The Implementation of Commercial Video Gaming in Rehabilitation:

A Scoping Review

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Abstract

There is a large global need for rehabilitation, and not enough sufficient methods of delivering it. Gamification, and specifically the use of commercially available video gaming, is a potential solution. The current state of knowledge in this field of research is scattered and inconclusive. Therefore, a scoping review with the aim of investigating the entire field was conducted with two main research questions:

1) What is the current state of the field of research on the use and implementation of commercial video gaming in rehabilitation?
2) What is known about the quality of measurements from commercial consoles regarding rehabilitation?

The search strategy resulted in 631 relevant articles that were categorised in nine themes based on a content analysis. Each theme represents a different section of the research, and comments on the current state of the field. It was found that although the methods can be characterised as inconsistent, there are promising results for the use of commercial video gaming in several different rehabilitation settings. Further, the reliability and the validity of the measurements relevant for rehabilitation settings from both the Xbox Kinect, and the Nintendo Wii were investigated. The clinical relevance of these measurements was also investigated by scrutinising the research on the consoles ability to diagnose and evaluate patients. The findings suggest that the measurements from commercial consoles are both valid and reliable and can contribute to evaluating and diagnosing patients. However, there is need for further research in the entire field, and especially in order to consolidate the findings on the value of measurements from commercial consoles.
Acknowledgements

I would like to thank my supervisor, Cato A. Bjørkli, for his patience and dedication to this master thesis. I would also like to thank him for the numerous and terrible film analogies and reinforcing Star Wars references.

The work the practitioners at Sunnaas Sykehus has done towards this project must be acknowledged – thank you so much for the enthusiasm you have shown.

A big thanks is also extended towards Hege Kristin Ringnes for her patience in showing me how to conduct a search in databases with way too long and complicated search strings.

I also owe my family for feeding me and providing me with an empty house when the research got tough, and to my little brother for destroying an entire week of work by showing me that you can shoot hoops on Facebook. I would also like to thank those who have stayed my friends during this year – I don’t know how you do it.

Lastly, and most importantly, a huge thanks to Malin Knudtzon Neergaard for reminding me to stay human throughout this process, for making sure that I eat and sleep, and for supporting me and telling me that I’m brilliant even though I rarely believe it.
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1. Introduction

1.1 The world wide need for rehabilitation

The World Health Organisation (WHO) states “Rehabilitation of people with disabilities is a process aimed at enabling them to reach and maintain their optimal physical, sensory, intellectual, psychological and social functional levels. Rehabilitation provides disabled people with the tools they need to attain independence and self-determination.” (WHO, Rehabilitation). Therefore, they are currently working on guidelines for delivering health related rehabilitation as a part of the global disability action plan 2014-2021 (WHO, Rehabilitation). The WHO also states that rehabilitation is a significant contributor for helping individuals with disabilities back into their homes, labour market, education, and community. Furthermore, access to rehabilitation can greatly improve an individual’s health and the quality of it, as well as reducing the cost and use of health services.

Although there is a great need for rehabilitation globally, there is not enough supply. Therefore, there exists a need to investigate the most efficient methods of providing these kinds of health services. The guidelines the WHO is developing are aiming to provide evidence-based recommendations for technical assistance, tools, and training packages. The WHO states that only 5-15% of those who require assistive devices and technologies actually have access to them, which testaments to current global need for rehabilitation. Disability is a public health, human rights, and development issue and more than a billion people in the world experience some kind of disability (WHO, Disability and Rehabilitation). Furthermore, most states in the European Union spend more then 50% of their healthcare expenditure on curative and rehabilitative services (Eurostat, Healthcare statistics). The need for rehabilitation will likely grow over time, as the world population continually increases along with the average age. This illustrates well the relevant and current concerns on the state of rehabilitation, and the essence of the solution will likely be in how to meet the need for supply.

1.2 Games that achieve more than entertainment

It is essential to investigate how to deliver rehabilitation most efficiently, as both the need and the associated costs are great. Gamification is a promising field of research that
has seen a lot of popularity and positive outcomes in recent years. First and foremost, it is utilised as a motivational tool for several different tasks that may not be inherently motivating (Kapp, 2012; McGonigal, 2011). The most popular use for this concept is in education and learning, where it has been used to strengthen retention and increase motivation (Hamari, Koivisto, & Sarsa, 2014; Aparico, Vela, Sánchez, & Montes, 2012; Kapp, 2012; Stott & Neustaedter, 2013). It has also been used, among others, in contexts of health and exercise, workplaces, behavioural change, well-being of the elderly, and intra-organisational systems (Hamari et al., 2014; Aparicio et al., 2012).

Kapp (2012) defines a game as a system that consists of one or more players, challenges, rules, interactivity, feedback, quantifiable outcomes, and typically an emotion reaction in an abstract game reality. Further, he states that gamification is based on games and consists of game mechanics and aesthetics. It also involves game thinking in terms of competition, cooperation, exploration, and story telling (Kapp, 2012). The goal of gamification is to engage and motivate and it can also involve learning and problem solving. Deterding, Dixon, Khaled, and Nacke (2011) define gamification as “the use of game design elements in non-game contexts”. Thereby, the term gamification has a very broad definition and can include anything from completely self-designed systems to commercially available games and consoles, which means that the scope of this field is large. As a consequence, the term has become more widespread in recent years (Deterding et al., 2011). However, the concept of introducing games to motivate learning is not new, and researchers as well as laypeople have for several years developed games where the intention is more than just entertainment (Deterding et al., 2011). The field of research on the use of gamification is now wide spread in many different contexts, aspects, and generations (Deterding et al., 2011, Kapp, 2012).

1.3 Can games rehabilitate?

The intention of gamification is to motivate and engage the players towards the objective of the game (Kapp, 2012, Aparicio et al., 2012). Introducing this to rehabilitation can be highly effective, cost-effective in the right contexts, as well as an efficient way of helping individuals participate in society (Wood et al., 2003). Engaging patients in games which objective is to rehabilitate has previously demonstrated positive outcomes. Moreover, gamification has been used in several health care settings in a number of different ways for a
range of illnesses and disabilities. However, gamification is complex when it comes to health care as it is applied differently with everything from self-designed system, to commercial games and systems, to virtual reality, and robotics (Palacios-Navarro, García-Magarino, & Ramos-Lorente, 2015; Sin & Lee, 2013; Spencer et al., 2008). One of the main goals of these gaming scenarios is to increase the motivation of patients in order to complete the frequently repetitive movements that are required for rehabilitation (Laver, George, Thomas, Deutsch, & Crotty, 2012). Furthermore, games can facilitate for rehabilitative movements (Ruivo, 2014) and contribute to evaluating patients’ current state (Olesh et al., 2014).

The effectiveness of gamification on rehabilitation and motivation seems to be positive, but it is difficult to draw any long-term conclusions from previous studies (Thomson, Pollock, Bugge, & Brady, 2014; Webster & Celik, 2014). Ruivo (2014) conducted a review of the evidence for the effect of active video gaming in the rehabilitation of cardiac illnesses. There were promising outcomes for the patients, but the data directly on impact were almost non-existent. A Cochrane review on the effect of virtual reality on stroke rehabilitation found that there were statistically significant improvements in the use of upper limbs and activities of daily living. However, there were typically small sample sizes and poor reporting in the majority of the studies (Laver et al., 2012). The fact that the use of games and gamification show positive results in terms of rehabilitation is evident in a large range of studies. However, these studies also often have poor methodology, poor reporting, or no indication of long term effects. This is the case in reviews and meta-analyses evaluating rehabilitation by gamification of Cerebral Palsy (Mitchell, Ziviani, Oftedal, & Boyd), balance (Booth, Masrud, Connell, & Bath-Hextall, 2013), Multiple Sclerosis (Taylor & Griffin, 2014), traumatic brain injury (Pietrzak, Pullman, & McGuire, 2014), and sensorimotor disorders (Sandlund, McDonough, & Häger-Ross, 2009).

Although there is a range of positive results for the use of gamification in rehabilitation settings there is currently no systematic knowledge of the field. There is a need for a framework in which to investigate the effect and impact more closely. Aparicio et al (2012) suggest that in order to make the process of gamification effective there has to be a clear identification of the main and underlying objectives, a clear selection of the game mechanics, and an analysis of the effectiveness based on fun, satisfaction, and quality. The current state of the research is not in line with this framework, nor any other framework.
Therefore, there are still unanswered questions about how to best and most efficiently implement gamification in rehabilitation.

