Motion interactive games for children with motor disorders

Motivation, physical activity, and motor control

Marlene Sandlund
To my family

“The whole is greater than the sum of its parts”

Aristotle (384 BC–322 BC)
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>7</td>
</tr>
<tr>
<td>SVENSK SAMMANFATTNING</td>
<td>9</td>
</tr>
<tr>
<td>ABBREVIATIONS</td>
<td>12</td>
</tr>
<tr>
<td>ORIGINAL PAPERS</td>
<td>13</td>
</tr>
<tr>
<td>PREFACE</td>
<td>14</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>15</td>
</tr>
<tr>
<td>Virtual reality</td>
<td>15</td>
</tr>
<tr>
<td>Virtual reality systems</td>
<td>16</td>
</tr>
<tr>
<td>Motion interactive video games</td>
<td>17</td>
</tr>
<tr>
<td>Virtual reality in rehabilitation</td>
<td>19</td>
</tr>
<tr>
<td>Virtual games and motivation for practice</td>
<td>19</td>
</tr>
<tr>
<td>Motion interactive games and physical activity</td>
<td>21</td>
</tr>
<tr>
<td>Motion interactive games and motor control in children with sensorimotor disorders</td>
<td>22</td>
</tr>
<tr>
<td>Cerebral palsy</td>
<td>23</td>
</tr>
<tr>
<td>Definition of cerebral palsy</td>
<td>23</td>
</tr>
<tr>
<td>Prevalence and classification</td>
<td>24</td>
</tr>
<tr>
<td>Theories of motor control in relation to cerebral palsy</td>
<td>26</td>
</tr>
<tr>
<td>Physiotherapy for children with cerebral palsy</td>
<td>28</td>
</tr>
<tr>
<td>My theoretical perspective</td>
<td>31</td>
</tr>
<tr>
<td>Rationale for the thesis</td>
<td>32</td>
</tr>
<tr>
<td>AIMS OF THE THESIS</td>
<td>33</td>
</tr>
<tr>
<td>Specific aims</td>
<td>33</td>
</tr>
<tr>
<td>METHODS</td>
<td>34</td>
</tr>
<tr>
<td>Systematic review</td>
<td>34</td>
</tr>
<tr>
<td>Literature search</td>
<td>34</td>
</tr>
<tr>
<td>Data extraction and rating</td>
<td>34</td>
</tr>
<tr>
<td>Intervention study</td>
<td>36</td>
</tr>
<tr>
<td>Participants</td>
<td>36</td>
</tr>
<tr>
<td>Intervention procedure</td>
<td>38</td>
</tr>
<tr>
<td>Quantitative methods</td>
<td>39</td>
</tr>
<tr>
<td>Qualitative methods</td>
<td>45</td>
</tr>
<tr>
<td>Ethical approval</td>
<td>46</td>
</tr>
<tr>
<td>RESULTS</td>
<td>47</td>
</tr>
<tr>
<td>Interactive games in motor rehabilitation for children, a systematic review</td>
<td>47</td>
</tr>
<tr>
<td>Motivation for physical training with interactive games</td>
<td>48</td>
</tr>
<tr>
<td>Influence on physical activity</td>
<td>50</td>
</tr>
<tr>
<td>Motion interactive games and motor control</td>
<td>51</td>
</tr>
</tbody>
</table>
ABSTRACT

As motion interactive games have become more widespread the interest in using these games in rehabilitation of children with motor disorders has increased among both clinical professionals and the families of these children. The general aim of this thesis was to evaluate the feasibility of using interactive games in rehabilitation of children to promote motivation for practice, physical activity, and motor control. A systematic review of published intervention studies was conducted to obtain an overview of existing research and the current levels of evidence for using interactive games in motor rehabilitation of children. Sixteen studies met the inclusion criteria, out of these three were randomized controlled trials while half were case series or case reports. Thirteen studies presented positive findings, which indicated a promising potential. However, more convincing research is needed.

Commercially available motion interactive games have only been used in a few studies on motor control, and in none of these home based practice was provided. Moreover, no earlier studies have evaluated if these games may increase motivation for training and daily physical activity among children with disabilities. To address these issues a feasibility intervention including 15 children in the ages 6-16 years and with mild to moderate cerebral palsy was conducted. Each child was provided with a Sony PlayStation2™ and the EyeToy™ games in Play3, and was recommended to practice with the provided games for at least 20 minutes/day during four weeks. The intervention was evaluated with gaming diaries, physical activity monitors (SenseWear Armband), interviews with the parents, and the clinical motor tests Movement Assessment Battery for Children-2 (mABC-2), Bruininks-Oseretsky Test of Motor Proficiency subtest 5:6, and the 1 Minute Walk Test. In addition, 3D motion analysis was used to evaluate effects on quality of goal-directed arm movements towards virtual and real objects, respectively.

Motivation for practice and compliance of training were high, although declining somewhat during the course of the four weeks. The children’s physical activity increased significantly during the intervention. However, four children were excluded from this analysis due to lack of complete data from the physical activity monitors. According to mABC-2 the children’s motor performance improved, but there were both floor and ceiling effects, indicating a low sensibility of this test. The two additional motor tests showed only non-significant progress. Results from the 3D motion analysis suggest that the children improved movement precision when playing the games, movement smoothness when reaching for real objects, and used a more economic reaching strategy with less trunk involvement. In the interviews the parents expressed the view that motion interactive games promote positive experiences of physical training and add elements of social interaction to the training. They also experienced
less urge to take on a coaching role. The training provided by the games was considered unspecific and there was a desire for individualized games to better address the unique rehabilitative need of each child.

In conclusion, it is feasible to use motion interactive games in home rehabilitation for children with cerebral palsy to promote short term motivation for practice and general physical training. Specific effects on motor control need to be further explored and there is also a need for reliable tests that are adequate and sensitive enough to capture changes in movement control. In future development of interactive games for rehabilitation purposes, it is a challenge to preserve the motivational and social features of games while at the same time optimizing an individualized physical training.
SVENSK SAMMANFATTNING


Den systematiska litteraturstudien genomfördes för att sammanfatta resultatet av de studier som publicerats inom området samt undersöka vilken evidens som fanns för att använda spel i tränning av barn med motoriska nedsättningar. Sexton studier som överensstämde med inklusionskriterierna identifierades. Av dessa var endast tre randomiserade kontrollerade studier medan hälften av studierna var okontrollerade studier eller fallbeskrivningar. På grund av dessa begränsningar klassades den rådande evidensen som låg men det faktum att 13 av de 16 granskade studierna visade på positiva resultat indikerade ändå en lovande potential och ett behov av mer forskning inom området.

Kommersiella rörelsestyrd spel har bara använts i ett fåtal av de studier som undersökt effekter på motorisk kontroll och i ingen av dessa erbjuds barnen träning i hemmet. Vidare har ingen tidigare studie undersökt hur kommersiella spel påverkar motivationen för tränning samt den fysiska aktivitetsnivån hos barn med rörelsehinder. För att adressera dessa aspekter genomfördes en studie där 15 barn mellan 6-16 år med cerebral pares av en mild till moderat form deltog. Barnen i studien försågs med det rörelsestyrdaspelet EyeToy® Play 3 för Sonys PlayStation2© och ombads att spela minst 20 minuter/dag under fyra veckor. Syftet med studien var att ur ett brett perspektiv undersöka om det är genomförbart att använda kommersiella spel som ett hemträningsprogram för barn med motoriska nedsättningar samt att informera framtida studier genom att undersöka lämpligheten i de utfallsmått som tillämpades. Interventionen utvärderades med hjälp av speldagböcker, aktivitetsmonitorer (Sense-Wear Armband), intervjuer med föräldrarna samt de motoriska testerna Movement Assessment Battery for Children-2 (mABC-2), Bruininks-Oseretsky Test of Motor Proficiency subtest 5:6 och 1 Minute Walk Test. I tillägg till detta undersöktes barnens rörelsekvalitet mer i detalj med hjälp av avancerad tredimensionell rörelseanalys. I dessa analyser studerades målinriktade armrörelser som utfördes mot virtuella objekt i ett interaktivt spel samt i en motsvarande uppgift med verkliga fysiska objekt som barnen sträckte sig mot.
Motivationen för spelträning skattades främst genom speldagböckerna där det dokumentrats hur mycket barnen spelat samt om de själva tagit initiativ till träningen. Resultaten visade att barnen i genomsnitt spelade ca en halvtimme 5-6 dagar i veckan och att de själva tog initiativet till träningen i en majoritet av alla speltillfällen. Detta tolkades som att barnens motivation för spelträningen generellt var hög men resultaten visade också på ett avtagande intresse under loppet av de fyra spelveckorna.

Data från aktivitetsmonitorerna visade att barnen ökade sin aktivitetsnivå markant under de veckor de hade spelet hemma. Den tillämpade aktivitetsmonitorn var lämplig och okomplicerad att använda för att skatta daglig energiförbrukning hos barn med cerebral pares, däremot missade några barn att använda mätaren periodvis under de aktuella mätdagarna. Detta orsakade komplikationer vid analysen där fyra barn måste exkluderas.

Av de motoriska testerna visade mABC-2 på en något förbättrad rörelsekontroll efter spelveckorna. Dessa resultat bör däremot tolkas med försiktighet då detta test resulterade i omfattande golv- och takeeffekter bland barnen, vilket också tyder på att mABC-2 inte är tillräckligt känsligt för att använda bland barn med cerebral pares även av märket grader. De övriga två motoriska testerna indikerade bara icke signifikanta förbättringar. Resultaten från rörelseanalyserna visade att barnen hade en högre precision i sina rörelser när de spelade spelet efter träningstidperioden samt jämnare rörelser när de sträckte sig mot fysiska objekt utanför spelet. I övrigt visade denna analys ett mer kontrollerat rörelsemönster där de förflyttade kroppsvikten mindre under armrörelser efter träning, vilket var speciellt markant vid rörelser med den icke dominanta armen. Det faktum att både virtuella och fysiska objekt användes i analysen av barnens rörelsekvalitet visade tydligt på viheten av ett noggrant val av kinematiske parametrar där den motoriska uppgiftens krav och begränsningar vägs in i analysen.


Sammanfattningsvis var det realiserbart att använda kommersiella rörelsestyrda spel som en motiverande form av generell fysisk träning i hemmet för barn med cerebral pares. Specifika effekter på motorisk
kontroll behöver undersökas vidare i framtida studier och det finns även ett behov av lämpliga och reliabla motoriska tester som är tillräckligt känsliga för att utvärdera effekter efter kortare träningsperioder. I utveckling och användning av spel för rehabilitering av barn är det extra viktigt att bevara spelens motiverande element samtidigt som möjligheter att optimera effekten av tränigen utvecklas.
## ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D</td>
<td>Three Dimensional</td>
</tr>
<tr>
<td>AACPDM</td>
<td>American Academy for Cerebral Palsy and Developmental Medicine</td>
</tr>
<tr>
<td>ADHD</td>
<td>Attention Deficit Hyperactivity Disorder</td>
</tr>
<tr>
<td>BOTMP</td>
<td>Bruininks-Oseretsky Test of Motor Proficiency</td>
</tr>
<tr>
<td>COP</td>
<td>Centre of Pressure</td>
</tr>
<tr>
<td>CP</td>
<td>Cerebral Palsy</td>
</tr>
<tr>
<td>CV</td>
<td>Coefficient of Variation</td>
</tr>
<tr>
<td>EE</td>
<td>Energy Expenditure</td>
</tr>
<tr>
<td>GMFCS</td>
<td>Gross Motor Function Classification System</td>
</tr>
<tr>
<td>GMFCS-E&amp;R</td>
<td>Gross Motor Function Classification System, Expanded and Revised</td>
</tr>
<tr>
<td>ICF</td>
<td>the International Classification of Functioning, Disability and Health</td>
</tr>
<tr>
<td>mABC</td>
<td>Movement Assessment Battery for Children</td>
</tr>
<tr>
<td>MACS</td>
<td>Manual Ability Classification System</td>
</tr>
<tr>
<td>MET</td>
<td>Metabolic Equivalent Unit</td>
</tr>
<tr>
<td>RCT</td>
<td>Randomized Controlled Trial</td>
</tr>
<tr>
<td>SDT</td>
<td>The Self-Determination Theory</td>
</tr>
<tr>
<td>SWA</td>
<td>SenseWear Armband</td>
</tr>
<tr>
<td>VR</td>
<td>Virtual Reality</td>
</tr>
</tbody>
</table>
ORIGINAL PAPERS


III Sandlund M, Dock K, Häger C, Lindh Waterworth E. Motion interactive video games in home training for children with cerebral palsy: parents’ perceptions. (Conditionally accepted for publication in Disability and Rehabilitation).


Original papers have been reproduced with kind permission from the publishers.
When I first started to work as a physiotherapist in the mid 1990s we still used a typewriter for all patient documentations. I remember thinking that a computer would have been a tremendous asset. This was not such a long time ago but nevertheless we can hardly imagine our world without computers and the internet today. About this time I began to gain interest in the various benefits of information technology, an interest that eventually ended up with a master's degree in informatics. During my studies I started to recognize the advantages of combining my experiences from rehabilitation with knowledge in human-computer interaction. In research, I saw the perfect opportunity to combine my two professions in studies on how interactive techniques may be used to enhance rehabilitation. This is how my journey with this thesis began.
INTRODUCTION

During the last decade many health professionals and parents have discovered motion interactive games and their potentials for use in rehabilitation of children.\(^1\)\(^-\)\(^2\) It is not unusual that paediatric clinics in the search for fun and engaging rehabilitation methods consider to, or already have started to, use these games in their activities. However, research on the topic is still rather limited, especially regarding the utility and use of commercially available low-cost games. The primary focus of this thesis was to review research related to this area and to explore the feasibility of using motion interactive video games in a home based intervention for children with motor disorders. The population targeted in the intervention was children with cerebral palsy (CP), which is the largest diagnostic group treated in paediatric rehabilitation.\(^3\) The research projects that form the basis for this thesis have been implemented in a close collaboration between the Division for Physiotherapy and the Department of Informatics at Umeå University.

Motion interactive games can be considered a form of virtual reality (VR). Although VR is often associated with advanced forms of technique it is actually less complex systems that are most frequently applied in motor rehabilitation.\(^4\) In the following sections I will start to define the concept of VR by providing a short historical flashback and an introduction to various forms of VR systems, in particular motion interactive games. This part is followed by an introduction to VR applications used in rehabilitation and a brief review of studies examining the use of games to promote motivation for practice, increase physical activity, and enhance motor control in children. The subsequent sections deal with cerebral palsy, definition, prevalence and classifications. I will also briefly describe prevailing theories of motor control and current physiotherapy treatment for children with cerebral palsy. The introduction ends with a glance into my theoretical perspectives and the rationale for this thesis.

Virtual reality

Virtual reality is in a broad interpretation described as an advanced form of human-computer interaction which allows the user to be part of and interact with a computer generated environment. The key feature that distinguishes virtual environments from other forms of visual imaging, like video or television, is real-time interaction. However, the interaction can be achieved in various ways. In basic systems devices like a computer mouse or a joystick can be used, in other more advanced systems the user can interact with the virtual environment in a more naturalistic way merely through body movements.\(^5\)
Virtual reality has its roots in arts and theatre and huge 360-degrees art murals painted centuries ago can be considered early foretastes. As a technology VR appeared for the first time in the 1950s with a theatre machine called Sensorama. This machine, developed by the cinematographer Morton Heilig, was constructed to address all senses. Sensorama combined projected film, audio, vibration, wind, and odours, all to make the user feel as if they were actually being in the film rather than simply watching it. For example, one experience provided was driving a motorbike on the streets of New York. Heiligs initial work was continued in the 1960s by the computer scientist Ivan Sutherland who developed one of the first head-mounted displays (HMDs), which allowed users to be immersed inside a virtual environment with computer-generated scenes. Although, compared to the technology of today both interface and realism were primitive, and the HMD was so heavy it had to be suspended from the ceiling.

The potential of VR was recognized by researchers from many fields and particularly military investments pushed the development forward. The following decades VR grew rapidly both regarding technological advancements and in areas of implementations. VR expanded from being associated purely with entertainment into serious simulators for the military and applications for education and medicine.

