: a highly dexterous DH to perform both fine and gross manipulations, and a strong and an adequately dexterous NDH to ensure an adjustable stabilization of the objects. The therapist cannot assume that the reduction in hand impairments will result in a corresponding higher manual ability, therefore it is more important for the child to manage daily activities to be autonomous than to have“ normal” hand functions. A comprehensive intervention should always endeavour to improve manual ability by training the child to perform the daily activities that are limited. The therapist should teach the child to optimize the use of his or her existing hand functions in the management of meaningful activities (Arnould et al., 2008). Since reaching is involved in many activities of daily living, the focus of therapeutic treatment for children with spastic CP is to improve control of their upper extremities by practicing reaching movements (Odle, 2009). The therapist should enable the child to have an active role in finding adaptive strategies for the achievement of daily activities. The success of adapted strategies will depend on the integrity of both the dominant hand and the non-dominant hand, but also on children's adaptability, motivation, emotional control, cognitive skills, familial and social environment (Arnould et al., 2008).

5.3 Balance

Tarakci et al. (2013) evaluated the efficacy of the Wii-based balance therapy on balance functions. Fourteen children with cerebral palsy (7 diplegic type, 5 hemiplegic and 2 diskinetic) in the mean age of 12 years were included in this study. Exercises were performed two times a week for 12 weeks. Outcome tests were one leg standing, the functional reach test, the timed up and go test, and the 6-minute walking test. The intervention resulted in statistically significant improvements of balance ability in all outcome measures after 12 weeks.

Table 24: Outline of Wii-Fit exercise programme (Tarakci et al., 2013)

Parameter	Description
Ski Slalom	Ski Slalom elicits a lower limb balance strategy and improves loading of the lower extremities.
Soccer heading	This game improves movements of the trunk and extremities in a large spectrum of balance perturbations that vary in both amplitude and location of the destabilizing force.
Tilt Table	Tilt table elicits control over the whole body through dynamic balance training on a virtual balance board.
Walking a tightrope	Walging on the tightrope improves dynamic balance and trunk control through right and left transfer of body weight.

Unlike the above-mentioned research, another study from Sweden by Ramstrand & Lygnegård (2012) showed non-significant improvements in balance after playing the Nintendo Wii Fit. Eighteen children in the age bracket of 8-17 years with hemiplegic or diplegic cerebral palsy were involved in this study. The children were tested after five weeks of playing Wii Fit games (a minimum of 30 minutes a day, 5 days a week) and five weeks without any intervention. The aim was to evaluate the possibility of using the Nintendo Wii balance board and Wii Fit software as an unsupervised home-based balance-training tool. Effects on standing balance, reactive balance and lateral weight shifting ability were specifically investigated. The study showed no significant difference between testing after Wii Fit intervention and after weeks without any intervention. On modified sensory organization test when standing on an unstable surface with eyes open, a total of 6 falls were recorded before the intervention and 1 fall was recorded after five weeks of exposure to Wii Fit. No falls were recorded after 5 weeks without exposure to Wii Fit. When standing on an unstable surface with eyes closed, 26 falls were recorded before the intervention, 18 falls after 5 weeks of exposure to Wii Fit, and 20 falls were recorded after five weeks without exposure to Wii fit. The reactive balance test revealed no significant difference in onset latency of lower leg muscles following perturbations in different direction. The rhythmic weight shift test revealed that directional control did not significantly differ.

Jelsma et al. (2013) evaluated the effect of the Nintendo Wii Fit on balance control and gross motor function of children cerebral palsy. Fourteen participants in the age range of 6-12 years with spastic hemiplegic cerebral palsy were playing interactive video game (IVG) for 3 weeks instead of regular physiotherapy sessions. Outcome measures included modified balance and running speed and agility scales of the Bruininks--Oserestky test of Motor Performance 2 (BOTMP-2) and the timed up and down stairs (TUDS). The results showed that balances score improved significantly, whereas changes in the running speed and agility scales and the TUDS were not significant.

Many individuals with bilateral cerebral palsy, who spend most of their time sitting, experience difficulties maintaining their balance and carrying out postural adjustments in response to triggered perturbations. Wade & Porter (2012) investigated whether sitting ability could be improved through the use of computer games controlled by leaning in one of four directions in a seated position (a sitting platform that can detect changes in the distribution of pressure). Thirteen children (within the age range of 7 to 16 years) with bilateral CP participated in the study. Improvements were seen at some of the postural components of the Chailey sitting ability scale, specifically spinal profile and shoulder girdle position. This indicates that the participants were able to sit more upright and with shoulders retracted, which should help to facilitate better upper limb function. Proximal sitting stability during reaching and the overall quality of reaching were improved.