1.4 Commercially available rehabilitation

The field of research on gamification covers a range of topics, not only in terms of where it is applied, but also how it is applied. An extensive component of the field of gamification is the use of commercial video gaming. In this context commercial video gaming indicates the games and consoles that are available off the shelf, and it is a potentially efficient way to implement gamification in rehabilitation. The expertise in the knowledge of engaging and captivating video gaming is in the commercial market, and it is potentially beneficial to transfer this into rehabilitation. In relation to rehabilitation, commercial video games might have a bigger potential to not only facilitate for movements, but also engage the patients in more emotional and challenging game scenarios compared to serious games, and thereby create a better gaming experience (McGonigal, 2011).

There have been a few reviews that have investigated the use of commercial video gaming in several rehabilitation settings and found positive results. Taylor, McCormick, Shawis, Impson, and Griffin (2011) did a literature review on activity promoting gaming systems and their ability to rehabilitate. They found that the Nintendo Wii increases energy expenditure and is comparable to walking, in addition to being safe for patients. However, it was not comparable to real life sports. Thomson et al. (2014) and Pietzak, Cotea, and Pullman (2014) studied the effects of commercial video games on the rehabilitation of stroke. It was found that the devices encourage repetitions of movements that are beneficial for these patients, and there were promising results for the effectiveness of these interventions. The potential of using commercial video gaming in rehabilitation is therefore great, however, to this date there is no complete compendium of this field of research.

There are a number of commercial consoles and games that have been used in rehabilitation settings. The two most popular consoles are the Nintendo Wii (occasionally with the balance board) and the Xbox Kinect. These consoles have been used in a large range of studies. The Nintendo Wii has most frequently been used for balance (e.g. Bainbridge, Bevans, Keeley, & Oriel, 2011), while the Kinect is used in several instances, for example to rehabilitate stroke patients (e.g. Sin & Lee, 2013). The Kinect is frequently used for motion capture and for assessing the movements of patients, while the Nintendo Wii is used
primarily for motivational purposes and facilitating movements. Although, the Kinect is frequently used for this purpose there are no studies that have compiled the results of these experiments. Furthermore, a compiling of evaluations of the Nintendo Wii is also lacking. Even though they are the most frequently used consoles, the reliability and validity of the measures and data that they provide have rarely been investigated for rehabilitative purposes, and there exists no compilation of these studies to date.

There are some attempts at summarising all of the research in area of commercial rehabilitation, for example the scoping review by Ravenek, Wolfe, & Hitzig (2015). They attempted to encompass the whole field but excluded a large range of studies in their search strategy. Despite their statement that there is a need for a broad review of this field, the study by Ravenek et al (2015) only included 30 articles. Furthermore, they were not able to conclude regarding the effectiveness of these kinds of interventions, as there were too few studies and the methods were not rigorous. Several other studies also comment that this field of research is characterised by small sample sizes and not enough empirical evidence, as well as poor reporting (Taylor et al., 2011; Thomson et al., 2014; Pietzak et al., 2014). On the other hand, the potential benefits of using commercial video gaming in rehabilitation are immense. Thereby, the empirical studies should move forward in a clearer direction. While the reviews and meta-analyses on the use of commercial video gaming in rehabilitation settings are few and far in-between, there exists a large volume of studies in the topic. The question therefore remains as to whether or not it is possible to conclude anything about the use and effectiveness of commercial video gaming in rehabilitation with the knowledge from existing studies.

1.5 Creating an overview

This study aims to summarise a developing and scattered field of research, consequently the selection of a method is important. There are several ways of creating an overview of a given field of research. This includes meta-analyses, literature reviews, and systematic reviews. However, the current state of this field and the poor reporting that exists makes these methods unfeasible at this stage. Furthermore, there is a need for an extensive overview before the field grows even further. Therefore, a scoping review will be conducted. Arksey and O’Malley (2005) define scoping reviews as a broad literature review that aims to map the existing literature in terms of key concepts. A scoping review is not
necessarily as in depth as a systematic review, but rather aims to include all types of findings in a given field of research. Many see scoping reviews as a simpler and more rapid systematic review (Pham et al., 2014; Davis, Drey, & Gould, 2009; Grant & Booth, 2009). However, several researchers argue that a scoping review is a method in its own right and can yield important and useful results (Anderson, Allen, Peckham, & Goodwin, 2008; Davis, Drey, & Gould, 2009).

Arksey and O’Malley (2005) suggest four purposes for a scoping review – to look at the range, nature, and extent of the previous research on a topic, to determine whether a systematic review should be undertaken, to compile and outline previous research on the topic, or to identify gaps in the previous research. In the case of this study several of the purposes for scoping reviews are relevant, firstly this article will attempt to summarise the existing literature as well as looking at the range, nature and extent of it. Simultaneously, gaps in the literature will be identified. Furthermore, this study will comment on the future of this field, and analyse the pivotal components.

### 1.6 Aim of this study

The aim of this study is to investigate the current state of the research on the use and implementation of commercial video games in rehabilitation. Specifically, it aims to address the issue of whether the measurements from commercial consoles can be used in rehabilitation settings. Even though there is a widespread research in the field of gamification in rehabilitation, there is little consistencies between the studies and a lack of overview of the entire field. Therefore, this scoping review will summarise the whole field and comment on the different elements of it. Further, it will focus on one of the foundations of the use of commercial video gaming in rehabilitation – whether or not the data from the consoles are of a high enough quality to be used in rehabilitation settings. This issue is important, as it can give an indication on how commercial consoles can be used in rehabilitation settings. This will be achieved by investigating how the consoles hold up in test-retest studies, and how they compare to other motion capture systems or tracking devices. Lastly, whether the technology and internal validity is good enough in itself to be used in these kinds of settings. This second stage of this review the focus will be on two consoles in particular, the Microsoft Kinect and the Nintendo Wii. The fact that they are the two most popular consoles for rehabilitative purposes, and the different uses for these two
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consoles, makes them interesting to compare in terms of whether their data can be used in rehabilitation settings. The results of this review might then provide a starting point for health personnel in how they can use gamification in their work with rehabilitation.

Thereby, this scoping study has two main research questions:

1) What is the current state of the field of research on the use and implementation of commercial video gaming in rehabilitation?

2) What is known about the quality of measurements from commercial consoles regarding rehabilitation?
   a) What is known about the reliability of the measurements?
   b) What is known about the validity of the measurements?
   c) What is known about the clinical usefulness of the measurements?
2. Method

This project is part of a larger project at Sunnaas Sykehus, where they aim to incorporate commercial video gaming in their rehabilitation process. This scoping review was conducted by two master students at the University of Oslo (UiO), including the author of this study, in cooperation with the academic staff at UiO, namely Cato A. Bjørkli, and health practitioners at Sunnaas Sykehus. The scoping review, in terms of the development of search strategy and the screening and coding process, was conducted by the students, while consulting with the University’s library and the stakeholders both in academia and at Sunnaas.

2.1 Scoping framework

Scoping reviews have become more popular in recent years, and most studies are published after 2012 (Pham et al., 2014). Thereby, there has been a call for a proper and extensive framework and definition of scoping reviews. This study will use the framework proposed by Arksey and O’Malley in 2005, with the enhancements suggested by Levac, Colquhoun, and O’Brien (2010) as well as Daudt, Mossel, and Scott (2013). Arksey and O’Malley’s (2005) framework consists of five stages, with an additional optional sixth stage, which goal is to make the process of a scoping review more transparent. Stage one is identifying the research question on which the search strategy can be built. Stage two involves identifying relevant studies through different sources and to define the limits of the scoping review. They recommend that the researches search through databases, reference lists of central articles, and the resources of other relevant organisations, networks, and conferences. Stage three is the study selection where the inclusion and exclusion criteria will have to be defined. Stage four is charting the data, or mapping the articles found in the search, in terms of key issues and themes. Decisions about what kind of information to focus on will have to be made at this stage. Finally, stage five revolves around summarising and reporting the results and presenting an overview of the literature found in the previous stages. The sixth and optional stage, which will be included in this study, is consulting with stakeholders, whom both Levac et al. (2010) and Daudt et al. (2013) recommend. There also exists some discussion about whether or not to include quality assessment in scoping reviews (Grant & Booth, 2009; Levac et al., 2010; Wagman, Håkansson, & Jonsson, 2015).
Some researchers propose that this is not relevant for scoping studies, while others advocate for its inclusion. This study will briefly assess the quality of the research found, as it is an important aspect of how the research should move forward.