**Virtual reality systems**

Although it is difficult to categorize VR systems a traditional classification is according to the degree of *immersiveness* the system offers; from fully immersive to non-immersive or desktop systems. In the immersive systems the user is completely, or almost completely, surrounded by the virtual environment. These systems require special equipment enabling stereoscopic three dimensional (3D) images, such as HMDs, or large projection walls, which curves around the user producing a wide-angle view. Advanced forms can also include various devices for interaction like gloves or maybe even a whole body suit, and even haptic instruments with sensory feedback that provides the user with a sensation of actually touching the virtual objects. The key to immersive systems is that the individual is cut off from the ordinary reality and its sensory cues and is thus fully absorbed in the virtual environment, with most of the normal sensory input being replaced by artificial. Intuitively, fully immersive systems may seem best for rehabilitation but this may actually not be the case, in part because of practical issues like that immersive environments are more prone to generate cyber-sickness, but also due to the higher cost of the systems. On the other side of the continuum, the non-immersive systems requires less advanced hardware and is potentially more available for public use. The most common types display the virtual environment on a standard desktop monitor or TV-screen. In these systems normal sensory cues are not cut off and the user “remains” surrounded by the real
world. Interaction does usually occur by means of standard joysticks or a computer mouse, but non-immersive systems can also include more advanced forms of interaction like haptic devices and/or naturalistic gestures.

High immersive systems and HMDs are commonly associated with original forms of VR, but VR today is actually done mostly by using large projection screens or ordinary personal computers. Lately, many researchers have adopted a broader definition of VR where the degree of immersion, in terms of technological devices used and sensory modalities involved, may vary depending on the purpose of the application.

Common to all VR applications are interaction and various degrees of immersion. Together the level of immersion and interaction are important factors in establishing the degree of presence, which is the feeling of really being there in the virtual environment. Today, when various forms of video games have become the most widespread form of VR, immersion is often defined according to the human experience rather than the technology. Consequently, the distinction between presence and immersion has become more and more blurred. It has been argued that immersion in a gaming context corresponds to presence in a VR context, and that the intensity of immersion in video games is depending on how high the level of engagement is. An alternative model of immersion in games derived from interviews with children and their parents identifies three types of immersion: sensory; challenge-based; and imaginative. Sensory immersion is achieved by dominant sensory information from large screens and mighty sounds that overpower stimulus from the “real world” so that the gamer entirely focuses on the game. Challenge-based immersion is most powerful when there is a perfect match between the abilities of the player and the challenge of the game. Finally the imaginative immersion appears when the player identifies with game characters and becomes absorbed with the story line.

It has been suggested that movement-based interfaces has an influence on immersion since they offer the user a natural interaction. Body movements appear to help the gamer enter into the fantasy world of the game, achieve a feeling of presence, and become more engaged.

**Motion interactive video games**

In the last decade ordinary video games have increasingly started to use different forms of spatial tracking that allow users to interact with and control the gaming environment with movements of their body. At the time this thesis was written the most widespread examples of such platforms were EyeToy for Sony’s PlayStation and the later version Move for PlayStation (Sony Computer Entertainment Inc., Tokyo,
Japan), Kinect® for Microsoft’s Xbox 360® (Microsoft Inc., Redmond, Washington, USA), and Nintendo’s Wii® (Nintendo Inc., Kyoto, Japan).

EyeToy®, and Kinect® is based on video-capture technology which means that the user does not need any other game controller than naturalistic body movements. The user stands or sits facing the TV-screen where the virtual gaming environment is displayed. A video camera plugged into the gaming console is used to place a real-time image of the user inside the simulated environment where she can move around and interact with virtual objects. In some games, the user can see a full image of herself embedded into the virtual environment. In other games the image of the player is placed in a small window adjacent to the simulated environment and in yet other games the user is represented of an animated character, which is controlled by the movements of the player.14-15 (Figure 1).

Figure 1. Examples of different views: completely embedded into the virtual environment; embedded in an adjacent window; and represented by an animated character.

Video-capture technique based on a single camera, such as the EyeToy®, can only detect movements in one plane, usually the frontal plane. So even though the user actually moves in three dimensions the games can only capture two dimensions. This means that the games cannot distinguish movements that occur in depth.15 The Kinect® technology is somewhat more advanced than EyeToy®. Instead of just one camera Kinect® utilizes a sensor that also includes a depth sensor, which allows tracking in 3D.

With the gaming console Wii®, Nintendo has invented another approach to track movements of the user. This system uses a wireless controller with a combination of built-in accelerometers, gyroscopes, and infrared detection that makes it possible to track the position of the controller in 3D space and thus, the arm movement of its holder. The controller allows the user to play the game through both physical gestures and traditional button presses. The controller does also provide haptic feedback through vibration, which generates an impression of contacting virtual objects, although this sensation is not exactly as in real life.16, 17 When playing Wii® the user is represented in the virtual scenario by an avatar (a virtual
figure) whose appearance can partly be designed by the user. Sony’s latest contribution PlayStation Move® is a combination of the PlayStation3® system, video-capture technique and a motion controller. A sphere at the end of the motion controller is tracked by the camera which makes the tracking of the movements more precise in 3D space compared to in earlier PlayStation2® EyeToy®.

The interest for using VR technology and video games in health care is steadily increasing and to date applications of various forms and for a wide range of purposes have been applied.

Virtual reality in rehabilitation
The last decades the field of VR has grown immensely and the number of applications and types of platforms has expanded to the point where it has become increasingly difficult to track all new designs. Practical applications cover many fields from flight simulators for pilot education and military applications to industrial machine training, and medical purposes.4–15 Medical applications of VR started to take form in the early 1990s in order to make it possible to visualize large amounts of complex medical data for surgical planning, and image-guided navigation during surgical procedures.7 Since then VR has been successfully integrated into several areas of medicine and psychology as for example: training and education in surgical procedures;18 education of medical students;19, 20 assessment and treatment of mental health problems including phobias21 and post-traumatic stress disorders;22 pain management through distraction;23 and in motor rehabilitation4–24 where examples of explored areas are upper limb rehabilitation in persons with acquired brain injury;25 fall risk reduction in Parkinson’s disease;26 and particularly stroke rehabilitation.27, 28

When it comes to VR applications in motor rehabilitation of children the research area is growing but is still quite limited both in number of studies as in the quality of study designs.1–2, 29 Below follows a brief review of literature presenting work where virtual games of different kinds have been used to study motivation for practice, influence on physical activity, and motor control in children.

Virtual games and motivation for practice
The desire to invent rehabilitation methods that are motivating, fun and engaging is perhaps one of the best reasons to why an interest for games in rehabilitation has awakened. However very few studies have proven that games actually improves children’s motivation for practice, at least in the long run. The existing research about motivation for games in rehabilitation can be divided into two areas with different focus: to
explore aspects within games that stimulate motivation; or to concentrate on the experience of the player. A few studies of the later kind have looked at compliance in gaming interventions.

Motivational aspects of gaming has earlier been described in accordance with the self-determination theory (SDT) and has frequently also been related to the concepts of intrinsic motivation, presence, and flow. Intrinsic motivation, is based on the inherent satisfaction of doing an activity and is the core type of motivation in sports and play, and also relevant for digital gaming. According to the SDT, activities that support the basic human psychological needs autonomy, competence and relatedness will be experienced as joyful and motivate to further play. Autonomy is high when the player is in control, is allowed to make choices and is given non-controlling instructions. Feelings of competence is achieved if the player is optimally challenged. Competence is believed to be among the most important satisfactions provided by games and is often linked to the concept of flow. Flow is a feeling of being completely absorbed and in control of an activity and can only appear when there is a perfect match between the skill of the player and the challenges in the activity. Clear goals and immediate feedback is important factors for experiences of flow. Feelings of autonomy and competence are also believed to create a sense of presence, which further is connected to levels of engagement. The intuitiveness of the game controls is one aspect that has been suggested to influence the level of presence perceived. If the technology behind and the interface of the game is unobtrusive to the players they will most likely feel more present and engaged. The third psychological need relatedness is experienced when a person feels connected with others while playing. According to the SDT, interaction with others can support feelings of relatedness and consequently influence motivation and increase the likelihood of sustained engagement. Several studies involving children have concluded that playing together was more fun and motivating than playing alone.

A few studies have examined what characteristics of virtual games that will stimulate motivation and playfulness in children with CP. The gaming features that were considered positive for motivation were challenge, variability, and competition. Aspects of games that seemed to stimulate play and produced the highest ratings on the Test of Playfulness all allowed creativity, persistence with the task, pleasure, and a certain degree of control.

The experiences of the players are commented upon in most of the studies that have tested any form of virtual games in treatment of children. There are also a few studies that explicitly assessed short term motivation for therapeutic gaming and all came to the conclusion that children enjoyed the games and were motivated to play. However, very few studies have investigated how the motivation evolves over time when children are allowed to practice in their home or voluntarily in a clinical setting.
In one study 30 children with obesity who practiced with a dance game were followed over six months. Thirteen children reported that the dance game was boring within four weeks and from three months only two children practiced with the game twice a week. In another study obese children were offered to play motion interactive games at several predefined but optional daily sessions in a clinic during 12 weeks. After four weeks the median duration of use per participant was zero minutes and it remained so until week 12. Yet another study included 60 typically developing children who practiced with a dance game during 10 weeks. In this study playtime declined with 33% over the intervention period. Accordingly, it seems like children’s motivation for playing motion interactive games is transitory. In a focus group study, investigating the probability of sustained use, parents reported that although children initially enjoyed playing active video games the novelty of these games quickly wore off. The fading interest was mainly attributed to a lack of challenge in motion interactive games. Multiplayer sessions that add both challenge and competition to gaming have been seen to substantially improve motivation measured as dropout rate and minutes played among healthy children.

**Motion interactive games and physical activity**

High levels of screen-time like watching television, playing electronic games and computers, are generally associated with decreased physical activity and obesity. However, the new-generation active video games are considered interesting alternatives to passive games. Instead of competing against video game playing, which for children often is a valued activity, an appropriate strategy may be to replace passive screen-time with active. The number of studies investigating the use of motion interactive games to promote physical activity among children has increased rapidly the last years. Following this increased interest expressions like “exergaming” and “active video games” have been coined.

The effects of active gaming on physical activity have primarily been studied among healthy or overweight/obese children. No earlier studies have evaluated if these forms of active gaming can increase physical activity among children with disabilities, but one cross-sectional study have investigated effects on energy expenditure (EE) among adults with CP when playing Wii-sports.

Several studies have compared EE measured with indirect calorimetry or by an activity monitor during play of different motion interactive video games to EE during other activities of various physical exertions. A general conclusion achieved was that active video games generates higher EE compared to rest and sedentary screen time activities but not as high EE values as performing the corresponding real activity in itself.
A common way to compare activity levels is by metabolic equivalent units (MET). MET is a physiological concept expressing the energy cost of physical activities and is defined as the ratio of metabolic rate during a specific physical activity to a reference rate of the metabolic rate at complete rest. Thus 1 MET corresponds to the metabolic rate while at complete rest and 2 METs represent a doubling of the energy consumption. A common grading of physical activity according to METs is: sedentary (<3METs); moderate (3-6 METs); vigorous (6-9 METs); and very vigorous (>9 METs). MET values above these are generally considered the cut-off for being physically active. Playing motion interactive games has been found to increase EE to light or moderate levels around 3 METs, similar to brisk walking, skipping, jogging or stair climbing. Sustained vigorous activity above 6 METs is generally not obtained during play. Energy expenditure during play is also highly variable depending on engagement and type of game played. Games that rely primarily on upper body movements generate lower EE compared to games that engage the lower body and even higher values are achieved when whole body movements are required. A few intervention studies have evaluated effects on physical activity in home use and/or long term use of active video games. The general conclusion was that active games can provide a moderate increase in physical activity and decrease sedentary screen time. Home based interventions have ranged from 10-28 weeks in duration so the effects of long term use of active games are uncertain. Several studies did also report a decrease in playtime during the intervention.

In summary the evidence seems to support the use of active video games as an enjoyable medium for self-directed physical activity of light to moderate intensity. Playing active video games should not be considered as a replacement of vigorous sport activities but rather as a possibility to convert time spent on passive/sedentary gaming to more active routines. A question that still remains is whether playing motion interactive games can generate sufficient EE to reach public health recommendations.

Motion interactive games and motor control in children with sensorimotor disorders

Children with CP is the most commonly involved population when motor rehabilitation using motion interactive games have been studied. Positive influences on motor control have also been found in for example children with down syndrome, attention deficit hyperactivity disorder (ADHD), and acquired or congenital upper limb motor deficits. Quality of movements have also been studied in typically developing children with our without previous game experiences. Arm- and hand control is the most targeted area studied.
When we planned the research projects for this thesis no systematic review regarding interactive games in rehabilitation of children had been published. Therefore, one of the aims in the present thesis was to systematically examine the evidence for the application of interactive computer play in rehabilitation of children with sensorimotor disorders. Extended results from intervention studies in this area are presented in the result section.

Remarkably, to date only two studies conducted have provided home based gaming practice.61, 67 and low-cost commercially available motion interactive games have been used in very few studies.16, 40, 68 There is thus clearly a need to further investigate if commercial low-cost games are feasible to use in home rehabilitation of children.

Cerebral palsy

In most European countries children with CP are the largest diagnostic group treated in paediatric rehabilitation.3 Therefore children with CP were the targeted population for the intervention project in this thesis.

Definition of cerebral palsy

Cerebral palsy is an umbrella term which is used to define a group of closely related conditions that are caused by an injury to the immature brain. However, there is a large heterogeneity in both manifestation and causes to the condition. The diagnosis of CP is primarily based on clinical assessments and observations and not on laboratory testing or neuroimaging.72, 73 To find an accepted international definition of CP have been somewhat a challenge, but the proposed prevailing international definition today reads.

“Cerebral palsy (CP) describes a group of permanent disorders of the development of movement and posture, causing activity limitation, that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, perception, cognition, communication, and behaviour, by epilepsy, and by secondary musculoskeletal problems.”74

Cerebral palsy is a non-progressive condition meaning that the brain damage occurs either prenatally, during birth or during the first two years of life. The brain injury are presumed to arise from one single, or discrete series of events, and can for example be caused by birth defects, infections...
or disorders of brain blood circulation.\textsuperscript{74} Although the underlying abnormality of the brain is permanent the clinical picture of CP can evolve over time and change with development, learning, and therapies etc.\textsuperscript{74, 75} Abnormal motor functioning causing activity limitations are core features of CP.\textsuperscript{74} However, the degree of motor capabilities varies between children from those with only mild problems with hand and/or foot function to those that are fully incapable of controlling their movements. In addition to disorders of movement and posture, about half of the children with CP have one or several other neurodevelopmental disorders.\textsuperscript{74} Learning disabilities have for example been reported in 40\%, epilepsy in 35\%, visual impairments in 20\% and infantile hydrocephalus in 9\%. Children with severe degrees of CP are more often affected by additional diagnoses.\textsuperscript{3, 76}

Prevalence and classification

In western countries CP is the most common disorder that severely impair motor function in children.\textsuperscript{3, 72} The prevalence ranges between 1.5-2.5 per 1000 live birth.\textsuperscript{77} The prevalence has been stable for decades except for children with very low birth weight and very preterm infants. Among these children the occurrence increased with advancements in perinatal and neonatal intensive care but started to decrease again during the 1980s.\textsuperscript{3, 78} In Sweden the crude prevalence has been reported to be 2.18 per 1000 live birth,\textsuperscript{78} and about 250 children are diagnosed with CP each year.\textsuperscript{79}

All children with CP have difficulties with control of muscle tone. They may have increased muscle tone, reduced muscle tone, or a combination of the two. The most common neurologic abnormality in CP is spasticity, which is defined as a velocity dependent resistance of a muscle to stretch, a resistance that increases with increasing speed of stretch or rises rapidly above a threshold speed or joint angle.\textsuperscript{80} A classification of CP types, based on the nature of the movement disorder and the typographical distribution, has been established by the Surveillance For Cerebral Palsy in Europe (SCPE).\textsuperscript{81}

\textit{Spastic CP}: This form is characterized by at least two of the following symptoms: abnormal pattern of posture and/or movement; increased tone; pathological reflexes. Spastic CP is classified as either unilateral or bilateral. \textit{Spastic unilateral CP} is diagnosed if limbs on one side of the body are involved. \textit{Spastic bilateral CP} involves limbs on both sides of the body.