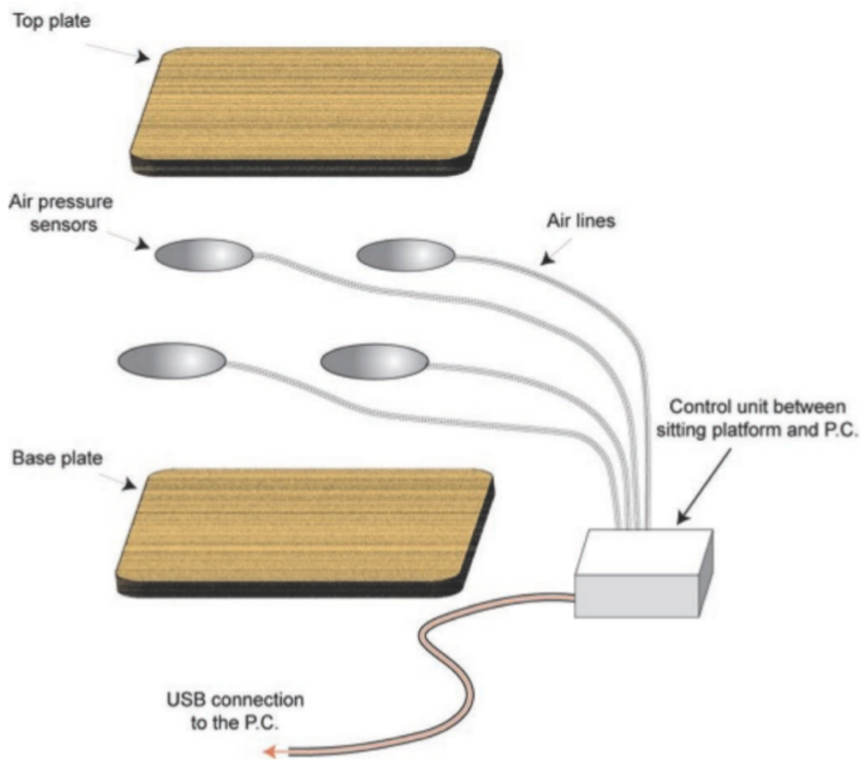

Figure 6: Schematic drawing of sitting platform (Wade & Porter, 2012)

6 Selected Reviews

Snider and colleagues (2010b) reviewed and analyzed 13 studies of VR training in CP. A search of thirteen electronic databases identified all types of studies examining VR as an intervention for children with CP. Studies were searched using the key words: tetraplegi*, spastic*, quadriplegi*, quadrapare*, pes equinus*, monoplegi*, little* disease, hypotoni*, hemiplegi*, hemipare*, dystoni*, diplegi*, dyskine*, choreoathe*, atheto*, ataxi*, cerebral palsy, VR, virtual environment, computer* game* and computer* simulation*. Only articles written in English or French were included and individuals aged 18 and younger were considered. Articles focused predominantly on individuals with stroke, traumatic brain injuries, physical disabilities or adults were excluded. The outcomes investigated in this review were categorized into the following: body functions (motor skills, quality of movements, visual-spatial skills); structures (fMRI); activities and participation (self-care and leisure activity performance, playfulness); personal factors (motivation, self-perception, self-efficacy). Thirteen studies from 11 articles were retrieved for the final analysis. The authors found conflicting but generally positive evidence that the VR therapy is effective in enhancing body structures or functions when compared to traditional or no intervention. Of the nine studies included in this review examining brain reorganization, motor skills or visual-spatial outcomes, seven indicated positive results in this area. Duration of treatment in the studies varied greatly, as well as the choice of outcome measures. All studies had small sample sizes, and in the two experimental studies, inconsistency at baseline between the intervention and control groups was not always considered. There was no strong evidence for increasing activity and participation. Overall, the majority of studies up to date (2010) were mostly observational or case reports with small sample sizes.