### 2.2 Search strategy

This scoping review’s broad aim is to answer the research question “What is the current state of the field of research on the use and implementation of commercial video gaming in rehabilitation?” by mapping and summarising the literature in the field. The article search was done in five databases, which were chosen in collaboration with a librarian, namely Pubmed (Medline), PSYCinfo, ERIC, Scopus and Web of Science (WOS). The search string was thoroughly tested and developed in cooperation with stakeholders in academia and practitioners at Sunnaas Sykehus. Several different words, phrases, and combinations were evaluated in order to achieve a search string that was not too broad, and thus included a too large number of articles, nor too narrow. The entire process can be found in appendix 1. The final search string included several words and phrases in order to incorporate everything in the field of gamification concerning commercial video gaming and rehabilitation. The first part of the word string attempted to include every variation of relevant commercial gamification terms. The second part included several phrases that encompassed the topic of rehabilitation. The last part excluded categories of articles that were not relevant to this scoping study. The final search string is shown below:

("video game*" or gaming or videogame* or "commercial game*" or "entertainment game*" or "video rehabilitation*" or xbox or kinect or Nintendo or wii or playstation) and (rehab* or neurorehab* or cognitive or cognition or "brain injur*" or "spinal cord injur*" or stroke or "multiple sclerosis" or "cerebral palsy") not ("serious games" or app or apps or gambl* or aggress* or addiction or "gaming disorder" or radio)

The final search was conducted on 29.09.15 and there were no restrictions on either language or year of publication, however, it would have to be a journal, article or book that was published before this date. Furthermore, the reference lists of the relevant reviews, analyses, and central articles in the database were manually searched, as well as the most relevant journals, to yield the maximum number of articles.
2.3 Screening process

The next step in the framework was screening the articles titles, abstracts and keywords to evaluate if they met the inclusion criteria. The inclusion criteria were: the article must include commercial video gaming incorporated in a rehabilitation setting, either directly with the patients or testing whether it is feasible. At this point articles mentioning virtual reality were also included, as this term is not consistently used in the literature and many of these concerned commercial video gaming. Meta-analyses and reviews were also included. Articles in other languages than English were included at this stage, but were later removed. The exclusion criteria were as follows: rehabilitation of mental illnesses, including Alzheimer’s and dementia. Articles that only included healthy, or obese but otherwise healthy, participants were also excluded. Furthermore, articles that researched gaming apps were excluded, as this would be too broad for the scope of this review. Two independent raters manually screened all articles, and the agreement in this process was calculated using Cohen’s kappa. Any articles that the two raters diverged on were discussed and an agreement was reached. In all stages of this process the two raters met regularly to discuss disagreements, the criteria, and articles in general, to ensure that both were fully updated throughout.

2.4 Coding process

In the next stage the relevant articles were accessed in full-text versions and coded in terms of the inclusion and exclusion criteria. Any articles that at this stage were found to not meet the inclusion criteria were removed. After all the non-relevant articles were removed the remaining articles were categorised on the basis of a content analysis. A content analysis is a way of systematically reading and analysis a body of text, in this case articles, in order to extract meaning from it (Krippendorff, 2004; Neuendorf, 2002). Furthermore, a more narrow focus of this scoping review was decided. The articles regarding this focus were coded based on which consoles and games were used, what they were compared to, the aim of the study, the result and calculations in the study, and other notable contributions to the research field. This second part of the scoping review will attempt answer the research question “What is known about the quality of measurements regarding rehabilitation from commercial consoles?”
3. Results

This search resulted in 14262 references and later 9691 articles after duplicates were removed in the reference manager program EndNote X7. After the two raters screened through all of the 9691 articles checking them against the inclusion and exclusion criteria, a total of 1529 remained. At the end of this process a Cohen’s kappa of .840 (CI 95% .824 – .856) p<.001 was obtained, which is categorised as almost perfect (Landis & Koch, 1977). Cohen’s kappa was checked throughout the process to make sure that the criteria were rigorous enough for the two rates to be in agreement. Table 1 shows the development of the kappa value in the initial screening process.

<table>
<thead>
<tr>
<th>Range calculated</th>
<th>Kappa value</th>
<th>Confidence interval</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-35</td>
<td>.268</td>
<td>-.057 – .593</td>
<td>p=.110</td>
</tr>
<tr>
<td>36-70</td>
<td>.400</td>
<td>.010 – .790</td>
<td>p=.016</td>
</tr>
<tr>
<td>71-100</td>
<td>.783</td>
<td>.373 – 1.193</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>101-200</td>
<td>.851</td>
<td>.702 – .992</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>201-300</td>
<td>.831</td>
<td>.700 – .962</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>301-500</td>
<td>.669</td>
<td>.542 – .796</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>501-1000</td>
<td>.800</td>
<td>.743 – .857</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>1001-4846</td>
<td>.878</td>
<td>.856 – .900</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>4847-9691</td>
<td>.827</td>
<td>.802 – .852</td>
<td>p&lt;.001</td>
</tr>
</tbody>
</table>

Table 1: Cohen’s Kappa throughout the screening process

The agreement between the raters was not adequate in the beginning of the process, but it quickly developed into an acceptable and later almost perfect value as the two raters discussed the inclusion and exclusion criteria, and the individual articles.

After a manual search it was found that 371 of the 1529 relevant references were duplicates. There were also 165 articles that were not available in full-text versions.

A manual search of the 49 reviews and meta-analyses yielded another 4 articles. Furthermore, it also became apparent that one reference in the database was a conference paper, which yielded 23 additional relevant articles.

Finally, when scrutinising the relevant references in full-text versions it was found that another 347 references were excluded because they did not include commercial video gaming or were not relevant in some other way, and another 42 articles were excluded due
to language barriers. After this process a total of 631 articles remained, and they were included in the further analysis. The whole process and the corresponding number can be found in figure 1.

![Screening process diagram](image)

**Figure 1: Screening process**

### 3.1 Themes in the database

The remaining 631 articles were then categorised in themes based on a content analysis. Due to time limitations this coding process was initially executed by one researcher and then scrutinised at a later point by the second researcher. A brief outline of all the themes that were developed is provided in table 2 below.
<table>
<thead>
<tr>
<th>Category</th>
<th>No. of articles</th>
<th>Content</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluations</td>
<td>92</td>
<td>This category includes articles where researchers in several fields have evaluated whether or not commercial gamification should be used in rehabilitation. It also includes the views of patients, their caretakers, and health personnel on gamification in rehabilitation.</td>
<td>These articles illustrate how extensive the research on gamification in rehabilitation is, as both researchers and the individuals involved directly in rehabilitation can evaluate its value.</td>
</tr>
<tr>
<td>Analyses/Reviews</td>
<td>49</td>
<td>Meta-analyses, systematic reviews, literature reviews, etc. of gamification in rehabilitation.</td>
<td>The reference lists of these articles were manually searched.</td>
</tr>
<tr>
<td>Tele-rehabilitation</td>
<td>26</td>
<td>The articles in this category focus on tele-rehabilitation in combination with commercial video gaming.</td>
<td>The term tele-rehabilitation is loosely applied and some of the articles in this category could be included in other categories.</td>
</tr>
<tr>
<td>Robotics</td>
<td>4</td>
<td>The articles in this category use commercial video gaming in combination with robotic rehabilitation.</td>
<td>Some use of commercial video gaming, but not consistent.</td>
</tr>
<tr>
<td>Developing accessibility</td>
<td>13</td>
<td>These articles evaluate and test how commercial video gaming can be made accessible for people with disabilities.</td>
<td>This is extended to how commercial video gaming can be used in rehabilitation.</td>
</tr>
</tbody>
</table>
Firstly, the Kinect will be analysed in terms of reliability by summarising the test-retest measurements and data from the commercial consoles Kinect and Nintendo Wii. In order to achieve this, the data from the studies in this category will be investigated in several steps. The second part of the analysis looks at the validity and reliability of the commercial consoles only. In order to achieve this, the data from the studies in this category will be investigated in several steps.