\textit{Ataxic CP}: This kind is characterized by both abnormal pattern of posture and/or movement and loss of systematic muscular coordination resulting in movements with abnormal force, rhythm, and accuracy.
Dyskinetic CP: This type is dominated by both abnormal pattern of posture and/or movement and involuntary, uncontrolled, recurring, occasionally stereotyped movements. Dyskinetic CP may be either dystonic (reduced muscle activity and usually increased muscle tone) or choreo-athetotic (increased muscle activity with involuntary, purposeless movements, especially in the face, arms, and trunk and usually decreased muscle tone).

The prevalence of CP types has been reported in a recent Swedish study of children born during the period 1999-2002. The unilateral spastic forms accounted for 38%, bilateral spastic CP for 39%. Ataxic types were only reported in 5% and dyskinetic CP in 17% of all children diagnosed with CP.78

In addition to the classification described above it is also recommended to classify the level of functional severity and activity limitation among children with CP. For this purpose the Gross Motor Function Classification System (GMFCS) has been widely employed.82 The GMFCS defines gross motor function of children and youth with CP in a five-level classification system based on children’s self-initiated movement with particular emphasis on sitting, walking, and the need for assistive devices. The system emphasizes clinically meaningful differences and to a lesser extent the quality of movement. The GMFCS has recently been revised and is now expanded to include also an age band four youth 12-18 years of age, GMFSC-E&R.83 The general headings of each level in GMFCS-E&R is presented in Table 1. Distinctions between the levels and the different age bands are further specified in the manual.83 The interrater reliability and the test-retest reliability of GMFCS have both been reported to be high with a generalisability coefficient of 0.93 and 0.79 respectively. In addition have the positive predictive value of the GMFCS at 1-2 years of age to predict walking ability at 6-12 years been reported to 0.74 and the corresponding negative predictive value to 0.90.84 Even GMFCS levels reported by parents agree well with levels assigned by therapists.85,86 The distribution of children with CP at different GMFCS levels have been reported as 32% at level I, 29% at level II, 8% at level III, 15% at level IV, and 16% at level V.87

Table 1. General headings for each level in the Gross Motor Function Classification System-E&R. Cited from Palisano et. al. 2007.83

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level I</td>
<td>Walks without Limitations</td>
</tr>
<tr>
<td>Level II</td>
<td>Walks with Limitations</td>
</tr>
<tr>
<td>Level III</td>
<td>Walks Using a Hand-Held Mobility Device</td>
</tr>
<tr>
<td>Level IV</td>
<td>Self-Mobility with Limitations; May Use Powered Mobility</td>
</tr>
<tr>
<td>Level V</td>
<td>Transported in a Manual Wheelchair</td>
</tr>
</tbody>
</table>
Besides gross motor function a comprehensive description of an individual with CP would also include a report of upper extremity and fine motor function. For this purpose the Manual Ability Classification System (MACS) is often used. The MACS has been developed to classify how children with CP usually use their hands when handling objects in daily activities. The classification rates manual ability in five levels. Children at level one handles objects with ease and success but can have limitations in performing manual tasks that require speed and accuracy. Children at level five cannot handle objects at all and requires total assistance. Because MACS is more an appraisal rather than a single test, determination of the level must be done by asking someone who knows the child. Parents, teachers or the child itself could be asked. The system have demonstrated good validity and reliability with an intraclass correlation coefficient between therapists of 0.97 and between parents and therapist of 0.96.88

Theories of motor control in relation to cerebral palsy

An awareness of our perceptions about motor development and motor control theories may increase our ability to be creative in developing new and innovative treatment strategies. In paediatric physiotherapy many ideas and principles of treatment have, over the years, been derived from research conducted within areas of motor control. During the 1930s and 1940s a number of researchers were engaged in work to identify children’s normal motor development (eg Mary Shirley, Arnold Gesell, Myrtle McGraw, and Nancy Bayles). Theories formulated during this time expressed the view that children’s motor development can mainly be explained by maturation of the nervous system, while environmental factors are subordinate. A common assumption during this period was that movements of the small infant is dominated by primitive reflexes and only as the nervous system matures, more complex movement patterns can gradually unfold. During this time it was also a common belief that children first learns to control the proximal parts of the body as the trunk, shoulders and hips, and only when having these under control learns to control the hand and foot.79

About the same time Karel and Berta Bobath introduced the Bobath approach also known as the Neuro-Developmental Treatment (NDT) that has largely influenced management of children with CP. The NDT is based on a neuro-maturational, hierarchical view of development and the belief that “normal” movement patterns are best for the child. Through handling and positioning the approach aims to inhibit primitive postural patterns and reflexes and facilitate normal movement patterns. Children are discouraged from performing activities that use abnormal movement patterns even if these appear to be functional for the child. The method stress the need for proximal control and to a lesser extent deals with
training of hand function and mobility. The NDT has been criticized for its emphasis on normalization and the quality of movements. However, the Bobath approach recognizes the importance of the child’s own activity, participation, and repetition for learning.79, 89, 90

In the mid 1900s the physiologist Nicolai Bernstein expressed a completely new approach to study the control of movement - the Systems Theory. He believed that it is impossible to understand the neural control of movement without understanding the characteristics of the whole moving system as well as the external and internal forces acting on the body. He showed that the same neural command could result in different actions due to differences in the system as a whole. Bernstein described the body as a mechanical system with many degrees of freedom that must be controlled during movements. He proposed that a hierarchical control exists to simplify the control of the body. In such a control higher levels of the nervous system can activate synergies of muscles that work together as units.91 At about the same time another researcher named James Gibson started to explore how our motor system uses purposeful perceptual information in interaction with the environment to perform goal-directed movements. This was the first time researchers focused on how actions require perceptual information relevant for the task, and how we use this information to control our movements.91

During the 1980s and 1990s a new interest in motor development research awoke partly due to the availability of new technologies that made it possible to analyze aspects of movements that are not visible to the naked eye (e.g. 3D motion analysis and electromyography). Since then many researchers have been working to develop an integrated theory, which encompass thoughts from several previous theories on motor control. One of the most influential is the Dynamic Systems Approach.92 The Dynamic System Approach emphasizes that each movement involves a variety of both intrinsic and extrinsic constraints that are relevant for motor control and development. For example, when an infant reaches for a toy the maturation of the nervous system, the weight of the arm, the child's ability to perceive the properties of the toy, the motivation for the task, and the surrounding environment are all factors involved. The child learns to master the task by repeated attempts and when she is able to perform it she will complete the movement relatively similar from time to time. However, if one of the factors changes then the child once again enters into an unstable phase, which requires additional practice. Such a change will for example occur when the child learns to sit without support. In this way, the child undergoes phases of stability and instability in which the transitions from one phase to another seemingly can result in poorer movement control. The Dynamic Systems Approach has helped to deepen our understanding of how motor development proceeds. The approach has also clarified the importance of the child's own activity. Necessary experience, with many repetitions is needed for a child to gain improved motor control, and coordinated movements can only evolve
when the child is allowed to explore its movement abilities in different situations. Thus, the best possibilities for motor learning is provided by active problem solving in an ecological setting where the child is inspired and motivated for the task so that many repetitions are performed. 79-93

Physiotherapy for children with cerebral palsy

Paediatric habilitation clinics in Sweden provide family-centred service where the family is seen as the most important entity in the child’s life. Parents are recognized as experts on their child’s needs and abilities and professionals are encouraged to work with them in partnership to address the family’s issues.94-97 In a family-centred service an interdisciplinary team is formed for each family. Since each child has a unique set of needs, the composition of the team must be flexible and can vary over time. The team usually includes a paediatrician, physiotherapist, occupational therapist, speech therapist, special pedagogue, psychologist, social worker, and a nurse. Together with each family the team makes an individual plan for treatment, advice, and support. The plan is based on the needs and interests of both the child and the family. The objective of the plan is to stimulate the child to mental, social and motor development, as well as to interaction, communication, learning, and play. The self-esteem of the child and ability to perform daily activities and participate in community life is important. It is also considered important to support and empower the whole family in their every-day life and work. The contact with the paediatric habilitation centre is often most intense during the first years of the child’s life.98

Children diagnosed with CP are a very heterogeneous group. Type of brain lesions, the severity of the symptoms, as well as additional disorders can be very disparate so every child needs unique treatment interventions. CP is considered characterized by a disorder in the supraspinal activation of motor units. The onset of motor unit activation is slow and the recruitment is prolonged which results in reduced movement speed and low levels of force production. This slow recruitment may also increase muscle co-contraction and thus further limit muscle coordination. Consequently, children with CP expend excessive energy to regulate movements.97 It has also been reported that children with CP have deficit in the anticipatory planning of movements. Anticipatory planning is the ability to predict the forthcoming motor demands in a sequential motor task and to make necessary regulations when for example reaching for and handling an object.99, 100

To overcome these problems children with CP needs a lot of movement practice. As earlier mentioned current motor control theories supports the importance of frequent and variable practice of motor tasks. This practice can be provided through activity-based interventions
incorporated into the child’s daily routines. At early ages, such ecological strategies are commonly applied. Functional task are practiced in a natural setting to promote better functioning in the contexts of daily life. By taking advantage of everyday situations as the child plays, eats, and dressed just the right challenge that stimulates the child to active practice can be created, and the high number of repetitions needed for motor learning can be achieved. In this way, learning can also occur without the child actually feels like training. Most of the physiotherapy training is thus home based and conducted by the parents. The physiotherapist will primarily serve as a tutor and counsellor for the parents and for staff when the child attends preschool or school. The physiotherapist does also regularly control how joints and muscles develop for the timely detection of problems that require treatment. In Sweden children with CP are generally part of The Swedish National Health Care Quality Program for Prevention of Hip Dislocation and Severe Contractures in Cerebral Palsy (CPUP). This register and health care program for children with CP was established in Sweden in 1994. The main aim of CPUP is to prevent hip dislocation and severe contractures. Additional goals are to describe the course of functioning and development in CP, to evaluate treatment methods and increase cooperation between health care professionals. Twice a year the child’s local physiotherapist and occupational therapist fill in an assessment form including CP-subtype, GMFCS, MACS, measurements of passive range of motion, clinical findings, and use of orthoses and other treatments. The results are captured in a database, and the local health care team receives a report showing the child’s development over time. With this information, it is possible to detect deterioration at early stages in order to prevent the development of severe contractures, hip dislocations, and scoliosis. When needed periods of intensive training can be applied. To train intensively can be demanding for both children and parents, therefore intense training should be time-limited and the results always evaluated when the intervention is completed.

A family-centred approach can often serve as an effective framework for the care of children with CP. An increased parental participation in the planning and treatment may also contribute to increased well-being and satisfaction with rehabilitation services. On the other hand, parents to children with CP do already cope with a higher burden of care giving demands compared to parents of typically developing children. Caring for a child with CP can affects a parent’s physical well-being, social well-being, freedom and independence, as well as family well-being and the financial stability. It has been reported that care giving demands and stress can strongly influence the psychological and physical health of caregivers to children with CP. To add further responsibility, as for example involvement in physiotherapy for their children, may become an extra stress factor that influence the health and well-being of the parents. It is important to reflect upon to what extent family-centeredness of services, is associated with better health outcomes also for the parents.
Therapy should, most favourable, be optimized to benefit both children and parents.107, 111

Two common goals of physiotherapy interventions for children with CP are to improve muscle strength and to optimize muscle length. A vast majority of children with CP have spasticity that needs management to prevent contractures, deformities and pain as well as to promote optimal function. Spasticity can be reduced by injections with botulinum toxin A in the spastic muscle,112, 113 which has proved to be especially successful when combined with training approaches.114, 115 Spasticity can also be treated by medications with Baclofen116, 117 or by selective dorsal rhizotomy.118 Additional treatment can include acupuncture,119 casting,120 orthoses,121 stretching,122, 123 and orthopaedic surgery.124 All treatment alternatives are preferable complemented with physiotherapy.

Reduced muscle strength is a contributor to decreased balance and coordination for children with CP. Earlier it was considered that strength training was not appropriate and would lead to increased spasticity.79 However, nowadays there is good evidence for positive effects of strength training in individuals with CP.125, 126 Specific training to improve hand function is often needed especially for children with unilateral spastic CP to prevent “learned non-use”. Besides daily functional practice, intensive interventions can encourage the child to start to involve the affected hand more in activities, and hopefully create a virtuous circle of sustained use. For these purposes Constraint-Induced Movement Therapy (CIMT) have gained in popularity and reported successful.127, 128 Together with other members of the team the physiotherapist is also working to empower the child in all areas of life to increase self-esteem, independence and participation. These efforts can involve adaptations of assistive aids, modifications of home and school facilities, and ergonomic adjustments. Therapists can also assist in finding suitable leisure time activities.79, 129, 130

Lately the participation of children with CP has gained increased interests among researchers. The literature to date suggests that children with CP are less involved in leisure activities compared to typically developing children.129, 131-134 Particularly the involvement in more active physical activities is considered to be low.132 Several studies do also confirm that children and adolescents with CP are less physically active compared to children without disabilities.135-138 This is a major concern since the level of activity in children may also predict the level of physical activity as an adult,139 that is inactive youth often become inactive adults and consequentially risk numerous health problems. Accordingly, there is a need to help children with CP to become more physically active in their everyday lives.140 However, level of gross motor function may influence activity levels and children at GMFSC level I appear to be as physically active as normally developing children.135 Physical activity is also related to age in the sense that activity decrease with higher ages.141, 142 There is a need for more research regarding effects of physical training programs for
children with CP. Such studies should also evaluate effects on activity, participation and quality of life.\textsuperscript{143}

**My theoretical perspective**

It is important to keep in mind that VR is not really a treatment in itself; rather, VR is a new technological instrument that can be applied for therapeutic purposes. But the success of VR systems in this aspect will depend very much on how familiar designers and developers are with concepts of motor control and learning as well as specific needs of the clinical population. This understanding is a key factor to designing appropriate therapeutic systems for successful implementations in rehabilitation settings. In addition, considerable engineering skills as well as knowledge about human-computer interaction is required to understand the potential capabilities of various technologies and to make the most of it in suitable applications. Thus, to achieve successful results, work within this area require collaborative efforts in an interdisciplinary team (e.g. physiotherapy, informatics, and engineering) Equally important is that children (the target group) and parents participate in the process as they are the real experts in the area.\textsuperscript{4, 144} The projects that form the basis of this thesis has been conducted in close collaboration with the Department of Informatics and to some extent with engineers and psychologists. Consequently, my theoretical framework when working with this thesis has included a variety of theories from different scientific fields. Although I do not intend to give a comprehensive list of the theories that have influenced me during this project, I will mention a few. Some of these theories have also been briefly described in this introduction. Being a physiotherapist I am of course influenced by theories of motor control and learning.\textsuperscript{145, 146} When dealing with motivational issues I have also been inspired by theories from the fields of human-computer interaction and psychology especially the theory of flow,\textsuperscript{33, 147} the concept of presence,\textsuperscript{5} play,\textsuperscript{148} and intrinsic and extrinsic motivation,\textsuperscript{31, 32} as well as the self-determination theory.\textsuperscript{30} My background in informatics have in addition contributed to that a user centred design philosophy,\textsuperscript{149} and iterative design methods\textsuperscript{150} have been central to this project.

It has also been my goal to mediate a holistic perspective on how games can contribute to rehabilitation of children. The World Health Organization's classification system, the International Classification of Functioning, Disability and Health (ICF) provides a common language for describing health, functioning, and disability. ICF encompasses most aspects of health; body structure, function, activity, and participation. It is intended to be a universal classification system, meaning that it covers all people, not just people with disabilities. ICF reflect the interactive relationship between health conditions and contextual factors. The model emphasize that the concept “disability” is a social construction involving
an interaction of the person and community or society, in contrast to that
disability resides just within the person. Thus, this “biopsychosocial”
model of disability encourages a more holistic approach to rehabilitation.
It’s not entirely about “fixing” impairments but to promote functional
activity and facilitate the child’s full participation in all aspects of life.
The biopsychosocial approach is consistent with family-centred care
for children with disabilities and has also been central to this thesis.

**Rationale for the thesis**

Ever since commercial motion interactive games have become more
widespread the interest in using these games in rehabilitation of children
with motor disorders has increased among both clinical professionals and
parents to these children. It is not unusual that paediatric rehabilitation
clinics consider to, or already have started to use these systems in their
activities. Perhaps the main reason for this interest is that games may
provide an opportunity to create fun and motivational forms of exercise.
The hope is also that games will stimulate the children to be active,
perform many repetitions, explore the limits of their abilities, and solve
motor problems. Accordingly, games may provide a training situation that
appeal to the prevailing theories of motor control and learning. In
addition, playing games that require body movements may also lead to
increased physical activity, another important goal for children with
disabilities. Nonetheless, there is no established evidence for the
effectiveness of such training. No earlier studies have evaluated if motion
interactive games may increase the daily physical activity among children
with disabilities. Moreover, commercially available motion interactive
games have been used in very few studies on effects on motor control and
none of these provided home based practice.