Wang and Reid (2010) reviewed the current status (up to date) and use of virtual reality (VR) for children with specific neurodevelopmental disorders including cerebral palsy. The authors formulated three major classes of human-computer interaction afforded by the display devices of the different VR systems: (1) feedback-focused interaction, (2) gesture-based interaction, and (3) haptic-based interaction. A literature search was conducted using the following databases: Scholar's Portal, Medline, Embase, AMED, Cinahl, IEEE, Biosis, Scopus, and Web of Science. The inclusion criteria were as follows: the publication year between 2000 and 2010 (up to date); the study using VR as a treatment tool; the study focusing on remediating the primary deficits of ADHD, autism or cerebral palsy; the study participants being children (aged 18 and under). A total of 20 articles were identified, 13 for cerebral palsy. For the category involving feedback-focused interaction, the authors have found integration of VR with other devices, such as treadmill training in virtual scenario resulting in increased walking speed; or combination of robotics and VR to lower-limb rehabilitation using the Lokomat System through Robotic Assisted Gait Training (RAGT). In the study found, the Lokomat System was used as a multidimensional feedback system during a virtual game of soccer. Gesture-based systems have been used exclusively to address primary deficits in children with cerebral palsy. Therefore, the results of searching turned out to be abundant. The authors found studies about using the Interactive Rehabilitation and Exercise System (IREX) to improve the upper-extremity functional deficits (4 studies). One study found investigatedthe customized Hands-Up system similar to the IREX programme which uses specialized tracking technology to capture the movements of specific parts of the body based on attached markers. The feasibility studies of the commercially available Sony Playstation 2 EyeToy were explored as well, resulting in 2 studies about their usefulness for upper-extremity rehabilitation. According to results, the authors stated that not all entertainment games have the capacity to elicit specific motor behaviours, because they were primarily designed for entertainment. The study evaluating the Wii system to improve posture and lower-extremity difficulties was found with reported improvements in postural control, functional mobility, and increased travelled distance. The studies engaged in gesture-based systems on upper-extremity rehabilitation were relatively consistent in using standardized measures of upper-limb function, such as the QUEST, BOTMP, and MAUULF. However, according to the authors of the review, functional assessment should also be included. The haptic-based interaction systems within a virtual environment were the third category of the review. One study describing the VR system designed specifically for hand rehabilitation using sensor glove was found. Another study went further and developed compatibility between the Playstation system and a customized sensor glove. The authors also found one study evaluating the integration of force-controlled haptic robotics within a virtual environment on improving the movements of the upper extremities.

Overall, the studies provided preliminary support for all three systems mentioned above. Nevertheless, stronger and large-scale comparison studies, with larger sample sizes, should be a requisite to determine the effect of VR. The outcome measures chosen for a study need to be consistent across studies, and a more holistic view should be considered. New tests should be described in a way that other researchers can use them. The studies included in this review focused mainly on the evaluation of discrete skills or motor behaviours, rather than functional activities that affect a child's quality of life.

7 Discussion

This thesis analyzes the available literature on the application of virtual reality in the form of gaming systems in children with cerebral palsy. Two databases (PubMed and CINAHL) were compared, the results explored and further divided under the exclusion and inclusion criteria. This resulted in 27 studies, including two reviews. Most of the studies were pilot studies or case studies with a small number of probands included in the research. The type of cerebral palsy involved in the studies was very variable, the authors often reported inconsistent sample and thus different movement capabilities and skills of disabled children. Most studies have examined the use of virtual system with spastic type of CP with different severity of motor impairment. The total number of participants in all studies was 257 ranging in age from 3 to 17 years.

The largest number of probands was included in a randomized-controlled trial measuring upper limb function (Rostami et al., 2012). Virtual reality in this study was used but only in the form of a virtual environment, and the actual intervention was the Constraint-Induced Movement Therapy. The authors often examined the applicability of gaming systems, such as Nintendo Wii, Sony EyeToy, Mandala GestureXtreme technology or IREX system, that have not been developed primarily for therapeutic purposes. The disadvantage or limitations of these applications is their relative rigidity, which does not allow individual adjustment to the needs of the affected individual.

The output data were mostly measured using standardized motor tests or questionnaires, which, although objectively evaluating the data, also reduce the assessment in the context of the tests. The results of the individual studies are described in the previous chapter, measurement methods in the table within the overview of selected articles. During this discussion, I would like to consider the application of virtual reality systems within the context of the motor learning and motor control theory, and also mention the possibility of using these systems for the treatment of other diseases or functional problems. The search was narrowed down to the application, particularly for neurological problems, although during the search for relevant information I found a number of studies examining the therapeutic use in other impairments.