### Table 2: Themes developed from the database of articles

<table>
<thead>
<tr>
<th>Category</th>
<th>No. of articles</th>
<th>Content</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurements</td>
<td>69</td>
<td>This category is divided into three subcategories:</td>
<td>This research creates a grounding on which gamification in rehabilitation could be justified.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>assessment of the console, assessment of diagnosis, and</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>assessment of movements. Concerning respectively</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>assessing the reliability of consoles, the feasibility of using</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>commercial video gaming to assess diagnoses, and the</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>consoles ability to facilitate movements.</td>
<td></td>
</tr>
<tr>
<td>Commercial consoles only</td>
<td>157</td>
<td>The articles in this category only use commercial video</td>
<td>Although these articles often use games designed by researchers rather than commercial games, the consoles are still commercially available.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>game consoles and not their respective games in rehabilitation.</td>
<td></td>
</tr>
<tr>
<td>Commercial games only</td>
<td>16</td>
<td>The research in this category only uses commercial video games in</td>
<td>Several diagnoses and games are represented here.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>combination with a computer in rehabilitation.</td>
<td></td>
</tr>
<tr>
<td>Commercial consoles and games</td>
<td>205</td>
<td>This category of research includes every article that uses both</td>
<td>This category, while broad, shows that commercial video gaming has been extensively researched in terms of rehabilitation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>commercial consoles and games in rehabilitation of any kind of diagnosis or illness.</td>
<td></td>
</tr>
</tbody>
</table>
values. Then in the validity will be investigated by summarising the studies comparing it to other motion capture systems and tracking devices. The results from studies that investigate if the Kinect is able to discriminate movements will also be summarised. Secondly, a similar summarisation of the studies investigating the Nintendo Wii will be presented. In both of these steps an interpretation of the implications of the result will be done by categorising them as poor, moderate, or high. Lastly, studies that evaluate whether the measurements from the Kinect and Nintendo Wii are able to assist health personnel in diagnosing and evaluating patients will be investigated.

3.2.1 Kinect

The Microsoft Kinect is a motion capture system that consists of a depth and a RBG (Red, Green, Blue) camera, an infrared laser speckle pattern projector and a multi-array microphone, which purpose is to sense 3D movements (Tanaka et al., 2012). This following section will investigate the reliability and validity of the Kinect in terms of the motion capture data derived from it.

Table 3 summarises the test-retest results all of the studies looking at the motion tracking data from Kinect. These are the studies that have two separate sets of measurements from the Kinect and have compared their values. All of these studies reported their test-retest values in Intra-Class Correlations (ICC), which indicates how two groups compare to each other, or the reliability between them. These values can be described as poor (0-0.3), moderate (0.4-0.6), or strong (>0.7).
All of the studies find ICC values of over .70 for different kinds of movements, which means that the Kinect shows excellent test-retest results. Furthermore, the 83% of the results are in the high implication range. Several body parts have also been tested and although they show different values, most of them are in the acceptable range.

The next step in the analysis is to see how the Kinect compares to other motion capture systems (MCS) used in rehabilitation settings, as summarised in table 4 below.

Table 3: Test-retest results of the Kinect, reported in Intra-Class Correlations (ICC)

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Gait</th>
<th>Shoulder</th>
<th>Elbow</th>
<th>Trunk</th>
<th>Hip</th>
<th>Knee</th>
<th>Ankle</th>
<th>Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behrens et al</td>
<td>2014</td>
<td>&gt;.90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clark et al</td>
<td>2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huber et al</td>
<td>2014</td>
<td>&lt;.26</td>
<td>&lt;.71</td>
<td>&gt;.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bonnechere et al</td>
<td>2013</td>
<td>&gt;.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clark et al</td>
<td>2015</td>
<td>&lt;.24</td>
<td>&lt;.70</td>
<td>&gt;.73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobini et al</td>
<td>2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Test-retest results of the Kinect, reported in Intra-Class Correlations (ICC)

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The next step in the analysis is to see how the Kinect compares to other motion capture systems (MCS) used in rehabilitation settings, as summarised in table 4 below.
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>MCS</th>
<th>Body</th>
<th>Shoulder</th>
<th>Elbow</th>
<th>Wrist/fingers/hand</th>
<th>Trunk</th>
<th>Hip</th>
<th>Knee</th>
<th>Head</th>
<th>Reported results</th>
<th>Int. of results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nixon et al</td>
<td>2013</td>
<td>VICON</td>
<td></td>
<td>.10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Average absolute error</td>
<td>Moderate</td>
</tr>
<tr>
<td>Tao et al</td>
<td>2013</td>
<td>Optotrack</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Constant and variable error</td>
<td>Moderate</td>
</tr>
<tr>
<td>Olesch et al</td>
<td>2014</td>
<td>Impulse</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Correlation</td>
<td>Moderate</td>
</tr>
<tr>
<td>Bonnechere et al</td>
<td>2013</td>
<td>VICON</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Correlation, session 1 &amp; 2</td>
<td>Moderate</td>
</tr>
<tr>
<td>Lim et al</td>
<td>2015</td>
<td>VICON</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Correlation x, y, &amp; z</td>
<td>Moderate</td>
</tr>
<tr>
<td>Li &amp; Pathiran</td>
<td>2014</td>
<td>VICON</td>
<td>±1.75°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Difference</td>
<td>Moderate</td>
</tr>
<tr>
<td>Zhao et al</td>
<td>2014</td>
<td>CORTEX</td>
<td>±10°</td>
<td></td>
<td>&gt;9°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Error</td>
<td>Moderate</td>
</tr>
<tr>
<td>Fernandez-Baena</td>
<td>2012</td>
<td>VICON</td>
<td>&lt;13°</td>
<td></td>
<td>&lt;10°</td>
<td>&lt;10°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Error</td>
<td>Moderate</td>
</tr>
<tr>
<td>Clark et al</td>
<td>2012</td>
<td>VICON</td>
<td>ICC&gt;.9</td>
<td>ICC&gt;.9</td>
<td>ICC&gt;.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ICC</td>
<td>High</td>
</tr>
<tr>
<td>Huber et al</td>
<td>2015</td>
<td>3D motion analysis</td>
<td>ICC&gt;.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ICC of different movements</td>
<td>High</td>
</tr>
<tr>
<td>Oh et al</td>
<td>2014</td>
<td>CROM</td>
<td>ICC&gt;.86</td>
<td>ICC&gt;.86</td>
<td>ICC&gt;.86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ICC of different movements</td>
<td>High</td>
</tr>
<tr>
<td>Meldaf</td>
<td>2013</td>
<td>VICON</td>
<td>&lt;12°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Max error</td>
<td>Moderate</td>
</tr>
<tr>
<td>Gieser et al</td>
<td>2014</td>
<td>VICON</td>
<td>.057m (.036)</td>
<td>.079m (.061)</td>
<td>.084m (.077)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean (SD) difference</td>
<td>Poor</td>
</tr>
<tr>
<td>Clark et al</td>
<td>2013</td>
<td>VICON</td>
<td>3.2° (2.2°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean (SD) difference</td>
<td>High</td>
</tr>
<tr>
<td>Scano et al</td>
<td>2014</td>
<td>BTS</td>
<td>3.32° ± 2.8°</td>
<td>5.60°±6.35°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean difference</td>
<td>Moderate</td>
</tr>
<tr>
<td>Huber et al</td>
<td>2014</td>
<td>Magnetic tracker system</td>
<td>3°-24.7°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean difference of different movements</td>
<td>Moderate</td>
</tr>
<tr>
<td>Chang et al</td>
<td>2012</td>
<td>Optitrack</td>
<td>Comparable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Only graphs</td>
<td>Moderate</td>
</tr>
<tr>
<td>Paolini et al</td>
<td>2013</td>
<td>VICON</td>
<td>r&gt;.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gait variables</td>
<td>High</td>
</tr>
</tbody>
</table>
The table shows that Kinect has been compared in a number of different ways to several different motion capture systems. It is also evident that the Kinect is comparable to an array of motion capture systems by looking at the implication levels, which are mostly in the moderate range, with some high. To further look into the validity of the Kinect the next step is to see how it matches other tracking devices, as shown in Table 5 below.