There is clearly a need for more research concerning commercial video
games in rehabilitation of children. But, before we can start to plan large
randomized controlled studies we need to explore if such games actually
are feasible to use in training of children. Questions to explore are for
example: how children and parents perceive this kind of training; if games
as a training device actually have the potential to improve motivation and
keep compliance for practice high; if commercial games are challenging
enough to enhance physical activity and improve motor control; and how
to measure these progresses.
AIMS OF THE THESIS

The overall objective of this thesis was to examine the use of interactive games in rehabilitation of children with sensorimotor disorders. The general aim was twofold, first to systematically examine previously published research and secondly to explore the feasibility of using low-cost motion interactive games as a home based intervention for children with cerebral palsy.

Specific aims

- To systematically examine and compile the evidence for the application of interactive computer play in rehabilitation of children with sensorimotor disorders. (paper I)
- To examine motivation for practice among children with cerebral palsy in the context of games for training. (paper II and III)
- To evaluate whether access to motion interactive games increases physical activity among children with cerebral palsy. (paper II)
- To explore parents’ perceptions of using low-cost motion interactive video games as home training for their children with mild/moderate cerebral palsy. (paper III)
- To determine if practice with low-cost motion interactive games may lead to improved motor control in children with cerebral palsy. (paper I, II and IV)
- To explore and compare the applicability of various kinematic measurements to evaluate quality of goal-directed arm movements in children with cerebral palsy using both a virtual and a real context. (paper IV)
- To evaluate if the instruments used to assess motor control and physical activity in this thesis are feasible and adequate to be applied in future research in this field. (paper II, IV)
METHODS
The thesis includes four papers based on one systematic review and one intervention study, which was evaluated with both quantitative and qualitative methods.

Systematic review (paper I)

Literature search
For the systematic review eleven electronic databases were searched for intervention studies aiming to evaluate the impact of interactive computer play (ICP) in the rehabilitation of motor control and learning in children with movement disorders. In this review, ICP was defined as any kind of computer game or virtual reality technique where the child could interact with virtual objects in a computer generated environment; the interaction did not necessarily have to be movement based. In addition, articles included were not restricted to studies of purely functional outcomes such as improved motor control. Articles were also included if they aimed to evaluate aspects of gaming that could optimize the children’s motor rehabilitation but where other factors, for instance motivation of the children, were the main outcome of interest. Only articles published in peer-reviewed journals from January 1995 to May 2008 were considered. The search phrase used was selected on the basis of repeated literature searches using different combinations of several keywords. A condensed combination of words that covered all relevant articles found in these searches was chosen. The search phrase used was a combination of ‘computer game’ or ‘virtual reality’ or ‘virtual environments’ and ‘child*’ and ‘rehab*’ or ‘motor control’ or ‘motor learning’. The reference lists as well as papers labelled in the databases as “related to” the included articles were explored to obtain further studies. In addition, researchers in the field were consulted.

Data extraction and rating
All articles obtained in the literature search were captured in the reference system EndNote® (Thomson Reuters, New York, NY USA) were doublets were removed. Two of the authors independently read the titles and abstracts and decided whether the paper should be included in the review or the reason for exclusion. Reasons for excluding were: the article was a commentary, descriptive or review article; the article did not include children or only typically developing children; the study did not concern motor rehabilitation; or the study was no intervention with repeated training sessions. In addition, studies with a qualitative research
Methods

design were excluded from the review but identified and mentioned in the reference list of the final report. Grading of research design and methodological quality was completed using the methodology to develop systematic reviews of treatment interventions developed by the American Academy for Cerebral Palsy and Developmental Medicine (AACPDM). The AACPDM grading system allows the inclusion of less rigorous study designs, which was necessary in this field due to the high proportion of small group studies and case reports. However, at the time of this study the AACPDM system was not adapted for assessment of qualitative research designs, which is why these articles were not rated in the review. Consistent with the AACPDM methodology two authors did independently review each article, extract data and code the level of evidence based on the design of the study (Table 2). Each study was also assigned a quality rating, strong (S), moderate (M), or weak (W), depending on the methodological quality and the rigor of study design. According to the AACPDM methodology, treatment outcomes were in addition analyzed and categorized according to the components of ICF.

Table 2: Levels of evidence for studies according to the methodology for systematic reviews of treatment interventions developed by the American Academy for Cerebral Palsy and Developmental Medicine (AACPDM).

<table>
<thead>
<tr>
<th>Level</th>
<th>Intervention (Group) studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Systematic review of randomized controlled trials (RCT’s)</td>
</tr>
<tr>
<td></td>
<td>Large RCT (with narrow confidence intervals) (n&gt;100)</td>
</tr>
<tr>
<td>II</td>
<td>Smaller RCT’s (with wider confidence intervals) (n&lt;100)</td>
</tr>
<tr>
<td></td>
<td>Systematic reviews of cohort studies</td>
</tr>
<tr>
<td></td>
<td>“Outcomes research” (very large ecologic studies)</td>
</tr>
<tr>
<td>III</td>
<td>Cohort studies (must have concurrent control group)</td>
</tr>
<tr>
<td></td>
<td>Systematic reviews of case-control studies</td>
</tr>
<tr>
<td>IV</td>
<td>Case series</td>
</tr>
<tr>
<td></td>
<td>Cohort study without concurrent control group (e.g. with historical control group)</td>
</tr>
<tr>
<td></td>
<td>Case-control study</td>
</tr>
<tr>
<td>V</td>
<td>Expert opinion</td>
</tr>
<tr>
<td></td>
<td>Case study or report</td>
</tr>
<tr>
<td></td>
<td>Bench research</td>
</tr>
<tr>
<td></td>
<td>Expert opinion based on theory or physiologic research</td>
</tr>
<tr>
<td></td>
<td>Common sense/anecdotes</td>
</tr>
</tbody>
</table>
Intervention study (paper II-IV)

The intervention was designed as a feasibility study. In this thesis, a feasibility study is defined as an explorative study examining a new method with the purpose of informing the design of future research programs. In this feasibility study both quantitative and qualitative methods were used to reflect a broad perspective on the potential of motion interactive games to enhance motivation for practice, physical activity, and motor control. An overview of methods utilized is presented in Table 3.

<table>
<thead>
<tr>
<th>Quantitative methods</th>
<th>Paper II</th>
<th>Paper III</th>
<th>Paper IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data collection</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gaming diary</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity monitor</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinical motor tests</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinematics/kinetics</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Analysis</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-parametric statistics</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Multilevel linear mixed models</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Qualitative methods</th>
<th>Paper II</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data collection</strong></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Semi-structured interviews</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Analysis</strong></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Content analysis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Participants

The inclusion criteria for children were: 1) age 6-16 years; 2) diagnosed with CP and with limited voluntary motor control of one or both arms; 3) attending regular school; 4) level 1-3 in the GMFCS-E&R;83 5) able to understand and follow simple instructions. Exclusion criteria were: 1) profound bilateral hearing loss with the use of hearing aids; 2) severe visual impairment; 3) serious seizure disorder or uncontrolled seizures; 4) genetic and syndromic conditions; 5) diagnosis of pervasive developmental disability or autism; 6) serious or recurring medical complications; 7) botulinum toxin injection in the arm within six months. Information about the study and a request for participation was sent to all families in the mid-northern part of Sweden having a child with CP who met the inclusion criteria for the study. The families were identified by employees at child habilitation centres in the counties of Västerbotten, Norrbotten and Västernorrland, who also sent out the first information letter. Only the contact information of the families who accepted to
receive more information about the study was conveyed to the responsible researchers. These families were contacted by phone for further information and a confirmation of the interest to participate in the study.

Fifteen families agreed to participate in the study, which was 42% of all families asked. Seven girls and eight boys with a mean age of 11 years and 1 month (range 6-16) were included. Characteristics of the participants are presented in Table 4. During the pre-assessment it was discovered that one child had recently received a botulinum toxin injection in the hand. This child was excluded from study II. However the injection was not regarded to affect the outcomes of study III and IV.

In study III interviews were held with parents to the children who participated in the intervention. The informants were the mother in nine cases, the father in two cases, and in four interviews both parents participated, thus the informants were in total 19 parents, 13 mothers and six fathers. All the participating families consisted of two adults and two to four children (median three children/family). In one case the siblings were older and no longer lived in the same household. At the time of the intervention one family lived in an apartment and the rest of the families lived a house of their own.

All participants did not participate in the intervention simultaneously. The intervention was carried out in three periods, the first starting in April 2007 and the last one ending in April 2008.
### Table 4. Characteristics of the participants.

<table>
<thead>
<tr>
<th>Child</th>
<th>Age (years)</th>
<th>CP diagnosis</th>
<th>GMFCS-E&amp;R</th>
<th>MACS</th>
<th>GA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>Spastic CP unilateral (L)</td>
<td>1</td>
<td>1</td>
<td>NA</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>Spastic CP unilateral (L)</td>
<td>1</td>
<td>2</td>
<td>NA</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>Spastic CP unilateral (L)</td>
<td>1</td>
<td>1</td>
<td>37</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>Spastic CP bilateral</td>
<td>2</td>
<td>2</td>
<td>26+4</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>Spastic CP unilateral (R)</td>
<td>1</td>
<td>2</td>
<td>NA</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>Spastic CP bilateral</td>
<td>3</td>
<td>4</td>
<td>NA</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>Spastic CP bilateral</td>
<td>3</td>
<td>1</td>
<td>NA</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>Spastic CP unilateral (L)</td>
<td>1</td>
<td>1</td>
<td>NA</td>
</tr>
<tr>
<td>9</td>
<td>11</td>
<td>Spastic CP bilateral</td>
<td>1</td>
<td>1</td>
<td>NA</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>Spastic CP unilateral (L)</td>
<td>1</td>
<td>2</td>
<td>NA</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>Spastic CP bilateral</td>
<td>1</td>
<td>2</td>
<td>25+2</td>
</tr>
<tr>
<td>12</td>
<td>13</td>
<td>Dyskinetic CP</td>
<td>1</td>
<td>1</td>
<td>NA</td>
</tr>
<tr>
<td>13</td>
<td>14</td>
<td>Spastic CP unilateral (R)</td>
<td>1</td>
<td>2</td>
<td>NA</td>
</tr>
<tr>
<td>14</td>
<td>15</td>
<td>Spastic CP Unilateral (R)</td>
<td>2</td>
<td>3</td>
<td>NA</td>
</tr>
<tr>
<td>15</td>
<td>16</td>
<td>Mild ataxic CP</td>
<td>1</td>
<td>1</td>
<td>NA</td>
</tr>
</tbody>
</table>

CP, Cerebral Palsy; GMFCS-E&R, Gross Motor Function Classification System, Expanded and Revised; MACS, Manual Ability Classification System; GA, Gestational Age (weeks+days). *NA indicates data not reported or extractable.

### Intervention procedure

Each child was provided with a Sony PlayStation2® equipped with the game EyeToy®, Play3 and were recommended to practice with the game for at least 20 minutes/day. Play3 includes about 20 different game experiences that typically involve arm-coordination, postural stability, and range of movement. Some games are aerobic challenging. The game allows up to four children to play simultaneously. The children were free to choose games within Play3 and they were also free to either play alone or together with someone. Before and after the four weeks of home practice the child and a parent visited the research lab for pre- and post-assessments described below. The design of the whole intervention is presented in Figure 2.
Quantitative methods

Gaming diaries (paper II)

The gaming diaries were used as a method to estimate the children’s motivation for training by documenting compliance with practice and if the children themselves took the initiative to play. The diary was composed of one sheet per day with short questions and pre-determined answer alternatives. Time spent on playing every day was recorded by marking one of the time sequences: 20-30 minutes; 30-60 minutes; 60-90 minutes; 90-120 minutes; or more than 120 minutes. Besides information on time and initiative taking the diary also documented: if the child played alone or together with parents, siblings or friends; what kind of games that were played; if the child did not play that particular day and the reason why not; and if the child did any other physical activity during the day, as for example school gymnastics.

Activity monitoring (paper II)

The physical activity monitor SenseWear Pro3 Armband (SWA, BodyMedia Inc., Pittsburgh, PA, USA) was used for registration of the children’s activity levels (Figure 3). This monitor is a multiple-sensor device that is worn over the triceps muscle on the upper right arm. The physiological parameters measured by the sensors are skin temperature, galvanic skin response, and heat flux—the rate at which heat is dissipating from the body. In addition SWA PRO3 includes a biaxial accelerometer and does also register number of steps.
Methods

Data registered by the SWA together with information about the wearer’s age, gender, height, weight, handedness, and smoking habits are converted into estimates of EE by proprietary activity-specific algorithms in the computer software InnerView Professional (BodyMedia, Inc., Pittsburgh, PA, USA). In this thesis version 5.1 of the software was used and it provides estimates of total EE, activity intensity in MET levels, as well as frequency and duration of physical activity. MET values above these were considered the cut-off value for being physically active. Moderate activity (e.g. walking) was defined as 3-6 METs and vigorous activity (e.g. running) was defined as an activity above 6 METs. These cut-off values have been used by others when defining physical activity intensity in children. The children were instructed to wear the monitor for a total of three periods of three days each. The first period was prior to the intervention start (baseline), the second during the first gaming week, and the third period during the last week (Figure 2). The children were expected to keep the monitor on during the whole measurement periods and to remove the device only when showering or taking a bath.

The manufacturer of SWA continuously updates the monitor and its software. In the version InnerView 5.1 specific activity algorithms for children (6-17 years) have been developed based on data from the activities resting, walking and stationary biking. The ability of SWA combined with InnerView 5.1 to assess energy cost in children has been investigated by comparing the obtained EE in activities of various intensity with indirect calorimetric measurements. In these studies SWA underestimated EE in activities of sedentary and moderate-to-high intense and the underestimation increased with increasing intensity. Conversely, when measuring EE in free-living conditions (during the course of a whole day) other conclusions have been made. One study involving healthy children reported that SWA (InnerView 5.1)
overestimated EE when compared to doubly labelled water (DLW).

Another study including overweight and obese children found a good agreement between SWA (InnerView 5.1) and doubly labelled water. To our knowledge no activity monitor has been validated so far during free-living conditions in children with CP. However, the SWA has been reported feasible and easy to use in order to measure physical activity patterns among children.

Clinical motor tests (paper II)

A combination of several motor tests was chosen to evaluate children’s motor performance before and after training. As it is crucial to employ outcome measures that reflect what is actually trained in an intervention we strived to find tests that involved tasks similar to what children performed while playing the interactive games. As the children in this study were allowed to freely choose games within the EyeToy Play3 and as we did not match games according to the specific need of each child, the motor control training provided by the games was quite general and not entirely concentrated to specific functions. Most of the gaming activities involved elements of goal-directed arm movements with timing and precision. Many games did also require the child to balance, jump, or run on the spot. Furthermore, the selected assessments had to be sensitive enough to capture changes in motor performance after a short period of practice. The tests finally included were: The Movement Assessment Battery for Children-2 (mABC-2); Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) subtest 5:6 (touching a swinging ball); and the 1 Minute Walk Test. The purpose of using these tests was as much to see if they appeared suitable for future intervention studies including children with CP, as to evaluate possible motor progress achieved by the children in the study.

Movement Assessment Battery for Children-2 involves motor control aspects close to those children may practice while playing the EyeToy Play3 games. The test is a revision of the Movement Assessment Battery for Children (mABC) and it is primarily used for: identification of children with mild to moderate movement disorders for clinical exploration and intervention planning; for evaluation of interventions; and for research. The mABC-2 test comprises three components, a standardised test, a checklist, and a manual describing the ecological approach to intervention for children with movement difficulties. In this thesis only the standardised test was used. This test is divided into three age bands: 3-6 years; 7-10 years; and 11-16 years. Each age band includes eight tasks that are distributed over three subtests, Manual Dexterity, Aiming & Catching, and Balance. The original mABC test has evidence of concurrent validity with other paediatric motor assessments and has demonstrated a very high inter-rater reliability with kappa coefficients ranging between 0.95-1. Also the test-retest reliability have been reported to be very high with an intraclass correlation coefficient of 0.95.
for the total test score. However, there is still a lack of research on validity and reliability for the revised version mABC-2. Preliminary reports on reliability and validity data is reported in the mABC-2 test manual, although the comprehensiveness, quality, and rigor of these reliability and validity studies are variable. To our knowledge it has not previously been tested whether mABC is suitable for use in children with mild to moderate CP.