7.1 Motor Control Theory

From the motor control point of view, we can discuss the feasibility of virtual systems from many standpoints. All of us are born with some skills and need only a little maturation and experience to produce those skills in nearly complete form. The performance of skills and the learning of skills characterize most of our lives as human beings. Children with cerebral palsy, as well as other motor disabled individuals, have different motor abilities and thus the capabilities of learning a new skill. Abilities are stable and enduring traits that are genetically determined and that underlie a person's skilled performance. Therefore, in disabled individuals this means their physiological and functional capacity to meet the goal of the task. When applying virtual reality, it is important to consider all those individual demands and individual differences to be able to provide accurate treatment. When considering the potential use of the VR systems, a therapist can use the notion of abilities to classify tasks according to the important abilities underlying task performance, and then design learning experiences that allow learners to capitalize on their stronger abilities and practice activities to compensate for their weaker abilities. Only a few custom-made games were developed following the actual physical state of disabled individual.

In the model of motor skill learning, the person begins to perform operations on information when he or she first receives it (input), continues to process the input using a variety of operations during several stages, and finally produces a response (output) (Schmidt & Wrisberg, 2000). Input is usually represented by a stimulus that is presented to the participant. The quality and quantity of stimulus is important in virtual reality gaming systems and their application, because a child reacts in response to that. Sensory information in the form of stimulus arises from several basic sources when playing the game. The game systems created for entertaining purposes are usually based on exteroceptive information, particularly vision. This can be provided via LTV screen where the child can see his/her avatar moving within the virtual environment. Transfer of movement is usually carried by the tracking video-camera technology (Sony EyeToy, Mandala GestureXtreme Technology, IREX system, Wii System) or using a special sensor glove or suit with sensors. The second major source of exteroceptive information is audition, or hearing. In the virtual reality systems included in this review, this modality is used as an additional source supporting the immersion. Nevertheless, audition can be an important source of sensory information for children with visual impairments.

More relevant for motor control is interoceptive information (proprioception), in virtual applications not commonly used. Some of the systems developed are using the haptic-based technology in a combination with visual information. The limitation for these systems is the requirement of additional equipment such as robotics, which is restricting for degrees of freedom and usually does not involve the whole body movement.

Sensory information should be considered also in terms of providing feedback during the learning experience. Summary feedback and average feedback (e.g., percentage score at the end of the game) are effective ways of providing learners with an optimal amount of information without creating feedback dependency. Feedback about features of movement pattern (e.g. timing or sequencing) leads to changes in the fundamental structure of the generalized motor programme (Schmidt & Wrisberg, 2000). All these facts about feedback provision can be used within virtual reality applications to stimulate the desired outcome.

After receiving an input, the decision-making is going through three information-processing stages. The first stage is stimulus identification. In the context of virtual reality environment, the child must have a sufficient level of cognitive ability to analyze the content of environmental information from a variety of sources listed above. Virtual reality is used for therapeutic purposes, because it allows performing the activities and movements that are impossible to be performed by a disabled child within the real world. Therefore, even though the identified stimulus might be similar to object in reality, the participant should be taught first about its characteristics in the context of virtual world. The second stage of information processing is response selection. The person must decide what, if any, the response should be. This stage depends on motor learning, memory, motivation, and experience. Therefore, the VR systems using the motivational tasks to stimulate the movement obtain more popularity among people playing them. The last stage is response programming – the motor system is organized for the production of the desired movement. These three stages of decision-making result in output (movement in real world projected in the virtual environment).

Children with cerebral palsy often have problems with decision-making in terms of reaction time (RT). This factor can be trained by increasing the number of stimulus-

-response alternatives or change of stimulus-response compatibility. Such a training results in faster and more automatic responses in the motor system.

Virtual reality as a therapeutic tool can be used either separately or as a possible supplement of the learning experience in the real world. The first decision concerning its application should be a goal setting. Goals that are challenging, attainable, realistic, and specific can have a beneficial effect on children's performance. Learners should be encouraged to set two specific types of goals. Performance goals are the goals that focus on a person's self-improvement relative to his or her own past performance (e.g., increasing percentage score). Process goals are the goals that emphasize particular aspects of skill execution (e.g., pumping the legs while running, keeping the head still during a golf swing, etc.) (Schmidt & Wrisberg, 2000). This knowledge can be transported in the application of virtual systems and their successful utilization. The therapist should consider whether the produced movement (outcome) is useful in terms of transfer of learning into the real world.