Table 5: Kinect compared to tracking devices

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Tracking device</th>
<th>Whole body</th>
<th>Shoulder</th>
<th>Arm</th>
<th>Hand</th>
<th>Reported results</th>
<th>Int. of results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barandas et al</td>
<td>2014</td>
<td>Accelerometer</td>
<td>2.91°, 13.13°, 18.02°</td>
<td></td>
<td></td>
<td></td>
<td>Mean error difference for abduction, flexion, and rotation</td>
<td>Poor</td>
</tr>
<tr>
<td>Scherer et al</td>
<td>2012</td>
<td>EMG</td>
<td>&lt;250ms</td>
<td></td>
<td></td>
<td></td>
<td>Time-lag compared to EMG</td>
<td>High</td>
</tr>
<tr>
<td>Lee et al</td>
<td>2015</td>
<td>Goniometer</td>
<td>ICC&gt;.864</td>
<td></td>
<td></td>
<td></td>
<td>ICC for several movements</td>
<td>High</td>
</tr>
<tr>
<td>Gal et al</td>
<td>2015</td>
<td>Goniometer</td>
<td>Identical results</td>
<td></td>
<td></td>
<td></td>
<td>Joint angles</td>
<td>High</td>
</tr>
<tr>
<td>Huber et al</td>
<td>2015</td>
<td>Goniometer</td>
<td>&lt;16.6°</td>
<td></td>
<td></td>
<td></td>
<td>Difference for different views and movements</td>
<td>Moderate</td>
</tr>
<tr>
<td>Huber et al</td>
<td>2014</td>
<td>Goniometer</td>
<td>&lt;27 ms</td>
<td>&lt;8°/sec</td>
<td></td>
<td></td>
<td>Mean difference for stride length and arm angular velocities</td>
<td>High</td>
</tr>
<tr>
<td>Gabel et al</td>
<td>2012</td>
<td>Gyroscope and pressure sensor</td>
<td>&lt;17.8°</td>
<td></td>
<td></td>
<td></td>
<td>Mean difference</td>
<td>Moderate</td>
</tr>
<tr>
<td>Bo et al</td>
<td>2011</td>
<td>Accelerometer and gyroscope</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Can be combined with Kinect</td>
<td></td>
</tr>
</tbody>
</table>
The studies that validate the Kinect by comparing it to tracking devices, such as accelerometers and goniometers, show similarities to those who compare it to motion capture systems. Experiments with the same devices and experimental setup still diverge in their results. It is also apparent that the Kinect to some degree has valid measurements compared to other tracking devices, as many of the results have high implications.

Finally, studies that investigate whether the Kinect is able to discriminate between correct and incorrect movements both in terms of accuracy of discrimination and accuracy in terms of millimetres and angles is summarised in table 6 below.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Whole body</th>
<th>Shoulder</th>
<th>Elbow</th>
<th>Hand</th>
<th>Foot</th>
<th>Int. of results</th>
<th>Reported results</th>
<th>Max error</th>
<th>Standard deviation</th>
<th>Correct detections</th>
<th>Detection error and step length error</th>
<th>Expected error</th>
<th>Detection error</th>
<th>Root mean square error of x, y, and z</th>
<th>Correct detections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strbac et al</td>
<td>2012</td>
<td>1 cm</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oliver et al</td>
<td>2015</td>
<td>&lt;1mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Da Gama et al</td>
<td>2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cancela et al</td>
<td>2014</td>
<td>20.51%</td>
<td>11.78%</td>
<td></td>
<td></td>
<td></td>
<td>Moderate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobini et al</td>
<td>2013</td>
<td>&lt;25mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobini et al</td>
<td>2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gonzales-Ortega et al</td>
<td>2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liu et al</td>
<td>2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Kinect’s ability to discriminate movements
With 88% of the implications in the high range it seems that the Kinect is able to discriminate between correct and incorrect movements to an accurate degree.

Three studies are not included in the previous tables due to the complexity of the different methods and reporting in the articles included in this analysis. These three studies are included in the measurements theme, but were not possible to place in the tables provided for separate reasons. A short description of these studies is provided.

Vernon et al (2015) compared the results of the Kinect with a clinical test (Timed Up and Go) and found ICC scores of over .73 and correlations of over .70. Furthermore, Pedro and Caurin (2012) found that the Kinect’s best range was at a distance of 1.5m. Lastly, Pogrzeba et al (2012) was not included because they did not provide any numbers or a clear method.

Although there are little consistencies across the studies looking at the validity of the Microsoft Kinect it seems that the console’s reliability and validity is acceptable. However, there is an issue of motion detection when the view of the Kinect is occluded or when the movement is not in the depth direction.

**3.2.2 Nintendo Wii**

This section will investigate the Nintendo Wii and Nintendo Wii Balance Board reliability and validity, as previously done with the Kinect. The Nintendo Wii consists of an infrared camera and a handheld controller with a gyrometer and an accelerometer. Furthermore, the Nintendo Wii Balance Board consists of a pressure sensor that the player stands on (Tanaka et al., 2012). There are far fewer studies looking into the measurements of the Nintendo Wii, so they will all be summarised in table 7 provided below, where Nintendo Wii is shortened to NW and the balance board to NW BB.
### Table 7: Results of studies on Nintendo Wii (NW) and Nintendo Wii Balance Board (NW BB)

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Ground truth</th>
<th>Console</th>
<th>Game</th>
<th>Centre of pressure</th>
<th>Balance</th>
<th>Other</th>
<th>Reported results</th>
<th>Int. of results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kho et al</td>
<td>2012</td>
<td>Assesses safety</td>
<td>NW</td>
<td>Wii sports</td>
<td></td>
<td></td>
<td></td>
<td>Only evaluated as safe</td>
<td></td>
</tr>
<tr>
<td>Sapsonik et al</td>
<td>2010</td>
<td>Nothing tested yet</td>
<td>NW</td>
<td>Wii sports, Cooking Mama</td>
<td></td>
<td></td>
<td></td>
<td>Preliminary study</td>
<td></td>
</tr>
<tr>
<td>Purkavatsha et al</td>
<td>2012</td>
<td>Computer calculated with gyroscope</td>
<td>NW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Correlation of the Wiimote with acceleration and angular velocity</td>
<td>High</td>
</tr>
<tr>
<td>Clark et al</td>
<td>2010</td>
<td>AMTI, test-retest</td>
<td>NW BB</td>
<td>ICC&gt;.66, ICC&gt;.77</td>
<td></td>
<td></td>
<td></td>
<td>ICC for test-retest and AMTI for different conditions</td>
<td>Moderate</td>
</tr>
<tr>
<td>Holmes et al</td>
<td>2012</td>
<td>AMTI</td>
<td>NW BB</td>
<td>ICC&gt;.92</td>
<td></td>
<td></td>
<td></td>
<td>ICC for different conditions</td>
<td>High</td>
</tr>
<tr>
<td>Wikstrom</td>
<td>2012</td>
<td>Clinical balance tests</td>
<td>NW BB</td>
<td>R&lt;.50</td>
<td></td>
<td></td>
<td></td>
<td>Correlation of balance scores from Wii Fit and clinical tests</td>
<td>Moderate</td>
</tr>
<tr>
<td>Prosperini et al</td>
<td>2014</td>
<td>Force platform (ProKin)</td>
<td>NW BB</td>
<td>ICC&gt;.87, ICC&gt;.77</td>
<td></td>
<td></td>
<td></td>
<td>ICC for test-retest and between devices</td>
<td>High</td>
</tr>
<tr>
<td>Bower et al</td>
<td>2014</td>
<td>Test-retest, clinical tests</td>
<td>NW BB</td>
<td>ICC&gt;.82</td>
<td></td>
<td></td>
<td></td>
<td>ICC of balance variables</td>
<td>High</td>
</tr>
</tbody>
</table>
As shown in the table the Nintendo Wii and the Balance Board compares well to other tracking devices and is reliable in test-retest situations with implications in the moderate to high range. On the other hand, one study only assessed the apparent safety of playing the games and another was a preliminary study without results.

Two studies were not included in this table because they assessed various games that can be played on the Nintendo Wii with a qualitative rather than quantitative approach (Deutsch et al, 2011; Burn et al, 2014).