As a complement to mABC-2 the subtest 5:6 from BOTMP was used. In this test item the child is required to hit a swinging ball with the top of the index finger and the number of hits in five attempts is counted. The reason for including this test was that striking moving objects with timing and precision is a frequently occurring activity in interactive games. In addition, this test has previously been used in several studies involving motion interactive games for children. The general motor function of the children was also assessed with the 1 Minute Walk Test where the walking distance during one minute is measured. This test have been validated in children with CP.

Kinematics and kinetics (paper IV)

Before and after the home practice period three dimensional kinematics were captured with a five-camera ProReflex System (ProReflex, Qualisys AB, Gothenburg, Sweden). The system consists of reflexive markers and cameras emitting and detecting infrared light. The reflexive markers were placed on 15 anatomical landmarks; middle of the forehead, sternum, and sacrum, and bilaterally on temples, acromion (midpoint), the 2nd and 5th metacarpophalangeal joints, mid phalange of index fingers, and on the superior anterior iliac spines. In addition rigid clusters with three markers each were attached on the fore-arm and upper-arm to define the arm segments. Thus 3D coordinates from a total of 27 markers were sampled. For ten children the sampling frequency was 240Hz and for five children the frequency was 120Hz.

Movement registrations were taken while children performed goal-directed arm movements under two different conditions: 1) A Virtual condition, captured while the children played one of the EyeToy® games reaching for virtual targets. 2) A Real condition, recorded while the children performed a non-practiced task, reaching for real objects (Figure 4).
Methods

Figure 4. The Virtual and the Real condition used for the movement analysis.

In the Virtual condition the child acts as the maestro of an orchestra. When playing the game rhythm icons move up towards one of five targets arranged in an arc at the top of the screen and the player should try to wave the hand over the correct target when the icon passes through it. The children were instructed to start each goal-directed arm movement with their hands placed on their knees. After allowing a few practicing trials movement registrations were performed while the children played the game three times at the beginner’s level.

The Real condition was designed to resemble the maestro game as much as possible, but in this task the children reached for real physical objects (tassels) instead of virtual markers. Five tassels were arranged in an arc above and slightly in front of the child similar to the targets in the maestro game. The height and the lateral position of the tassels were individually positioned according to the anthropometric measures of each child. Above each tassel a small light diode was placed and the children were instructed to reach out and touch the tassel where the lamp was lit, starting with their hands on their knees. The lamp diodes were manually lit by the test leader and reaching was performed in a self-selected pace with a new lamp lit at the touch of the preceding tassel. Practice was allowed prior to the test and a total of three sequences of 60 seconds was recorded.

During both conditions the children were seated on a stool approximately two meters in front of the television screen. When practicing at home the children were allowed to play standing up. The reason for playing in seated position during the assessments was that children moved around a lot during standing play. While seated, it was easier to get a standardised starting position and to isolate movements to the trunk and the arms. In addition, when planning the study we did not know if all participants would be ambulatory. In order to assess movements of the centre of pressure (COP) the children were seated on a force plate (custom made at the Dept. of Radiation Science, Biomedical Engineering and Informatics, Umeå University, after a design described in Chao & Chen 1997).
All data was low pass filtered at 6Hz, 4th order Butterworth filter and processed in the software Visual3D (C-Motion, Rockville, Canada). From both conditions goal-directed arm movements towards four of the targets, a high and a low target on each side, were picked out for analysis (the fifth target placed in the middle was omitted from the analysis). Six successful hits of each target, within each condition, and from each test were chosen for analysis. Thus, for each child the kinematic data analyzed from pre- and post-test consisted of in total 48 reaches towards the virtual targets and 48 reaches towards the corresponding real targets. Half of the movements were performed with the dominant hand (preferred writing hand) and half with the non-dominant.

The kinematic parameters that were primarily investigated included the spatiotemporal parameters: Mean velocity; Peak velocity; Placement of peak velocity (in relation to movement duration); and Straightness of the movement (movement path ratio), as well as the variances of these parameters (calculated as the coefficient of variation, CV). In addition Movement smoothness, Movement precision, and the Maximal shoulder angle were calculated. Movement smoothness was estimated as a zero-cross index normalized to time and defined as the number of zero-crosses in the acceleration curve. Movement precision was calculated as the 95% confidence interval of the 3D volume (cm$^3$) of the ellipse defined by the end-positions of the hand in the six reaches towards each target. The spatiotemporal parameters, Movement smoothness and Movement precision were all calculated from recordings of the reflexive marker on the 2nd metacarpophalangeal joint while the Maximal shoulder angle was calculated as the rotation angle of the upper arm relative to the upper body, i.e. the helical angle.$^{170}$ The helical angle was chosen because we were interested in the angle between the elevated arm and the trunk regardless of if the movement was a pure flexion or a pure abduction. The helical angle method provides one angle in contrast to the Euler/Cardan approach$^{171}$ that gives separate angles for flexion, abduction and rotation.

Finally, kinetic data obtained from the force plate was used to register movements of the COP during each reach. When seated trunk movements are reflected in shifts of the COP, thus changes in COP will also indicate involvement of the trunk. The cumulative COP path from start of reach to the end-position was calculated for this purpose.

**Statistical analysis and data handling**

Statistical analyses were carried out in paper II and IV and calculations were performed in SPSS (SPSS Inc., Chicago, Ill, USA) version 16 and 18 respectively. The level of significance for all statistical analyses was set at $p < 0.05$. The non-parametric paired test Wilcoxon signed ranks test was used in paper II to analyze data from the gaming diaries, the clinical motor tests, and the activity monitors. This method was also used in paper IV to calculate changes in gaming scores.
Methods

The kinematic and kinetic characteristics in paper IV were calculated in Visual 3D and transferred to SPSS for statistical analyses. Multilevel linear mixed models were applied to calculate differences between pre- and post-test. Such models can handle data with a hierarchical structure while allowing both fixed and random regression coefficients (intercept and slope). Thus, the model copes with large variation between individuals, which was considered important since the participating children differed substantially both regarding ages and the severity of symptoms. Data with hierarchical structures are commonly occurring in the sense that some variables (at level 1) are nested within other variables (at level 2). For example, in this study the same individual performed many repeated trials and repeated trials from the same individual cannot be considered completely independent of each other. This concern can be controlled in a hierarchical data structure.172

In the analysis for paper IV individuals were treated as level 2 variables and the trials (level 1) were nested within the individuals. A mixed model was developed for each variable and each condition (virtual and real). In each model “test” (pre/post), “side” (dominant/non-dominant) and “target” (high/low) were set as covariates. The intercept for each individual as well as the trend between pre- and post-test were set as random, meaning that the intercept and slope were allowed to vary between individuals. Exceptionally, only the intercept was set as random when modelling the Movement precision and the variability of the parameters, as these parameters were derived from summary of trials. The residuals of the final models were checked for normality. In case of uncertainty the robustness of the results were compared with new models adjusted either by removing outliers or by logarithmic transformations of the data.

Qualitative methods

Semi structured interviews (paper III)

Interviews were held with the children at both the pre- and post-assessments and with the parents at the post-assessment. For this thesis only the interviews with parents were analyzed. The interviews were held at the university and were conducted by one of the co-authors. A thematic interview-guide was used as a support and provided open-ended questions within three areas of interest for the study: 1) activities of the child, leisure time and play as well as rehabilitation and exercise habits and changes related to the intervention; 2) use and meaning of the interactive game, for example impact on children’s motivation for practice, motor performance, activity and participation; 3) usability and properties of the game used. The lengths of the interviews ranged from 10 to 40 minutes, they were recorded digitally and transcribed verbatim.
Content analysis (paper III)

A qualitative content analysis approach\textsuperscript{173, 174} was applied to the analysis that in most part was conducted by the first and the second author of paper III. To start with, all interviews were listened and read through several times to obtain a general impression of the content. The texts were then studied in detail and the program OpenCode 3.4 (OpenCode\textsuperscript{©} 2007, UMDAC and Division of Epidemiology and Public Health Sciences, Department of Public Health and Clinical Medicine at Umeå University, Sweden) was used to encapsulate the content in meaning units and codes. After coding three interviews separately the authors met and discussed the codes derived in order to reach agreement on how to proceed with the rest of the coding procedure, which was carried out by one author alone. After processing all texts the derived codes were examined and sorted into categories based on content and relationships. The categories that emerged were presented and scrutinized during a seminar with researchers in Physiotherapy and Occupational Therapy. In the next step the categories were revised to clarify their internal relationship and grouped in themes. Three themes and seven sub-themes emerged and were formulated in English. Finally the interviews were read in the light of the analysis and after discussing the results at two additional seminars, as well as internal discussions among the authors, adjustments were made and a final version was agreed upon.

Ethical approval

Both parents and children were informed of the purpose of the study, and that participation was voluntary and could be ended at any time. Written consent was obtained from both parents and children prior to the intervention. For the interviews the informants gave their permission to be recorded. The study was approved by the Regional Ethical Review Board (dnr 07-128).
RESULTS

The result section starts with a presentation of findings in the systematic review. Results from the intervention are reported in the subsequent paragraphs with focus on motivation for practice, physical activity, and motor control in a mixture of quantitative and qualitative data under each heading.

Interactive games in motor rehabilitation for children, a systematic review (paper 1)

In order to obtain an overview of existing research and the current levels of evidence for using interactive computer games in motor rehabilitation of children a systematic review was conducted. A total of 74 original articles were identified, of these 16 studies met the inclusion criteria. Altogether these studies included 257 participants of which nearly two-thirds were children with CP. The interactive technology that was most frequently applied in the studies was video-capture technique. The most common length of intervention period was four weeks, ranging between five sessions to 12 weeks. With regard to the ICF 12 studies addressed outcomes on body functions whereas only five studies investigated topics related to activities and participation. However, some of the outcome measures used could address several dimensions of the ICF. The main areas investigated were movement quality, spatial orientation and mobility, and motivational aspects.

Nine studies investigated effects on movement quality and arm function was the most commonly assessed aspect. The evidence for the effectiveness of using interactive games to enhance motor control was inconclusive. Only one of three RCTs showed significant improvements, however the design and/or power of these studies were questionable. Of the studies classified at the lower levels of evidence (IV-V according to the AACPDM methodology) all presented positive findings in at least one outcome measure of motor performance. Three controlled but not randomized studies (level III) explored the use of games as a means to enhance spatial skills. In two of these studies significant effects on tests of spatial skills and orientation were reported after practice with interactive games. Another controlled study (level III) evaluated the suitability of games when learning how to operate a powered wheelchair with positive results.

Motivational aspects were studied in four papers. One RCT study did, in addition to effects on movement quality, measure self-perceived self-efficacy among children with CP after practicing with interactive games. No significant results were shown except in subtests.
concerning social acceptance. Conversely, three low level studies (level IV) presented positive effects on self-efficacy, \(^7\) volition and motivation during game play, \(^6\) and playfulness. \(^7\) These studies reported that games which included elements of challenge, variability and competition produced higher levels of volition and games which allowed creativity, persistence with the task and control supported playfulness.

In summary 13 of the 16 studies identified presented positive findings. However, the main part of the published articles was uncontrolled studies with small samples. Thus, the main finding of this systematic review was that further and more convincing research is needed.

**Motivation for physical training with interactive games (paper II and III)**

In the present feasibility intervention motivation for practice was assessed through the gaming diaries by documenting time spent on playing the motion interactive games as well as how often the children themselves took the initiative to play. Motivational aspects of using games in home based training were also examined in the interviews with the parents. According to the gaming diaries, the children played on average 5.5 sessions per week during the course of the intervention, and the mean time per session was 33 minutes. Motivation for practice seemed to diminish over time. The children played a lot during the first week and after that gaming time levelled off and stabilized at a lower level. The initiative to play was taken by the children in 59% of all gaming sessions. The proportion of times that the children played on their own initiative remained quite stable until the fourth and last week were the parents’ part of initiative taking increased and approached the level of the children’s (Figure 5).
In general the play sessions lasted longer when the children themselves had taken the initiative to play. In these cases the average playtime was 35 minutes compared to 24 when the parents told the children to practice (p=0.003). Another factor that influenced playtime was if the child played alone or together with someone. The average time for sessions played together with someone was 37 minutes compared to 21 minutes when playing alone (p=0.001).

In the interviews the parents expressed the view that games helped to create a positive experience of physical training, which was considered important to promote motivation for practice. According to the parents the children did not experience gaming as training, it was rather perceived as a fun activity. The parents did also point out that gaming practice reduced the parental effort by making it easier to motivate the child for training and lowered the need for parents to support and supervise the training. All parents considered it a great feature that the games allowed children to play together. The parents perceived that training could become a social activity through the games, which greatly contributed to a positive practice experience and motivation for practice. If a friend took part in gaming it was easier to motivate the child to practice and they played for extended periods.

The parental interviews confirmed that the children’s interest in playing the motion interactive games faded during the course of the intervention. The first week the children were generally enthusiastic and eager to play, some played for hours if the parents let them. Nevertheless, the initial fascination diminished and during the last week it became increasingly common that parents had to remind or persuade the child to play.
However, when the child started to play the parent often noticed that gaming became fun and that the child could continue for longer periods. The parents believed that an obligation to play every day could, in the long run, lead to less motivation and that gaming would become more like ordinary training. Parents also pointed out that technical problems were frustrating and influenced motivation for practice negatively. An unobtrusive technology that is quick and easy to start running was regarded as important to overcome the first thresholds when motivating the child for practice.

**Influence on physical activity (paper II and III)**

During the intervention the total daily physical activity of the children was measured with activity monitors. The applied monitor SWA was feasible to use among children with CP. Wearing the monitor per se caused no major problems, a few children complained about a little itchiness and one child had difficulties to tighten the armband enough without causing oedema in the hand. However, a problem that occurred was that all children did not wear the monitor 100% of the time during the measurement periods, which caused missing data. The activity monitor SWA handles such data loss by replacing off-time with data corresponding to sedentary activity (rest). But, as we cannot know what the child actually did while not wearing the monitor this method may substantially influence the results, especially when off-time is frequently occurring. To deal with this problem a limit for required on-time was set to 85% of the time during each measurement day. Only ten children fulfilled this criterion. The leading cause of missing data among the excluded children was that they had forgotten to put on the monitor at numerous occasions during the measurement periods. In addition one child became ill the last week of gaming.

Among the ten children included in the analysis eight increased their physical activity during the gaming weeks. At the group level there was a significant increase in EE as well as number of steps from baseline compared to both the first and last gaming week. Median values and p-values are presented in Table 5. There was also a substantial increase in time spent as physically active (>3 METs) with about one and a half hour/day during the gaming weeks compared to baseline. Grading the activity pattern of the children further into categories according to intensity revealed in particular a significant change at the vigorous level (6-9 METs) with a median increase in 31 minutes/day. There were no statistical differences in the time that children wore the sensor between the three test occasions. A check for seasonal influences was carried out but there was no trend that children who participated in the intervention during springtime increased their physical activity more than children participating during fall or winter.
Results

Table 5. Changes in physical activity from baseline to gaming week 1 and 4 for ten of the children, measured with the activity monitor SenseWear Pro3 Armband.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Median (IQR) baseline</th>
<th>Median (IQR) week 1</th>
<th>Median (IQR) week 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE/day (cal)</td>
<td>1789 (900)</td>
<td>1950 (891)*</td>
<td>1966 (984)*</td>
</tr>
<tr>
<td>Steps</td>
<td>9815 (5569)</td>
<td>13 755 (5188)*</td>
<td>12 634 (7387)*</td>
</tr>
<tr>
<td>Time &gt;3 MET</td>
<td>5:44 (3:25)</td>
<td>7:13 (3:09)*</td>
<td>7:16 (3:47)*</td>
</tr>
</tbody>
</table>

*Wilcoxon signed ranks test p<0.05. IQR, Interquartile Range; EE, Energy Expenditure; MET, Metabolic Equivalent Unit.

The parents were convinced that practice with motion interactive games was a good way to increase physical activity. Many parents described that their child often became warm and sweaty while playing as the games involved whole body movements and frequently required the child to jump and run on the spot. The EyeToy® games were considered to be more physically challenging compared to other sedentary interactive games and the parents appreciated this general physical activation and regarded it as important.