7.2 Application of VR Systems in Other Disabilities

Research into the use of VR for motor rehabilitation has primarily focused on its application with adults who have sustained strokes or other neurological impairments (Galvin & Levac, 2011b). Cameirao et al. (2010) described the design of the rehabilitation gaming system called Spheroids using video-tracking system for arm movements in stroke patients. Data gloves were used to detect finger movements. In the following study (2012), evaluating the feasibility of different interfaces on upper extremity functional recovery (vision-based tracking, haptics, and a passive exoskeleton), they observed that the beneficial effects of VR-based training are modulated by the specific sensorimotor information presented to the user, i.e., visual feedback versus combined visual haptic feedback (Cameirao et al., 2012).

Saposnik et al. (2010) evaluated the effectiveness of virtual reality using the Wii Gaming Technology in stroke rehabilitation. Outcome measurements showed significant improvements in overall motor performance and motor function, particularly upper--extremity function. Similarly, Mouawad (2011) investigated the Wii-based movement therapy on upper extremity function in post-stroke patients. An intensive 2-week programme resulted in significant and clinically relevant improvements in functional motor ability of upper limb.

Rand et al. (2009) investigated the effectiveness of VMall, a virtual supermarket on a video capture system as an intervention tool to treat the weak upper extremity of people with stroke. Motor and functional ability of upper extremity increased according to outcome measurement.

Turolla et al. (2013) examined the combination of conventional physiotherapy with virtual reality intervention, including a computer workstation connected to a 3D motion--tracking system and LCD projector displaying the virtual scenarios on a large wall screen, on patients after stroke. This system involved performing different kinds of motor tasks with the patient holding a real manipulable object in his/her hands while interacting with a virtual scenario. The improvement obtained in upper extremity function with VR rehabilitation was significantly greater than that achieved with the conventional therapy alone.

Hijmans et al. (2011) concluded improvements in upper-limb motor performance of adults with chronic stroke with repetitive, game-assisted, self-supported bilateral exercises. A movement-based game controller similar to the Nintendo Wii remote was used for intervention, incorporated into a handlebar, making bilateral exercises possible by allowing the unaffected side to support and assist the affected side.

Piron et al. (2009) investigated the use of telerehabilitation to treat motor deficits in post-stroke patients. A virtual reality-based system was delivered via the Internet, which provided motor tasks to the patients from a remote rehabilitation facility. This strategy showed promising results and the authors were considering it in terms of early discharge from hospital.

Another study tested the validity of virtual environment in stroke patients performing the task similar to real environment. Nevertheless, results between real-world and virtual-environment performance were not significantly different (Edmans et al., 2006).

Kizony et al. (2010) presented improvements in dual-task performance during locomotion using virtual environment in patients with chronic post-stroke. The participants were walking on treadmill while viewing a virtual grocery aisle projected onto a screen placed in front of them.

Robotics systems are often combined with virtual environment, as shown in the study by Merians et al. (2011) and Takahashi et al. (2008), who evaluated upper extremity gaming simulations using adaptive robots in patients with hemiparetic stroke. The results of the measurement demonstrated improved proximal stability, smoothness and efficiency of the movement path.

One study by Neil et al. (2013) was comparing the Sony EyeToy and Nintendo Wii and their implications for stroke rehabilitation with no significant differences found between the usability of the consoles. EyeToy elicited significantly greater activity than Nintendo Wii.

The retrieved studies were also investigating the effect of virtual reality on other diseases. Balance training in older fallers using VR system was described by Duque et al. (2012). This training resulted in improvement in balance parameters and significant reduction in falls. A custom-made system called Balance Rehabilitation Unit (BRU) was used for intervention. BRU is a method that combines variable somatosensory, visual and vestibular conditions, which are used to assess and train balance. The assessment component of the BRU is posturography. Older fallers were the aim group of randomized-controlled trial made by Mirelman et al. (2013), who investigated intervention that combines treadmill training augmented by virtual reality. The results showed reduced fall risk, improved mobility and enhanced cognitive function in a diverse group of older adults. The same type of participants was the aim group in a study by Rendon et al. (2012), the intervention was the Nintendo Wii Fit balance training and post-intervention measurement showed significant improvements in dynamic balance. The Balance Rebahilitation Unit was used for patients with Menière's disease (Garcia et al., 2013), showing positive results. A system based on the Nintendo Wii Balance Board, called eBaViR (easy Balance Virtual Rehabilitation), was used for training balance in individuals with acquired brain injury. Patients using eBaViR had a significant improvement in static balance compared to patients who underwent traditional therapy. Regarding dynamic balance, the results showed significant improvement as well (Gómez et al., 2011). Yen et al. (2011) in a randomized controlled trial evaluated effects of virtual reality–augmented balance training using balance board on postural control in people with Parkinson disease. However, no significant differences in postural control were found in comparison with conventional balance training. Nevertheless, the similar system was investigated in chronic stroke patients by