3.2.3 Ability to diagnose and evaluate

The last part of this analysis will look at whether or not the two consoles are able to diagnose and evaluate impairments and illnesses in rehabilitation settings. More concisely, whether the data from the two consoles is able to contribute to a more accurate diagnosis of physical impairments and illnesses. This section will also investigate whether the data can provide information about, and discriminate improvement in, patients. This is summarised in table 8 provided below.
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Console</th>
<th>Diagnosis evaluated</th>
<th>Measured</th>
<th>Point of diagnosis</th>
<th>Result</th>
<th>Int. of result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobini et al</td>
<td>2015</td>
<td>K</td>
<td>Separation between healthy individuals and stroke patients</td>
<td>Speed, path, and angles of arm</td>
<td>Cut-off point that is larger than minimal detectable difference</td>
<td>Able to separate them, even after one month</td>
<td>High</td>
</tr>
<tr>
<td>Kusaka et al</td>
<td>2014</td>
<td>K</td>
<td>Case study of a patient with impaired arm movements</td>
<td>Range of motion</td>
<td>Improvement</td>
<td>Able to measure improvement</td>
<td>Moderate</td>
</tr>
<tr>
<td>Olesh et al</td>
<td>2014</td>
<td>K</td>
<td>Upper extremity movement impairment</td>
<td>Quality of movement</td>
<td>Categorisation accuracy</td>
<td>Assessment of severity of impairment as good as assessment as clinical assessment</td>
<td>High</td>
</tr>
<tr>
<td>Stone et al</td>
<td>2014</td>
<td>K</td>
<td>Gait impairments</td>
<td>Change in gait</td>
<td>Cut-off point in change</td>
<td>Gave helpful alerts in three case studies</td>
<td>Moderate</td>
</tr>
<tr>
<td>Otten et al</td>
<td>2014</td>
<td>K</td>
<td>Fugel-Meyer test of the upper body</td>
<td>Arm movements</td>
<td>Categorisation accuracy</td>
<td>Average accuracy of 86.1%</td>
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</tr>
<tr>
<td>Lee et al</td>
<td>2015</td>
<td>K</td>
<td>Range of motion in adhesive capsulitis of the shoulder</td>
<td>Range of motion</td>
<td>Cut-off point</td>
<td>Diagnosed 10 of 12 patients</td>
<td>High</td>
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<tr>
<td>Kastaniotis et al</td>
<td>2014</td>
<td>K</td>
<td>Gait impairment from 2-minute walk test</td>
<td>Gait variables</td>
<td>Categorisation accuracy</td>
<td>88.2% accuracy</td>
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<tr>
<td>Dolatabadi et al</td>
<td>2014</td>
<td>K</td>
<td>Gait impairment in total hip replacement patients</td>
<td>Change in mobility</td>
<td>Changes</td>
<td>Could detect significant changes in mobility</td>
<td>Moderate</td>
</tr>
<tr>
<td>Metteo et al</td>
<td>2014</td>
<td>NW</td>
<td>Balance in patients with mild traumatic brain injury</td>
<td>Balance</td>
<td>Frequency count of loss of balance</td>
<td>Could not accurately describe the patients state</td>
<td>Poor</td>
</tr>
<tr>
<td>Martin-Moreno et al</td>
<td>2008</td>
<td>NW</td>
<td>Movement impairment in shoulder, elbow, and wrist</td>
<td>Range of motion</td>
<td>Improvement</td>
<td>Could detect improvement in range of motion that can be used by physicians.</td>
<td>High</td>
</tr>
<tr>
<td>Yeh et al</td>
<td>2014</td>
<td>NW BB</td>
<td>Balance impairment</td>
<td>Centre of pressure and other indices</td>
<td>Categorisation accuracy</td>
<td>Could easily discriminate between patients and healthy controls (95%) but more difficult when discriminating between patients in different stages of recovery.</td>
<td>High</td>
</tr>
<tr>
<td>Clark et al</td>
<td>2014</td>
<td>NW BB</td>
<td>Weight bearing asymmetry</td>
<td>Weight bearing asymmetry</td>
<td>Higher values</td>
<td>People who have undergone anterior cruciate ligament reconstruction surgery had higher values of weight bearing.</td>
<td>High</td>
</tr>
<tr>
<td>Foo et al</td>
<td>2013</td>
<td>NW BB</td>
<td>Weight bearing asymmetry</td>
<td>Weight bearing asymmetry</td>
<td>Improvement</td>
<td>Could assess weight-bearing asymmetry and detect improvement.</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
Both consoles are to some degree able to assess and diagnose different forms of impairments in patients, with 93% of implications in the moderate to high range.

While many of the studies on both Kinect and Nintendo Wii show promising results for using the data in rehabilitation settings there are little consistencies between the studies in what the consoles are compared to and how the data is used. Furthermore, a number of the studies use some kind of filtering of the data before it is analysed. This means that the noise from either the Kinect or the Nintendo Wii is filtered out and the relevant data is left. In the studies done on Kinect 14 of the 52 studies use a filter on the raw data, or 27%. In the studies on the Nintendo Wii 4 out of the 15 studies use a filter, also 27%. 
4. Discussion

The aim of this study was to summarise the current state of the research on the use of commercial video games in rehabilitation. Specifically, it aimed to address the issue of whether the measurements from commercial consoles can be used in rehabilitation settings. Therefore, a scoping study was executed in accordance with Arksey and O’Malley’s (2005) framework. Firstly, this study differed from Ravenek, Wolfe, and Hitzig (2015) by including a larger number of articles and therefore uncovering several different aspects of the field. Secondly, this study is to a greater extent able to answer the question of what is known about the current state in this field of research. The articles found as a result of the search strategy were categorised in nine independent themes. These nine themes were named according to their content – evaluations, analyses/reviews, tele-rehabilitation, robotics, developing accessibility, commercial consoles only, commercial games only, commercial games and consoles, and measurements. Each theme encompasses a different section of the research on the use and implementation of commercial video gaming in rehabilitation.

Thereby, the more narrow research question could be based on the measurements theme: “What is known about the quality of measurements regarding rehabilitation from commercial consoles?” The reliability and validity of the measurements from both the Microsoft Kinect and the Nintendo Wii were then scrutinised by analysing the studies on this topic. It was found that although the studies in these categories were highly inconsistent, the numbers they provided concerning the measurements were promising in terms of reliability and validity. Furthermore, the clinical applicability of these measurements was investigated by looking at whether the measurements could be used for diagnosing and evaluating patients. The results from these studies are similar to the validity and reliability studies – promising but inconclusive. In the following section the different themes and their implications will be investigated and elaborated on. Furthermore, the implication of the studies that research the value of the measurements from the Kinect and the Nintendo Wii will be discussed and summarised.
4.1 The themes and their implication

The nine themes that were developed from the database, each show the current state of the research on commercial gamification in rehabilitation settings. There has been an explosion in the popularity of this topic, and thereby the research is extensive with a range of focus areas. The first theme “Evaluations” is a good demonstration of this. This theme evolves around articles that evaluate whether or not commercial video games should be used in rehabilitation settings. The fact that the views of several stakeholders are published in multiple journals illustrates just how extensive this field of research has become. However, as these viewpoints come from varying fields of research, it leads to an array of contrasting points and conclusions. The second theme “Analyses/reviews” supports the conclusions from the previous theme, as the different reviews and meta-analyses are distinct in significant ways. It is also important to note that not all of the reviews included in the database concentrate solely on the use of commercial video gaming, but they all incorporate it. However, the overall development in the field, as evident from the evaluations and reviews, advocates the use of commercial video gaming in rehabilitation.

“Tele-rehabilitation” is a theme that consists of research with a particular focus on how to implement commercial video gaming by the use of tele-rehabilitation. The term tele-rehabilitation, however, is used inconsistently and there is no agreed upon definition. The term is often applied to describe a situation where a medical practitioner can either communicate or observe a patient online. For example Gutiérrez et al (2013) used the Xbox Kinect with multiple sclerosis patients, while the session was being monitored via a videoconference by health care personnel. Golomb et al (2009), on the other hand, used Playstation 3 in a larger system for rehabilitation and did not specify how their study is relevant to tele-rehabilitation, although they use the term. The inconsistent use of terms is a prevalent issue in most of the research included in this study. For example, the term gamification is rarely used, and the term virtual reality is used loosely and can apply to almost any setting with gaming. This inconsistent use of terms makes the field enormously difficult to navigate.