**Motion interactive games and motor control (paper II, III and IV)**

The parents believed that motion interactive games could be used as a rehabilitation device to train motor function. Balance, coordination and range of motion were mentioned as functions targeted in the games. Many parents reported that their child became more skilled in the games, and some children started to use both their hands more while playing. A few parents did also report improved physical functions outside of the game, as for example improved jumping, increased range of arm movements, and steadier hand function. However, most parents were not able to point out transfer of improvements after the intervention and they perceived that four weeks of practice was most likely a too short period to achieve substantial motor progress.

The results of the clinical motor tests showed a small but significant improvement in the total test scores on mABC-2. When dividing the total score into the subtests for Manual Dexterity, Aiming & Catching, and Balance only the subtest Manual Dexterity reached significance. The two additional motor tests, BOTMP subtest 5:6 and the 1 Minute Walk Test showed only non-significant progress. Table 6 shows individual test
scores and p-values for statistical test on the group level in all motor performance tests.

The feasibility of using mABC-2 among children with CP was questionable. The test was easy to administer but the results indicated clear floor and ceiling effects. Especially children with GMFSC-E&R levels II-III had difficulties in performing several items on the tests (i.e. a floor effect), particularly in the subtest Manual Dexterity. In addition many test items did also suffer from ceiling effects. These effects did mainly occur in the Balance subtests, in which four children reached top scores in two or more items. Only one child completed the mABC-2 test without any top or bottom scores in any test item.
Advanced 3D motion analysis was used to evaluate movement quality when reaching for virtual objects in the game and in a corresponding task with real objects. Table 7 presents the results for the spatiotemporal characteristics of the goal-directed arm movements. As indicated in the table movements were performed slower at the post-tests, although not statistically confirmed in the Mean velocity measure in the Virtual condition. Further, we did expect a reduced variability (CV) in the spatiotemporal parameters after practice but these expectations were not confirmed.

Table 7. Spatiotemporal characteristics of goal-directed arm movements in the Virtual and the Real condition. Differences between pre- and post-assessments analyzed with multilevel mixed models.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Virtual condition</th>
<th>Real condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean velocity m/s</td>
<td>b = -0.14, t(18.32) = -1.43</td>
<td>b = -0.24, t(19.06) = -3.28</td>
</tr>
<tr>
<td></td>
<td>p = 0.170</td>
<td>p = 0.004</td>
</tr>
<tr>
<td>Peak velocity m/s</td>
<td>b = -0.38, t(18.74) = -2.46</td>
<td>b = -0.31, t(20.86) = -3.16</td>
</tr>
<tr>
<td></td>
<td>p = 0.024</td>
<td>p = 0.005</td>
</tr>
<tr>
<td>Placement of the peak</td>
<td>b = -0.41, t(29.91) = -0.17</td>
<td>b = -4.76, t(24.76) = -1.82</td>
</tr>
<tr>
<td></td>
<td>p = 0.867</td>
<td>p = 0.082</td>
</tr>
<tr>
<td>Movement straightness</td>
<td>b = -0.03, t(43.42) = -2.77</td>
<td>b = 0.00, t(42.17) = 0.02</td>
</tr>
<tr>
<td></td>
<td>p = 0.008</td>
<td>p = 0.988</td>
</tr>
</tbody>
</table>

Coefficient of variation

| CV Mean velocity            | b = -0.02, t(98) = -1.14 | b = -0.005, t(105) = -0.28, |
|                            | p = 0.257               | p = 0.783                  | |
| CV Peak velocity            | b = -0.041, t(98) = -2.08 | b = -0.01, t(105) = -0.56, |
|                            | p = 0.040               | p = 0.574                  | |
| CV Placement of the peak    | b = -0.01, t(98) = -0.41 | b = 0.04, t(105) = 1.21,   |
|                            | p = 0.682               | p = 0.228                  | |
| CV Movement straightness    | b = -0.01, t(98) = -1.04 | b = 0.02, t(105) = 1.40,   |
|                            | p = 0.299               | p = 0.164                  | |

b = the regression parameter for the effect of test.

The Precision of the movement and the Movement smoothness revealed results that were depending on the different accuracy constraints of the targets in the two conditions (Figure 6). In comparison to the pre-test the Precision of the movement was significantly improved at post-tests in the Virtual condition (b = -310.10, t(98) = -3.93, p = 0.000). This means that the volume of the 3D ellipse defined by the end-positions of the hand in the six reaches towards each target were smaller at the post-test. There were no corresponding improvements in the Real condition. Movement
smoothness, though improved significantly in the Real condition, at least when reaching for the lower targets. The model indicated a significant interaction effect between test and target ($b=-0.33$, $t(691)=-2.15$, $p=0.032$). When this interaction was broken down the increased smoothness did only reach significant levels at the low targets ($b=-0.56$, $t(345.15)=-3.65$, $p=0.000$). However, if this parameter was transformed logarithmically to reduce the effect of skewed residuals, Movement smoothness reached significance both at the high and low targets in the Real condition ($p=0.02$).

Figure 6. Movement precision in the Virtual condition and Movement smoothness in the Real condition. Differences in goal-directed arm movements between pre- and post-assessment analyzed with multilevel mixed models.
Further, the Maximal angle of the shoulder did not change between pre- and post-test, neither in the Virtual nor in the Real condition. Nevertheless, a calculation of the CV revealed a decreased variation in the Maximal shoulder angle at post-test in the Virtual condition \((b=-0.022, t(98) =-2.60, p=0.011)\). Finally, the COP path decreased in the Virtual condition \((b=-0.012, t(32.61) =-2.97, p=0.006)\) and likewise when reaching with the non-dominant arm in the Real condition \((b=-0.021, t(20.22) =-2.14, p=0.045)\), which indicated less involvement of the trunk during reach.

Remarkably, when examining side differences movements were smoother at the non-dominant side in the Real condition \((b=-0.30, t(691) =2.22, p=0.027)\). Also, unexpectedly the Maximal shoulder angles were larger at the non-dominant side compared to the dominant in both conditions (real: \(b=6.64, t(674) =7.69, p=0.000\), virtual: \(b=8.48, t(633) =6.70, p=0.000\)).

Several of the multilevel linear models developed resulted in skewed residuals. Generally the skewness was due to a few outliers and the models robust when outliers were removed. For the Placement of the peak and Movement smoothness in the Real condition the robustness of the models were checked after logarithmic transformations. The model for the Movement straightness in both conditions resulted in skewed residuals that could not be resolved either by transformations or by removing outliers, so the results of these two models should be interpreted with caution.

Although the parents were positive about using motion interactive games as a form of general practice the EyeToy game was not advanced enough to provide individualized training for specific motor functions. A common view was that the games were not exact enough to target training of specific movements. It was easy for the children to take shortcuts or cheat and parents disapproved of the possibility to ‘only mess around’ and still getting quite good scores. The parents suggested that future rehabilitation games should make it possible to control and reward that children actually perform specific movements. In addition such games should allow individual adaptations according to the specific needs of each child.
DISCUSSION

Main findings

In this thesis the use of interactive games in motor rehabilitation of children was examined through a systematic review of published literature and a feasibility study that included children with CP in an intervention. The systematic review conducted as a first part of the thesis indicated a promising potential for the use of interactive games in motor rehabilitation of children. Although the current level of evidence is low due to the small number of studies and a lack of well designed and controlled research, the vast majority of published papers presented positive findings. In addition, small pilot and feasibility studies are typical for early investigations of a new method. Before larger and well controlled studies can be conducted smaller feasibility studies are valuable and, indeed, appropriate. Particularly the use of low-cost commercially available games and/or home based practice has been sparsely investigated before.

The results of the present intervention suggest that motion interactive games in rehabilitation can promote a positive experience of physical training and enhance motivation for practice at least in the short term. The social interaction that games added to the training situation was particularly appreciated by children and parents and was considered important for motivation. Motion interactive games may also contribute to an increased daily physical activity among children with CP as measured with activity monitors. The activity monitor SWA was feasible to use in children with CP although data loss due to extended periods of off-time needs to be prevented. The parents believed in the potential of motion interactive games in training of motor control. However, the EyeToy® games were not considered advanced enough to provide individualized training for specific motor functions. Nevertheless, the results of the kinematic evaluations of movement quality indicated that children improved movement precision when playing the virtual games, increased movement smoothness when reaching for real targets, and reduced the involvement of the trunk especially when reaching with the non-dominant side. However, the clinical motor test (e.g. mABC) used in this intervention did only provide vague results. There is a need for valid and reliable clinical assessments that are adequate and sensitive enough to evaluate movement control when games are used in rehabilitation. It is also important to consider both the nature of the task and the context in which movements are performed when selecting and interpreting kinematic parameters.


**Games as a means to enhance motivation for physical training**

Generally, children and parents involved in the study had positive experiences of using interactive games to enhance motivation for training. Results from the gaming diaries showed that compliance with the intervention program as well as the intensity in practice and children’s own initiative to play were high. However, the children’s interest in gaming faded somewhat over time and the fourth and last week of the intervention it became increasingly common that parents had to remind or persuade their child to play.

One of the strongest reasons to why the use of games is considered interesting in rehabilitation of children is perhaps the desire for stimulating methods that will motivate children to exercise. However, very few studies have investigated if games actually contribute to children’s motivation for physical practice more than temporarily. The empirical evidence tells us that computer and video games seems to have a strong motivational impact on children. The general opinion today is that children and adolescents spend too much time in front of the screen, caught up in games of various kinds. Nevertheless, there may be a substantial difference in motivation when playing for fun compared to when playing for a rehabilitation purpose. When children play for fun they are able to choose and alter games all according to their preferences at the moment. However, when gaming becomes synonymous with practice the freedom will be restricted to a set of games and the choice of when, where, and how often to play may also be influenced. The experience does also tell us that many games have a stronger motivational impact initially, but lose their appeal in the long run. In accordance with the results of our study a few earlier studies involving typically developing children or overweight children have also concluded that motivation for practice with motion interactive games diminish over time and that playing eventually may become boring. According to the self-determination theory one explanation for this fading interest may be that when games are used as a training device and if children feel controlled and forced to play their feelings of autonomy may weaken and negatively influence the intrinsic motivation for the activity. In such a situation gaming stops being play and becomes an obligation, like any other ordinary training program. It has also been suggested that a decrease in motivation may be attributed to a lack of challenge in motion interactive games. Lack of challenge is detrimental for feelings of competence and flow and thus also for intrinsic motivation. In order to encourage sustained engagement in future games for rehabilitation such applications need to be able to closely follow individual progress and offer a continuous challenge at exactly the right level to stimulate the child.

In the interviews many parents reported that playing together with friends or siblings was appreciated by the children. This was confirmed in
the gaming diaries as the average time for sessions played together with someone was nearly double the amount of time when playing alone. The children did also like games that involved some kind of competition. Several studies involving children have concluded that playing together is more fun and motivating than playing alone. In addition, feelings of relatedness and connection to others while playing are, besides feelings of autonomy and competence, considered the most important psychological need to fulfil in order to support motivation. Playing together does, in addition to the social aspects, add both challenge and competition to gaming, so likely, one way to keep motivation on top may be to include or encourage multiplayer sessions. To offer weekly sessions in a multiplayer group in addition to home based training have indeed been found to substantially improve motivation for practice among healthy children.

Apparently, children have high demands on quality and entertainment values of the games that they choose to play. In addition, to maintain motivation over time children need to be able to choose from many different kinds of games. These requirements do also apply to games developed for rehabilitation. To design and develop custom made games for rehabilitation purposes is both time consuming and expensive. Consequently, there is a substantial risk that such games will never be able to compete with commercial games made for entertainment purposes by large corporations like Sony, Nintendo and Microsoft. Thus, if commercial games are used for rehabilitation purposes the risk that gaming will be perceived as tedious will probably be smaller compared to if custom made games are applied. Using existing games does also make it possible for children to play the same kind of games as their friends and siblings, which is of importance for feelings of relatedness and participation.

Finally, as the results of both the present and others research indicates that children's motivation for playing motion interactive games seems to diminish over time, maybe these types of games are especially suitable for short periods of intensive practice, e.g. after botulinum toxin injection.

**Increasing physical activity through motion interactive games**

Data from the physical activity monitors were complete for only ten of the children and of these eight increased their physical activity during the gaming weeks. In addition the parents perceived motion interactive games as a good way to increase physical activity. The interviews with the parents contain several anecdotes about how children work themselves sweaty and warm while playing the games. These results indicate that motion interactive games seem to have the potential to stimulate an increased physical activity. However, it is uncertain if this form of gaming
can generate sufficient EE to reach public health recommendations for children.

The total time spent as physically active increased about one and a half hour/day during the gaming period compared to baseline assessments among the children in our study. At the same time, the number of steps increased about 3000 steps/day. At baseline only two children reached the recommended levels for typically developing children of 12 000 steps/day for girls and 15 000 steps/day for boys, but during the gaming weeks six children exceeded these levels. However, as we did not document all daily activities of the children we do not know for certain if the increased activity was primarily due to playing the interactive games. In fact, children played more during the first gaming week compared to the fourth week but this decrease in playtime did not result in a reduced total time as physically active (see Table 5). Moreover, the substantial daily increase in time spent as physically active, and in particular the increase of 31 minutes/day in vigorous activity (6-9METs), is a larger improvement due to gaming than reported by other studies of children. Even though significant increase at the vigorous level have been reported earlier the large increase in our study indicates that the degree to which the activity levels rose could probably not solely be explained by playing the motion interactive games. In former studies METs levels above six were rarely reached when EE was measured during shorter sessions of active games play. There was also a considerable variance between different types of games. In addition, even though the children in our study actually practiced about 30 minutes/day they were most likely not highly physically active during that whole time. On the other hand it is possible that access to the motion interactive games inspired the children to become more active even besides time spent on gaming. In the interviews several parents reported that their child became more active, inventive, courageous, and full of energy during the intervention. Most of the children in our study had mild degrees of CP (GMFCS I), and children on this level are often considered as active as typically developing children. It is possible that children on GMFSC levels II-III, which are likely to be more inactive in their daily lives, could benefit even more in physical activity from playing motion interactive games.

The activity monitor SWA was feasible and easy to use to evaluate physical activity in children with CP. Nevertheless some children occasionally forgot to put on the sensor despite reminders via Short Message Service (SMS). In future studies methods to prevent the children from forgetting the monitor should be developed. Frequent reminders via SMS or email as well as online monitoring over the Internet might be fruitful approaches. Another way to diminish excessive data loss may be to lengthen the measurement period to make it possible to exclude one or several days in the analysis. The recommendation is to achieve at least four days/measurement period to get reliable data. However, this
method would be less convenient for the child. Furthermore, the weekday on which physical activity is monitored may also substantially influence the results. Many children perform regular physical activities and sports on specific days during their leisure time, which means that comparing a Monday one week to Thursday the next week might yield very different results. The children in our study always wore the monitor Thursday, Friday and Saturday. Nevertheless, in future studies the measurement period should be lengthened to include at least four days.

A variety of methods can be applied to measure physical activity in children, both subjective self-reports (e.g. questionnaires, diaries, interviews) and objective techniques (e.g. doubly labelled water DLW, accelerometers, pedometers, heart rate monitors, and activity monitors).\textsuperscript{185} Self-report measures have the advantages of being low-cost and easy to administer. The negative side is that these methods are subject to considerable recall bias and may therefore not be suitable for use in children, especially under the age of ten.\textsuperscript{185} The most valid method for measurements of EE in free-living subjects is the DLW method that measures carbon dioxide production during a one to two-week period.\textsuperscript{186} Considering that this golden standard is a complicated and expensive method, other objective methods may be reasonable alternatives. Of these, activity monitors that combine information from several sensors (e.g. SWA) have the greatest potential for increasing the prediction accuracy of habitual physical activity EE in children and youth.\textsuperscript{187} The results of this thesis indicate that SWA is a feasible alternative. However, no activity monitor including SWA, has to our knowledge been validated to measure EE during free-living conditions in children with CP and this needs to be done to ensure valid measurements in future studies.