Cho et al. (2012) with significant improvements in the Berg Balance Score (dynamic balance). Kizony et al. (2005) used the GestureXtreme technology for providing some evidence about its usability in spinal cord injury (paraplegic patients). The results showed the potential of using this system as an additional tool during the rehabilitation for balance improvement. The effectiveness and satisfaction with a virtual reality-based balance rehabilitation system (BioTrak) was investigated by Lloréns (2013) on patients with acquired brain injury. The system is based on a tracking technology used in sitting and standing position. The results showed a high degree of usability in terms of presence, immersion and user-friendliness, as well as improvement in the Berg Balance Scale.

Resnik et al. (2011) considered using a virtual reality environment to facilitate training with advanced upper-limb prosthesis in patients with amputation. The authors suggested future use of this technology and believe that the value of virtual environment training for an upper-limb amputee is greater for those amputees who are obliged to master a greater number of controls.

An unusual study by Schmitt et al. (2011) examined the effects of immersive virtual reality as an adjunctive analgesic technique for hospitalized paediatric burn inpatients undergoing painful physical therapy. The results suggest that immersive virtual reality is useful for enhancing pain control during rehabilitation therapy in the paediatric burn population. Last but not least, adjunctive treatment with virtual reality demonstrated benefits, with better functional performance in patients undergoing cardiac surgery in a study made by Cacau et al. (2013).

In contrast to adults, children sustain brain injuries at a time when they are learning motor skills. Skills that have not yet been developed at the time of injury are at greater risk of delay. Although there are similarities in mechanism of injury between children and adults, the impact of age at injury and developmental stage means that rehabilitation strategies should vary to meet the developmental needs of each child (Galvin & Levac, 2011b). Research into motor assessment and interventions with adults does not necessarily transfer directly to children; for example, children may require adaptations of intervention in both content and intensity. Therefore, while the evidence for the use of VR in the rehabilitation of adults is promising, it is important to specifically investigate its use with children (Galvin & Levac, 2011a).

8 Conclusion

This thesis offers a brief overview of the literature describing the use of virtual reality for children with cerebral palsy. Since the technology and possibilities of virtual intervention are relatively unknown in the Czech Republic, all the studies included in this work are foreign, although I have found some attempts to analyze the selected gaming systems within the context of student's essays. None of them, however, has made any analysis and selection of the current available literature. A laboratory investigating 3D virtual reality for rehabilitation of patients with balance disorders has been established in cooperation with the First Medical Faculty (of the Charles University) and the Czech Technical University. Stabilometric platform (Nintendo Wii Fit Balance Board) and 3D projection using special glasses is a domain of this centre. Relevant research of its use has not yet been published. Information found on the website of the Technical University describes the quantification of the evaluation process of the project of rehabilitation of patients with balance disorders, which has been currently under way.

There might be several ways of explanation of the lack of use of this technology in the Czech environment. Physiotherapy at the Czech universities is more focused on the neurophysiological findings and their application in therapy. These methods can be easily applied with positive results, and do not require special equipment for their application.

Unfortunately, financial reasons may be singled out as another possible explanation for not using these technologies in rehabilitation care in our country. Healthcare has long been struggling with underfunding and although new technologies are widely used abroad, their implementation is expensive and probably would require additional sources of health-care financing.

While considering any future application, it would be necessary to promote in our country awareness of yet another aspect in terms of motor control and motor learning. Application of virtual reality lies on the borderline between physiotherapy and occupational therapy. And, seen in this light, greater cooperation of the occupational therapist and the physiotherapist is another vital prerequisite for outlining treatment plan and successful achievement of therapeutic goals when using virtual applications.

Writing this thesis has enriched my knowledge and brought an impetus for the possible future development of this subject in my further education or career. It was interesting to explore other parameters and deal with topics closely related to the overall function rather than individual movement components. If we cannot change the structure and the resulting disability, we should start with a task-oriented approach and change the external conditions to achieve the goal by influencing environmental constraints and task constraints. In children with cerebral palsy, virtual reality can be an ideal tool and a precursor before training in a real environment because it allows for easily changing the environment and the task within one system.

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