The theme “Robotics” is only comprised of four articles; consequently commercial video gaming is not often used in context with robotic rehabilitation. The console or controller is commonly used in a larger system rather than a stand-alone tool for rehabilitation (e.g. Spencer et al., 2008). Similarly, the theme “Developing accessibility”
contains articles where the researchers attempt to make commercial video gaming more accessible for people with disabilities and impairments. This is usually achieved by modifying the controller in a way that makes it functional for the particular individual or diagnosis (e.g. Fanucci, Iacopetti, & Rocella, 2011). Thereby, the use of the commercial part of the console or game is limited in both themes, and the research is not directly applicable to how commercial video gaming can be implemented in rehabilitation settings. On the other hand, this can be a useful indicator for health personnel on how to incorporate gaming in rehabilitation of specific impairments.

The theme named “Commercial consoles only” contains a large number of articles where commercially available consoles have been used, but without their corresponding games. There are two main uses for the commercial consoles in these articles. The first aspect is where the console is used in a bigger, self-designed, system, as Wilson et al. (2007) is an example of. Here the Wii remote and sensor bar is used in a system with a PC, LCD panels, stereo camera and Virtools software to facilitate for the assessment of upper extremity rehabilitation. The other aspect is well demonstrated in the article by Ave, Caro, Pacapac, and Salamanca (2013). They have designed a game for the Kinect in an attempt to motivate burn victims to complete their rehabilitation. Although these two types of uses are easily distinguished, there are many different ways of implementing a commercial console in a larger system, or designing games specifically for impairments. Consequently, the methods and results of these kinds of studies diverge.

“Commercial games only” is the mirror image of the previous theme – this theme contains articles where commercially available games have been played on a computer in order to contribute to the rehabilitation process. In this category there is typically a cognitive, rather than physical, focus. For example Caglio et al (2009) attempts to rehabilitate the spatial learning capacity of a traumatic brain injury patient by playing the video game “Grand Theft Auto”. Although there are an array of different methods, diagnosis, impairments, and thereby conclusions, there is an overall cautious optimistic approach to the use of commercial video games in rehabilitation settings.

Unsurprisingly, the theme with the largest number of articles is “Commercial consoles and games”. Here the research focus on rehabilitation settings where the consoles and their corresponding games has been used directly for motivation, for specific rehabilitative movements, or both. A range of different diagnosis have been investigated in
this category, from cerebral palsy, to stroke, to burn victims, to lung impairments. Consequently, a number of different consoles and games have been scrutinised. The most popular are Nintendo Wii with either games from Wii Fit or Wii Sports, Sony Playstation with Eyetoy Play, and Xbox Kinect with corresponding (although often unspecified) games. The overall outcomes of these studies are positive to the use of consoles and games in rehabilitation, although the research is often inconsistent and unable to conclude about the long-term effects.

The last theme “Measurements” is divided into three subthemes. The first subtheme concerns the articles that assess the validity and reliability of the measurements from the commercial consoles. The second subtheme contains the articles that research whether the measurements from commercial consoles can be used to evaluate and diagnose illnesses and impairments. The third subtheme consists of articles that look at whether the commercial consoles and games facilitate for movements that can be beneficial in rehabilitation settings. The first two subcategories have been further investigated in this scoping review, and will be discussed in the next section. Thereby, the research question “What is known about the quality of measurements regarding rehabilitation from commercial consoles?” can be investigated.

4.2 Reliability and validity of the Microsoft Kinect

The reliability and validity of both the Kinect and the Nintendo Wii were investigated to answer the questions “What is known about the reliability of the measurements?” and “What is known about the validity of the measurements?” These consoles were chosen because they are the most frequently used consoles in rehabilitation settings, and thereby the research around reliability and validity centred on these. Each and every article in the database with this focus was scrutinised and the relevant numbers were extracted. In order to interpret the results, a framework was set in place where the implication of the results of the studies were categorised as either high, moderate, or poor. This was based on the numbers provided and the evaluations of the corresponding researchers. Hence, the reliability and validity of the consoles could be assessed.

Most studies researching the reliability of the Microsoft Kinect found results in the high impact range with ICCs over .70 across several measurements of body parts.
Furthermore, several studies show that the validity of the Kinect is fairly good, ranging from moderate to high. These studies have compared the Kinect to several different motion capture systems and other forms of tracking devices, and 92% fall in the moderate to high implication range. However, the Kinect’s ability to detect motion is severely limited when the view of the camera is occluded by other body parts, or when the motion is in the depth direction. This becomes an issue when the rehabilitation requires movements that conflicts with this. Furthermore, a number of these studies use some kind of filtering on the raw data from the Kinect, which means that the original data was not robust enough to be used in its own right. It is not clear how the studies have used the different kinds of filters, so the issues that exist in the raw data are not clear.

The research on the reliability and validity of commercial consoles used in rehabilitation settings has methods that intermittently bear no resemblance. This ranges from comparing the consoles to other systems by either looking at correlation of the measurements (Bonnechere et al., 2013) or the difference in measured degrees/centimetres (Gieser et al., 2014), to simply implying whether or not they are comparable (Chang et al., 2012). Furthermore, some studies only look at whether the consoles are able to discriminate between correct or incorrect movements (Da Gama et al., 2012), while others look at time lags instead of measured kinematics (Scherer et al., 2012). It is apparent that the research in this area should have a clearer framework for investigating the reliability and validity of commercial consoles in rehabilitation settings. If the data from commercial consoles are to be used in rehabilitations settings the methods in the different studies will have to be more consistent.

4.3 Reliability and validity of the Nintendo Wii

The research questions “What is known about the reliability of the measurements?” and “What is known about the validity of the measurements?” were also investigated from the Nintendo Wii. There are far fewer studies looking at the validity and reliability of the Nintendo Wii and the Nintendo Wii Balance Board, even though these consoles are frequently used in rehabilitation studies. However, the studies that are summarised in the results section find promising results for both aspects of the measurements that the Nintendo Wii provides, with implications in the moderate to high range. The studies that
provide quantitative results are quite consistent in their reporting, although the methods differ. Studies investigating the Nintendo Wii have compared it to different motion tracking devices, computer calculated motion, clinical tests, and in test-retest situations. Furthermore, there was one study that only concluded that it was safe for intensive care patients to utilise the Nintendo Wii (Kho et al., 2012), and one preliminary study where the full version is unpublished (Sapsonik et al., 2010). This section of research also has the issue of filtering data that are not inherently adequate to be valuable.

The different methods used in these studies make it challenging to conclude whether or not the data from the Nintendo Wii and Balance Board can be used in rehabilitation settings. There were also an overall small number of studies evaluating the Nintendo Wii, so the fact that several studies had no quantitative conclusion is significant. Studies that evaluate the Nintendo Wii’s validity and reliability have the same issues as studies investigating the Kinect. The console has been compared to different systems, tests, and standards, in a number of different ways. Even with the low number of studies it is difficult to find many similarities between them, which makes any conclusions about the overall quality of the measurements near impossible.

4.4 Clinical relevance of measurements

The last section of this study investigated the research question “What is known about the clinical usefulness of the measurements?” This was executed by exploring the validity and reliability of the commercial consoles in clinical and practical terms. Thereby, exploring whether the measurements could be used to evaluate and diagnose impairments and illnesses. This exploration resulted in a number of articles focusing on different impairments and diagnoses, and different ways of evaluating them. Some studies looked at whether the consoles were able to provide a cut-off point for diagnostic purposes (e.g. Lee et al., 2015). Other studies investigated whether the measurements from the consoles were able to assist in evaluating improvement in impairments (e.g. Martin-Moreno et al., 2008). Other studies also explored whether the measurements could categorise people as either a patient with impairments or as healthy individuals (e.g. Yeh et al., 2014). In all these cases the implications were moderate to high which implies that the consoles can be used in
clinical settings. However, the research needs to be more consistent and cohesive in order to conclude that commercial consoles are valuable in evaluating and diagnosing patients.