**Assessment and training of motor control in interactive games**

The results from the kinematic assessments presented in this thesis indicate that the motion interactive games used are challenging enough to give measurable effects in movement quality. However, the effects on movement control were not large enough to be reflected in the clinical motor tests, in which the results were vague and modest. The BOTMP subtest 5:6 and the 1 Minute Walk Test were feasible to use and the walk tests has been validated in children with CP.\textsuperscript{162} The mABC-2, on the other hand, has not been validated for children with CP so our intention was to test the feasibility of this test within this particular population. The results of the assessments revealed clear floor and ceiling effects in mABC-2, which indicate that this test is actually not sensitive enough for children with CP. As mentioned earlier the mABC-2 test was chosen because we strived to find outcome measures that involved activities similar to what children performed while playing the interactive games i.e. goal-directed movements with timing and precision. We experienced that it was hard to
find suitable outcome measures that seemed sensitive enough and were tested for validity and reliability for children with CP in the age span 6-16 years. Other frequently used assessment as the Pediatric Evaluation of Disability Inventory (PEDI) and the Gross Motor Function Measure (GMFM) are both validated measurements known to detect whole body functional change over time in children with CP. These tests are commonly used to assess gross motor function in children with CP but they are not tuned to measure specific arm and hand control and they are not validated for older children. Other validated measurements like the Melbourne Assessment of Unilateral Upper Limb Function or the Assisting Hand Assessment may be more specific but also mainly focused on movement control of the hand.

Another approach that might be fruitful in future interventions studies within this area is to use individual measurement tools. As children with CP constitutes a heterogeneous group there will also be a large disparity in therapy goals. Consequently, it is important to be able to measure and evaluate children’s progress towards individual goals. Standardized measurement tools often include so many items that their specificity and responsiveness to change is limited. In addition, it is often difficult to obtain a homogenous group of children with CP that is large enough to conduct controlled trials with an adequate power. An example of an individual measurement tool is The Goal Attainment Scale (GAS) that assesses progress toward individual goals that should be specific, measurable, acceptable and time-related. The GAS measures level of goal attainment on a five point scale with zero representing the expected level of progress. If a child achieves more than expected according to pre established criteria a score of 1 or 2 is given. If a child performs less than expected a score of -1 or -2 is given depending on the level of achievement. This method has proved to be valid and reliable in many fields and a critical review of the literature has concluded that GAS provides promising values for paediatric rehabilitation. However, the reliability of GAS when used with children needs to be confirmed.

Using kinematics to evaluate progress in training is another option that seemed feasible in our intervention. Kinematic registration is a well accepted method for gait analysis in children with CP. Upper limb analysis is considerably more complex due to the lack of cyclic movements, the variety of functions and abundant degrees of freedom of the shoulder. Nevertheless, kinematic analyses have lately been increasingly employed to describe reaching coordination in children with CP and researchers are also beginning to apply kinematic measurements to evaluate differences in movement ability as a result of interventions in children. To date a few studies have used kinematics to evaluate effects of motion interactive games in training for children with CP and one study have compared the quality of reaching movements in reality with movements performed in virtual reality among healthy adults and adults with mild hemiparesis.
Although advanced motion analysis is increasingly applied to describe and assess movement quality in children, 3D motion analysis can still be carried out in numerous ways, with different apparatus, technology, and marker placement. The applicability, validity, and reliability of kinematic evaluations need to be further investigated and discussed. To facilitate and encourage communication among researchers and clinicians, and to promote the standardisation of 3D upper limb movement analysis the International Society of Biomechanics (ISB), have published recommendations on the definition of joint coordinate systems and rotation sequences for the trunk, shoulder, elbow, wrist and hand. Furthermore, it is also important to tests the reliability of kinematic variables. Trajectory smoothness, trunk displacement, elbow extension, and shoulder flexion have been reported to be the most reliable kinematic variables in test-retest trials of functional upper limb reaching movements in children with CP. However, a routinely interpretation of kinematic variables is not to recommend. The applicability of various kinematic variables needs to be considered in relation to the specific aspects of motor control that are required due to the individual, the environment in which movements are performed, and the constraints of the task. I believe this matter needs to be further recognized and explored, preferably in interdisciplinary teams with expertise in both engineering and motor control.

The results from the movement analysis in our study clearly highlights the importance of considering both the nature of the task and the context in which movements are performed when selecting and interpreting kinematic parameters, perhaps especially in virtual environments. When analysing the goal-directed arm movements of the children a trend of slower movements at post-test was revealed. This could in a strict sense be interpreted as a reduction in movement control. However, in the game used during the motion analysis the child acts as a maestro of an orchestra and in this context fast and straight movements are not necessarily strived for, nor even optimal. Thus, the results regarding movement velocity must be interpreted in relation to the actual task including the purpose and pace of the game. An alternative and likely explanation for the slower movements may be that the children had learned the game, could relax and were able to anticipate and plan the next move without any stress. This explanation is supported by the fact that the children gained significantly higher scores in the game at post-test. In addition, at least in the Real condition, the goal-directed arm movements were completed in a self-selected pace which means that the results expressed in velocity parameters may not be reliable and also difficult to interpret. Altogether, the relevant kinematic parameters support the conclusion that practising motion interactive games resulted in an improved motor control. The reduced variability in shoulder angles as well as the shorter COP paths indicates that the children used a more economic reaching strategy with less trunk involvement during play. In addition Movement precision and Movement smoothness were
influenced, although the applicability of these parameters differed between the Virtual and Real conditions.

When planning this study the goal was to design the Real condition to resemble the virtual game as much as possible, except that the targets aimed for should be real physical objects. Our plan was to investigate if improvements in movement quality learned in a virtual context could transfer to a similar task outside the game with real objects as targets. During the analyses it became increasingly apparent that the differences that still existed between the two conditions highly influenced the results seen in the kinematic parameters studied and the interpretation of the effects. For example, the Movement precision and the Movement smoothness revealed results that were depending on the accuracy constraints of the targets. In the Virtual condition the accuracy constraint of the targets was quite low so the children did not have to fine-tune their movements as much in order to strike the target. Thus, the virtual task was not challenging enough to reveal significant improvements in Movement smoothness. However, as the accuracy required to hit the virtual targets was not highly restrained, it was possible to measure improvements in Movement precision. In the Real condition however, the accuracy constraints of the targets were higher so this task did not give much room to improve Movement precision; instead Movement smoothness was a more sensitive choice and did also reveal improvements. Although the reliability and appropriateness of parameters for kinematic analysis in gaming contexts need to be further explored, it seems feasible to use kinematics to evaluate hand and arm movements within virtual games. An additional advantage is that such kinematic evaluations may be incorporated into gaming applications to give feedback to the user, which is an important aspect for motor learning. Regular kinematic monitoring in games may also offer an excellent basis to perform more long-term evaluation or research. Integrating movement analysis into gaming applications for home use have been explored in patients after stroke, and in adolescents, and children with CP.

A possible advantage with interactive games is the possibility to design tasks in order to stimulate specific motor control aspects as for example timing, precision, velocity, smoothness, or a combination of several aspects. The parents of the children who participated in the intervention did not consider the EyeToy® games advanced enough to provide individualized training for specific motor functions. They asked for games that were more specific and possible to adapt to the individual rehabilitative need of each child. When using low-cost commercial games for therapeutic purposes the risk for experiencing such limitations is obvious and there is a risk that these games may not be able to provide highly specialized training. However technological improvements may reduce this problem and the latest applications on the market Kinect® and PlayStation Move® seem to provide much better motion tracking.
compared to the EyeToy\textsuperscript{\circledast}. Further, as discussed earlier, to develop special games for rehabilitation purposes is both time consuming and expensive. When using commercial applications the large selection of different games and interaction devices like dance mats and balance boards provide some opportunities to choose and match games according to the specific need of each child\textsuperscript{202}. In the present study the children were free to choose among more than 20 different games in the EyeToy\textsuperscript{\circledast} Play3 for PlayStation\textsuperscript{\circledast}. Selecting a few games, matched to the need of each child, would possibly have improved the results of the motor tests. On the other hand, such restrictions might have lowered the motivation for and intensity of practice as the possibility for variation would have been reduced. Another way to tailor games to the specific need and training goal of each child may be to develop new interaction devices for rehabilitation, which are compatible with commercial games but still add the desired training effect to the gaming activity\textsuperscript{144}.

Methodological considerations

Study design

In the systematic review a thorough effort was made to find all relevant articles published within the scrutinized data bases. The search terms used were selected on the basis of repeated literature searches using different combinations of words central to the subject. In addition related articles and reference lists of the included papers were examined. However, the lack of generally used keywords within the research field made it difficult to cover all possible alternatives. After publishing the review one additional pilot study published in 2008 was discovered\textsuperscript{40}. An alternative approach to the literature search might have been to use a few broad search terms and thus embrace many more articles for the manual review of titles and abstracts. Nevertheless, such a strategy would not guarantee that articles were not overlooked.

The AACPDM methodology for systematic reviews of treatment interventions\textsuperscript{154} was chosen because this method allows the inclusion of articles based on less rigorous study designs, such as case studies. Unfortunately, the AACPDM methodology was at the time of the study not customized for the assessment of qualitative studies. However, in the literature search of our review only two articles\textsuperscript{67, 203} were excluded solely due to a qualitative study design. A problematic matter when conducting systematic reviews is to evaluate the rigour of RCT designs. For example, according to the AACPDM methodology power issues are only one item on the scale that will determine the strength of study design. Consequently, a study with insufficient power may still be classified as a small, although perhaps week, RCT and as such still render a high level of evidence. However, a sufficient power is crucial for the interpretation of
the effects if insignificant results are reported in a RCT. In our review two studies that were classified as RCTs had questionable power.\textsuperscript{63, 175}

The purpose of a feasibility study is to evaluate and analyze the potential impact of a proposed treatment or method to determine if the investment in time and other resources will generate a desirable result. In the medical field a feasibility study is often considered equivalent with a pilot study.\textsuperscript{204} However, as I see it and how the concept is defined in this thesis, a feasibility study may be of a more explorative kind than a pilot study, with the purpose of informing the design of future research programs. Thus, a feasibility study may constitute the step before conducting a pilot study. In this view the intention of a feasibility study is to reflect a more comprehensive view of the topic while a pilot study is restricted to specific evaluations previous to an already planned larger study. The cause and nature of a feasibility study is important to remember when interpreting effects from the feasibility intervention reported in this thesis. The objective of this thesis was not to provide evidence for specific effects of training with motion interactive games. Rather the purpose was to evaluate the potential of these games as a home based training tool for children as well as the potential of the proposed outcome measures for use in future controlled trials.

As a specific aim of this thesis was to evaluate if the instruments and assessments used in the feasibility intervention were appropriate and sensitive enough to apply in future studies, these issues will not be discussed further in this section. The children in the study practiced with the games every day during four weeks, which is perhaps a too short period to be able to expect motor improvements. Generally six weeks is considered to be the minimum time needed to elicit a measurable effect although the actual time spent on practice is maybe more relevant to report. It would be interesting to let children play less intensively but during a longer period. This would provide better possibilities for motor improvements to develop as well as an opportunity to follow the development of the children’s activity patterns and motivation for practice over time. In the present study there is also a lack of follow-up measurements, both on activity levels and motor performance.

Participants

The participating families in the feasibility intervention were recruited from habilitation centres in the mid northern part of Sweden, a large but not very densely populated area. All families in this area having a child consistent with the inclusion criteria were asked to participate and 42\% accepted. It is possible that children have to be recruited on a national basis in order to conduct future larger controlled trials. The participating children had a large variation particularly in years of age but also in diagnosis and symptoms. A homogenous study population is preferable
when effects of practice are evaluated. However, for the feasibility aspects the heterogeneous population allowed us to investigate if the games used seemed better suited for children of a certain age, or if the more severely disabled children would be able to play. Furthermore, when conducting interviews disparity between the participants is important for the external validity of the results.
CONCLUSIONS

- Earlier published research indicates a promising potential for the use of interactive games in motor rehabilitation of children. Although the present evidence for positive effects is poor due to the small number of studies and a lack of well designed and controlled studies, the vast majority of published papers present positive findings. Most explored areas in the literature are movement quality, spatial orientation and mobility, and motivational aspects.

- It is highly feasible to use low-cost motion interactive games in home based training for children with mild to moderate CP to increase motivation and compliance for physical training.

- Motivation for practice was reflected by the children’s own initiative to practice for the majority of all gaming sessions. In general, the play sessions last longer when the child take the initiative to play and when the child play together with someone. Motivation for gaming practice seems to decrease over time; both playtime and the number of times children took the initiative to practice decreased gradually over the present intervention.

- Practice with motion interactive games at home may lead to increased physical activity in children with CP.

- From the parents’ perceptions it is concluded that games contribute to positive experiences of physical training, and thus promote motivation for practice. In addition, the games facilitate independent training and reduce the parental effort to stimulate the child to practice and supervise the training. However, there is a need for refinements of the games to provide individualized tailored training.

- The clinical tests and kinematic analysis indicate that motion interactive games have potential to enhance motor control in children with mild to moderate CP.

- Kinematic assessments are useful to evaluate quality of goal-directed arm movements in children with CP in both virtual and a real contexts. It is however important to select appropriate kinematic parameters and to interpret the results in relation to task prerequisites and the context in which the movements are performed.

- The activity monitor SenseWear Armband is feasible to use as an objective measure of physical activity in children with CP. The use of mABC-2 in children with CP is questionable due to floor and ceiling effects.
Clinical implications and future directions

Commercially available games may not be able to provide as specific training as would games designed particularly for rehabilitation purposes. But to develop special games is time consuming and expensive. In addition, children have high demands on the entertainment value of the interactive games that they prefer to play. The technological development and the ever-increasing assortment of motion interactive games on the market would potentially make it increasingly feasible to utilize commercially available games in rehabilitation. A large selection of different games and interaction devices provides opportunities to choose and match games according to the specific goal of the rehabilitation for each child. Finally, it is important to remember that, to date, the evidence for the effectiveness of motion interactive games as a training device is limited. Thus, every intervention involving games needs a clear goal and a careful evaluation.

In future research there is a need to further investigate how motivation for gaming practice in a rehabilitation context evolves over time. In assessments of physical activity the use of activity monitors seems feasible. However, the particular monitor needs to be tested for validity and reliability during free-living conditions in children with CP while methods of how to remind the children to wear the monitor may be considered. To verify effects on motor performance after gaming practice there is still a need for appropriate, sensitive, and valid motor assessments.
ACKNOWLEDGEMENTS

The years as a doctoral student have enriched my life in many ways both with knowledge, friendship, joy and work. It has been a true privilege to carry out my PhD studies at the Department of Community Medicine and Rehabilitation, division for Physiotherapy where the atmosphere is so friendly and open-minded. I’m also grateful for the advantage of being a part of the inspiring multidisciplinary academic milieu of The Vårdal Institute –The Swedish Institute for Health Sciences, and for the constructive collaboration with the Department of Informatics at Umeå University. I would like to express my sincere gratitude to all of you who have contributed with your time and experience and in many other ways supported me in my work with this thesis. I particularly would like to thank:

Charlotte Häger, my main supervisor for sharing your great experience and scientific knowledge. For encouragement and support throughout the work with this thesis. I especially appreciate that you took care to systematically introduce me to various scientific and academic assignments as well as to other researchers in your large contact net.

Eva Lindh Waterworth, my assistant supervisor for always being so positive and encouraging. Your knowledge in Informatics research has been of great value for this project and for me, having someone to share perspective with and to support my “informatical” ideas.

Lena-Karin Erlandsson, my assistant supervisor from The Vårdal Institute. Although you were not directly involved in my research projects you have willingly shared your great experience and advice during the Vårdal workshops. I deeply appreciate your interest in my work and I have always felt your support when needed.

Suzanne McDonough, my co-author at the University of Ulster, for introducing me to the world of systematic reviews. Thank you for a superb and pleasant collaboration, I learned a lot!

Louise Rönnqvist and Erik Domellöf, co-authors at the Department of Psychology, for numerous hours of inspiring discussions about movement analysis and for your valuable contribution to our first common article. I do hope for more to come!

Helena Grip, co-author and engineering resource, for your skilful help in the motion capture lab and in pre-processing of the data. Thanks for patiently answering all my questions.

Katarina Dock, co-author for your help during the intervention and for your engagement in the analysis of all interviews. It was a pleasure to work with you.
Monica Edström, for your reliable support in the lab during the pre- and post-assessments. It was an incredible asset to have a friend like you to help me out.

Kolbäcken Child Rehabilitation Centre and the Child Rehabilitation Centres in Piteå, Sunderbyn, and Sundsvall, for positive attitudes and for help in recruiting participants to the intervention study. I’m especially grateful to Barbro Renström and Gerd Andersson for all your advice and support and to Kerstin Norman for comments on my text about cerebral palsy.

Hans Stenlund, for excellent statistical guidance and support.

All children and parents who participated in the intervention study and contributed with your time and efforts to this research project. Without you this thesis would not have been possible.

My wonderful colleagues at the Division for Physiotherapy including all fellow PhD students. Thanks for the warm and friendly atmosphere at our department, which you all greatly contribute to. Thanks also for all the inspiring discussions during our research seminars and for refreshing chats and laughter during coffee and lunch breaks. Special gratitude to Gunnevi Sundelin, the head of the department for a great leadership and for showing that you care. To Marie Blomqvist Larsson, Monica Edström, Christina Jacobsson and Larry Fredriksson for practical support, you all contribute to form the best of workplaces with an extraordinary atmosphere.

All faculty members, staff and PhD students at the Division for Occupational Therapy, for showing interest in my work and for all cheerful times in the coffee room.

Gerd Ahlström, Ingalill Rahm Hallberg, Björn Carlqvist, Anna Blomgren, Edith Andersson, Ann Bengtsson, and the rest of the staff at The Vårdal Institute, for organizing all the fantastic Vårdal workshops that so pleasantly contributed to my education and to valuable friendships for the future.

My fellow PhD students and all researchers at the platform “Persons with long term illness and functional disabilities” at The Vårdal Institute, for interesting and stimulating seminars during our workshops and for constructive discussions on my papers. It has always been a true pleasure meeting you all at our workshops.

All members of the Q-life research group at the Department of Informatics, for letting me be part of your group. Special thanks to Kei Hoshi for creative collaborations regarding our prototype.
Solveig and Torgny Sandlund, my mother and father in law for helping us out and taking such a good care of our children in times of illness, and for being such wonderful persons and role models.

My sister Marie Brunneård and her fantastic family, for all fun get-togethers to look forward to. It’s always a pleasure spending time with you!

My dear Parents Ulf and Marianne Linder, for your endless love and support. It’s a grace to have been blessed with parents like you. Thank you!

Finally, my beloved family: Jonas my brilliant husband who supported me in so many ways during the work with this thesis. Thank you for all discussions, for listening, reading and offering advice, but most of all for your love and understanding. Our wonderful children Samuel, Alexine and Jonathan for telling us to stop talk about work and reminding me of what matters most in life. You’re the best!

Financial support for this work was gratefully received from the foundations of JC Kempe, Sven Jerring, Anna Cederberg, Muskelfond Norr, and Queen Silvia Jubilee Foundation (for research on children and handicap).
REFERENCES


75


76


Dissertations written by physiotherapists, Umeå University 1989–2011

Birgitta Bergman. Being a physiotherapist - Professional role, utilization of time and vocational strategies. Umeå University Medical Dissertations, New Series no 251, 1989 (Department of Physical Medicine and Rehabilitation)

Inger Wadell. Influences from peripheral sense organs on primary and secondary spindle afferents via gamma-motoneurones - A feedback mechanism for motor control and regulation of muscle stiffness. Umeå University Medical Dissertations, New Series no 307, 1991 (Department of Physiology)


Birgit Rösblad. Visual and proprioceptive control of arm movement - Studies of development and dysfunction. Diss. (sammanfattning) 1994 (Department of Paediatrics)

Charlotte Häger-Ross. To grip and not to slip - Sensorimotor mechanisms during reactive control of grasp stability. Umeå University Medical Dissertations, New Series no 429, 1995 (Department of Physiology)

Lars Nyberg. Falls in the frail elderly – Incidence, characterics and prediction with special reference to patients with stroke and hip fractures. Umeå Medical Dissertations, New Series no 483, 1996 (Department of Geriatric Medicine)

Margareta Barnekow-Bergkvist. Physical capacity, physical activity and health -A population based fitness study of adolescents with an 18-year follow-up. Umeå University Medical Dissertations, New Series no 494, 1997 (Departments of Physiology and Technology, National Institute for Working Life and Epidemiology and Public Health)

Britta Lindström. Knee muscle function in healthy persons and patients with upper motor neurone syndrome. Umeå University Medical Dissertations, New Series no 505, 1997 (Departments of Physical Medicine and Rehabilitation and Clinical Neuroscience)

Monica Mattsson. Body Awareness - applications in physiotherapy. Umeå University Medical Dissertations, New Series no 543, 1998 (Departments of Psychiatry and Family Medicine)

Hildur Kalman. The structure of knowing. Existential trust as an epistemological category. Umeå studies in the humanities. 145, 1999 (Department of Philosophy and Linguistics)

Hamayun Zafar. Integrated jaw and neck function in man: studies of mandibular and head-neck movements during jaw opening-closing tasks. Umeå University Medical Dissertations, New series no 74, 2000 (Departments of Odontology, Clinical Oral Physiology and Centre for Musculoskeletal Research, National Institute for Working Life, Umeå)

84
Lillemor Lundin-Olsson. Prediction and prevention of falls among elderly people in residential care. Umeå University Medical Dissertations, New Series no 671, 2000 (Department of Community Medicine and Rehabilitation, Physiotherapy and Geriatric Medicine)

Christina Ahlgren. Aspects of rehabilitation – with focus on women with trapezius myalgia. Umeå University Medical Dissertations, New Series no 715, 2001 (Department of Public Health and Clinical Medicine, Occupational Medicine)

Ann Öhman. Profession on the move - changing conditions and gendered development in physiotherapy. Umeå University Medical Dissertations, New Series No 790, 2001 (Departments of Community Medicine and Rehabilitation, Physiotherapy and Public Health and Clinical Medicine, Epidemiology)

Kerstin Söderman. The female soccer player – Injury pattern, risk factors and intervention. Umeå University Medical Dissertations, New Series no 735, 2001 (Departments of Surgical and Perioperative Sciences, Sports Medicine, and Community Medicine and Rehabilitation, Physiotherapy)

Lena Grönblom-Lundström. Rehabilitation in light of different theories of health. Outcome for patients with low-back complaints – a theoretical discussion. Umeå University Medical Dissertations, New Series no 760, 2001 (Departments of Public Health and Clinical Medicine, Epidemiology, and Community Medicine and Rehabilitation, Social Medicine)

Kerstin Waling. Pain in women with work-related trapezius myalgia. Intervention effects and variability. Umeå University Medical Dissertations, New Series no 762, 2001 (Departments of Public Health and Clinical Medicine, Occupational Medicine, and Community Medicine and Rehabilitation, Physiotherapy)

Eva-Britt Malmgren-Olsson. Health problems and treatment effects in patients with non-specific musculoskeletal disorders. A comparison between Body Awareness Therapy, Feldenkrais and Individual Physiotherapy. Umeå University Medical Dissertations, New Series no 774, 2002 (Department of Community Medicine and Rehabilitation, Physiotherapy and Department of Psychology)

Jane Jensen. Fall and injury prevention in older people living in residential care facilities. Umeå University Medical Dissertations, New Series no 812, 2003 (Department of Community Medicine and Rehabilitation, Physiotherapy and Geriatric Medicine)

Ann Cristina Fjellman-Wiklund. Musicianship and teaching. Aspects of musculoskeletal disorders, physical and psychosocial work factors in musicians with focus on music teachers. Umeå University Medical Dissertations, New Series no 825, 2003 (Department of Community Medicine and Rehabilitation, Physiotherapy)

Börje Rehn. Musculoskeletal disorders and whole-body vibration exposure among professional drivers of all-terrain vehicles. Umeå University Medical Dissertations, New Series no 852, 2004 (Department of Public Health and Clinical Medicine, Occupational Medicine)

Martin Björklund. Effects of repetitive work on proprioception and of stretching on sensory mechanisms. Implications for work-related neuromuscular disorders. Umeå University Medical Dissertations, New Series no 877, 2004 (Departments of Surgical and Perioperative Sciences, Sports Medicine Unit, Umeå University, The Center for Musculoskeletal Research, University of Gävle, Umeå, and Alfta Forskningsstiftelse, Alfta)

Karin Wadell. Physical training in patients with chronic obstructive pulmonary disease – COPD. Umeå University Medical Dissertations, New Series no 917, 2004 (Departments of Community Medicine and Rehabilitation, Physiotherapy; Public Health and Clinical Medicine, Respiratory Medicine and Allergy, Surgical and Perioperative Sciences, Sports Medicine)
Peter Michaelson. Sensorimotor characteristics in chronic neck pain. Possible pathophysiologica1 mechanisms and implications for rehabilitation. Umeå University Medical Dissertations, New series no 924, 2004 (Departments of Surgical and Perioperative Sciences, Sports Medicine Unit, University of Umeå, Southern Lapland Research Department, Vilhelmina, Centre for Musculoskeletal Research, University of Gävle, Umeå)

Ulrika Aasa. Ambulance work. Relationships between occupational demands, individual characteristics and health related outcomes. Umeå University Medical Dissertations, New series no 943, 2005 (Department of Surgical and Perioperative Sciences, Sports Medicine and Surgery, University of Umeå and Centre for Musculoskeletal Research, University of Gävle)

Ann-Katrin Stensdotter. Motor Control of the knee. Kinematic and EMG studies of healthy individuals and people with patellofemoral pain. Umeå University Medical Dissertations, New series no 987, 2005 (Department of Community Medicine and Rehabilitation, Physiotherapy)


Erik Rosendahl. Fall prediction and a high-intensity functional exercise programme to improve physical functions and to prevent falls among older people living in residential care facilities. Umeå University Medical Dissertations, New Series no 1024, 2006 (Department of Community Medicine and Rehabilitation, Geriatric Medicine and Physiotherapy)

Michael Stenvall. Hip fractures among old people. Their prevalence, consequences and complications and the evaluation of a multi-factorial intervention program designed to prevent falls and injuries and enhance performance of activities of daily living. Umeå University Medical Dissertations, New Series no 1040, 2006 (Department of Community Medicine and Rehabilitation, Geriatric Medicine and Physiotherapy)

Petra von Heideken Wågert. Health, physical ability, falls and morale in very old people: the Umeå 85+ Study. Umeå University Medical Dissertations, New Series no 1038, 2006 (Department of Community Medicine and Rehabilitation, Geriatric Medicine and Physiotherapy)

Karl Gisslén. The patellar tendon in junior elite volleyball players and an Olympic elite weightlifter. Umeå University Medical Dissertations, New Series no 1073, 2006 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit)

Gerd Flodgren. Effect of low–load repetitive work and mental load on sensitising substances and metabolism in the trapezius muscle. Umeå University Medical Dissertations, New series no 1130, 2007 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit, Centre of Musculoskeletal Research, University of Gävle, Umeå, and the Department of Community Medicine and Rehabilitation, Rehabilitation Medicine)

Staffan Eriksson. Falls in people with dementia. Umeå University Medical Dissertations, New series no 1135, 2007 (Department of Community Medicine and Rehabilitation, Physiotherapy and Geriatric Medicine)

Jonas Sandlund. Position-matching and goal-directed reaching acuity of the upper limb in chronic neck pain: Associations to self-rated characteristics. Umeå University Medical Dissertations, New series no 1182, 2008 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit, Umeå University, Centre of Musculoskeletal Research, University of Gävle, Umeå)

Gunilla Larsson. Motor function over time in Rett syndrome-loss, difficulties and possibilities. Umeå University Licentiate Thesis, 2008 (Department of Community Medicine and Rehabilitation, Physiotherapy)
Charlotte Åström. Effects of vibration on muscles in the neck and upper limbs. With focus on occupational terrain vehicle drivers. Umeå University Medical Dissertations, New series no 1135, 2008 (Department of Community Medicine and Rehabilitation, Physiotherapy)

Ellinor Nordin. Assessment of balance control in relation to fall risk among older people. Umeå University Medical Dissertations, New series no 1198, 2008 (Department of Community Medicine and Rehabilitation, Physiotherapy)

Bertil Jonsson. Interaction between humans and car seat. Studies of occupant seat adjustment, posture, position and real world neck injuries in rear-end impacts. Umeå University Medical Dissertations, New Series no 1163, 2008 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit)

Jenny Röding. Stroke in the younger. Self-reported impact on work situation, cognitive function, physical function and life satisfaction. A national survey. Umeå University Medical Dissertations, New series no 1241, 2009 (Department of Community Medicine and Rehabilitation, Physiotherapy)

Therese Stenlund. Rehabilitation for patients with burn out. Umeå University Medical Dissertations, New series no 1237, 2009 (Department of Public Health and Clinical Medicine, Occupational and Environmental Medicine)

Elisabeth Svensson. Hand function in children and persons with neurological disorders. Aspects of movement control and evaluation of measurements. Umeå University Medical Dissertations, New series no 1261, 2009 (Department of Community Medicine and Rehabilitation, Physiotherapy)

Helena Nordvall. Factors in secondary prevention subsequent to distal radius fracture. Focus on physical function, co-morbidity, bone mineral density and health-related quality of life. Umeå University Medical Dissertations, New series no 1252, 2009 (Department of Community Medicine and Rehabilitation Physiotherapy and Department of Surgical and Perioperative Sciences, Orthopaedics)


Ulrik Röijezon. Sensorimotor function in chronic neck pain. Objective assessments and a novel method for neck coordination exercise. Umeå University Medical Dissertations, New series no 1273, 2009 (Department of Community Medicine and Rehabilitation, Physiotherapy, Centre of Musculoskeletal Research, University of Gävle, Umeå)

Birgit Enberg. Work experiences among healthcare professionals in the beginning of their professional careers. A gender perspective. Umeå University Medical Dissertations, New series no 1276, 2009 (Department of Community Medicine and Rehabilitation, Physiotherapy and Department of Public Health and Clinical Medicine, Epidemiology and Public Health Sciences)

Per Jonsson. Eccentric training in the treatment of tendinopathy. Umeå University Medical Dissertations, New series no 1279, 2009 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit)

Taru Tervo. Physical activity, bone gain and sustainment of peak bone mass. Umeå University Medical Dissertations, New series no 1282, 2009 (Department of Surgical and Perioperative Sciences, Sports Medicine, Department of Community Medicine and Rehabilitation, Geriatric Medicine, Department of Community Medicine and Rehabilitation, Rehabilitation Medicine)
Kajsa Gildenstam. Gender and physiology in ice hockey: a multidimensional study. Umeå University Medical Dissertations, New series no 1309, 2010 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit)

Margareta Eriksson. A 3-year lifestyle intervention in primary health care. Effects on physical activity, cardiovascular risk factors, quality of life and costeffectiveness. Umeå University Medical Dissertations, New series no 1333, 2010 (Department of Community Medicine and Rehabilitation, Physiotherapy and Department of Public Health and Clinical Medicine, Epidemiology and Public Health Sciences)

Eva Holmgren. Getting up when falling down. Reducing fall risk factors after stroke through an exercise program. Umeå University Medical Dissertations, New series no 1357, 2010 (Department of Community Medicine and Rehabilitation, Physiotherapy and Department of Public Health and Clinical Medicine, Medicine)

Tania Janaudis Ferreira. Strategies for exercise assessment and training in patients with chronic obstructive pulmonary disease. Umeå University Medical Dissertations, New series no 1360, 2010 (Department of Community Medicine and Rehabilitation, Physiotherapy)

Sólveig Ása Árnadóttir. Physical Activity, Participation and Self-Rated Health Among Older Community-Dwelling Icelanders. A Population-Based Study. Umeå University Medical Dissertations, New series no 1361, 2010 (Department of Community Medicine and Rehabilitation, Physiotherapy)

Maria Wiklund. Close to the edge. Discursive, embodied and gendered stress in modern youth. Umeå University Medical Dissertations, New series no 1377, 2010 (Department of Public Health and Clinical Medicine, Epidemiology and Global Health and Department of Community Medicine and Rehabilitation, Physiotherapy)

Catharina Bäcklund. Promoting physical activity among overweight and obese children: Effects of a family-based lifestyle intervention on physical activity and metabolic markers. Umeå University 2010 (Department of Food and Nutrition)

Helene Johansson. En mer hälsofrämjande hälso- och sjukvård: hinder och möjligheter utifrån professionernas perspektiv. Medical Dissertations, New series no 1388, 2010 (Department of Public Health and Clinical Medicine, Epidemiology and Global Health)

Håkan Littbrand. Physical exercise for older people: focusing on people living in residential care facilities and people with dementia. Umeå University Medical Dissertations, New series no 1396, 2011 (Department of Community Medicine and Rehabilitation, Geriatric Medicine and Physiotherapy)