4.5 General discussion

Overall, the studies in this scoping review are optimistic about the use of commercial video gaming in a range of different rehabilitation settings. These are good news when considering the global need for rehabilitation and the large costs associated with it. The topic of commercial video gaming in rehabilitation is a trending one, and the popularity has exploded in the last decade. However, while the number and extent of articles have multiplied, the quality has not. The field is characterised by poor methods and inadequate reporting of the results. Thereby, it is difficult to conclude whether or not the use of commercial video gaming has an impact on either motivation or the general rehabilitation of patients. Moreover, there is no collected evidence on the matter of which games and/or consoles that are the most efficient in rehabilitation settings. This is lacking both in terms of which illnesses and disabilities they combine best with, and in the clinical usefulness. In many cases the consoles, games, or measures used in the intervention are neither validated nor found reliable in previous research. Further, the value of the measurements from commercial consoles remains unclear, as the studies done to this date are not consistent enough. This means that a consolidation of the conclusions is difficult, if not impossible. Furthermore, there exist little evaluations on the actual utility of commercial video gaming in rehabilitation compared to the motivational and cost-efficient aspects of it. There has to be a clearer framework for the research on commercial video gaming in rehabilitation.

When a clearer framework and direction of the research is in place, the value of use of commercial video gaming in rehabilitation settings, and health care overall, could be immense. Not only can the health sector in several countries cut the expenses on health care and rehabilitation – as is sorely needed, but the implementation and delivery of rehabilitation can become more efficient and manageable. The consoles and games in themselves are designed for easy access, and so the time spent on learning and training in conventional therapy can be significantly cut. Further, rehabilitation at home or in health care facilities with the implementation of commercial video gaming can be very flexible as the console and game are available at any hour of the day without the need for health
personnel. However, it is crucial that the games and consoles are evaluated for each disability and patient to make sure that the interface is feasible and safe.

It has been demonstrated that several different games and consoles can be implemented in the rehabilitation of several different diagnoses and illnesses. This indicates that the advantages this approach brings can be valuable in several different areas. Moreover, with the use of commercial video gaming in rehabilitation the training of health staff can be less time consuming as the games and consoles are designed with a very manageable user interface. Lastly, the advantages of having cost-effective and easily accessed measurements of patients are many, for example, the process of diagnosing and evaluating patients could become more efficient and require less expertise from health personnel in this aspect of the process.

4.6 Limitations

This study has some central limitations. While the search string proved to yield the appropriate number of articles, there is still the possibility that this scoping review has disregarded some relevant research. This is not only due to the search string, but also because of the limited time frame during the screening and coding process. The fact that this is a growing field of research is evident when conducting a new search. On the 22.04.2016 the same search was conducted and it yielded 1730 additional references. However, the Cohen’s kappa in the initial screening process was almost perfect, so the loss of potentially relevant articles at the original date is unlikely to be significant. Another issue were the unattainable articles that existed in the search database but were not in the reach of the institution of the researchers. Furthermore, the limits that were, in the end, set on language could have excluded some central articles. However, the articles included in the study often touched on the same subjects, and it is unlikely that a whole portion of the research was excluded. Finally, in the second and narrower focus of this scoping review it could be argued that a portion of the research is missing. While the research on reliability and validity of commercial consoles and games in rehabilitation settings is included, the same type of research outside the rehabilitation setting is not. In other words, there is a body of research outside the scope of this review that can potentially be relevant to rehabilitation settings. However, the focus of this review is on the rehabilitation setting, so these were not
included. The issue that this field of research has not properly investigated the validity and reliability of the equipment they use still stands, and this should be addressed before the field can move forward.

4.7 Future studies

Future studies should focus on bringing this field of research into a clearer direction that can yield conclusive results regarding the effectiveness and implementation of commercial video gaming in rehabilitation. After the creation of this compendium it should be clearer which aspects of the field should be improved and what the improvement should accomplish. With the current state of the research it is not possible to conclude anything about the value of the use of commercial video gaming in rehabilitation, and the most important task for future research is to address this issue. There are several advantages to the use of commercial video gaming in rehabilitation, for example cost-effectiveness and the motivational aspects, and future studies should aim to have conclusive results concerning this. Future studies should aim towards being able to conclude about the effectiveness of commercial video gaming in rehabilitation settings. This is done first and foremost by creating a framework and making it possible to conduct meta-analyses. These analyses will have to have meaningful effect sizes on different disabilities and illnesses with a range of games and consoles. Thus, it will be possible to conclude whether or not the use of commercial video gaming is effective in rehabilitation of different illnesses.

4.8 Conclusion

The research in this field is characterised by inconsistencies both in methods and reporting on the one hand, and an optimistic approach to commercial video gaming in rehabilitation on the other. The initial categorisation of the 631 articles show the extent this field of research has reached in a short amount of time, and this seems to have impacted the quality and consistency of the studies. However, with the explosion of research there is bound to be some aspects that are methodologically sound and with highly impacting results. Furthermore, commercial video gaming could contribute to a more efficient and motivating rehabilitation process, which means that the patients will improve quicker, and be able to lead a better life. At the same time the rehabilitation will be more cost-efficient.
The way forward is to be more aware of the previous research and incorporate this into the next stage of this field. This scoping study can contribute to making this field more consistent and to further the research in a productive and positive direction. Thereby, the global need for rehabilitation can be met with an approach that is both efficient and effective.
5. References


IMPLEMENTATION OF COMMERCIAL VIDEO GAMING IN REHABILITATION

In *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2012 6th International Conference on* (pp. 159-162). IEEE.


Spencer, S. J., Klein, J., Minakata, K., Le, V., Bobrow, J. E., & Reinkensmeyer, D. J. (2008). A low cost parallel robot and trajectory optimization method for wrist and forearm...


### 6. Appendix 1

#### Development of the search string

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IMPLEMENTATION OF COMMERCIAL VIDEO GAMING IN REHABILITATION

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IMPLEMENTATION OF COMMERCIAL VIDEO GAMING IN REHABILITATION

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("video game*" or gaming or videogame* or "commercial game*" or "entertainment game*" or "video rehabilitation*" or Nintendo or wii) and (rehab* or neurorehab* or cognitive or cognition) not ("serious games" or app or apps)

14772

("commercial videogame*" or "commercial video game*" or "entertainment game*" or "video rehabilitation*") and (rehab*) not ("serious games" or app or apps)

30

("commercial videogame*" or "commercial video game*" or "entertainment game*" or "video rehabilitation*") and (rehab* or neurorehab*) not ("serious games" or app or apps)

30

("commercial videogame*" or "commercial video game*" or "entertainment game*" or "video rehabilitation*") and (rehab* or neurorehab* or cognitive or cognition) not ("serious games" or app or apps)

79

("video game*" or gaming or videogame* or "entertainment game*" or "video rehabilitation*" or xbox) and (rehab* or neurorehab*) not ("serious games" or app or apps)

3014
("video game*" or gaming or videogame* or "entertainment game*" or "video rehabilitation*" or xbox or kinect) and (rehab*) not ("serious games" or app or apps)

("video game*" or gaming or videogame* or "entertainment game*" or "video rehabilitation*" or xbox or kinect or Nintendo) and (rehab*) not ("serious games" or app or apps)

("video game*" or gaming or videogame* or "entertainment game*" or "video rehabilitation*" or xbox or kinect or Nintendo or wii) and (rehab*) not ("serious games" or app or apps)

("video game*" or gaming or videogame* or "entertainment game*" or "video rehabilitation*" or xbox or kinect or Nintendo or wii or playstation) and (rehab*) not ("serious games" or app or apps)

("video game*" or gaming or videogame* or "entertainment game*" or "video rehabilitation*" ) and (rehab*) not ("serious games" or app or apps)

("video game*" or gaming or videogame* or "entertainment game*" or "video rehabilitation*" ) and (rehab* or neurorehab*) not ("serious games" or app or apps)

("video game*" or gaming or videogame* or "commercial game*" or "entertainment game*" or "video rehabilitation*" or xbox or kinect or Nintendo or wii or playstation) and (rehab* or neurorehab* or cognitive or cognition) not ("serious games" or app or apps or gambl*)

("video game*" or gaming or videogame* or "commercial game*" or "entertainment game*" or "video rehabilitation*" or xbox or kinect or Nintendo or wii or playstation) and (rehab* or neurorehab* or cognitive or cognition) not ("serious games" or app or apps or aggress*)

("video game*" or gaming or videogame* or "commercial game*" or "entertainment game*" or "video rehabilitation*" or xbox or kinect or Nintendo or wii or playstation) and (rehab* or neurorehab* or cognitive or cognition or "brain injur*" or "spinal cord injur*" or stroke or "multiple sclerosis" or "cerebral palsy") not ("serious games" or app or apps or gambl* or aggress* or addiction or "gaming disorder" or radio)