The Use of Virtual Reality Applications in Stroke Rehabilitation for Older Adults: Technology Enhanced Relearning

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Abstract: After stroke rehabilitation is a long-term relearning process that can be divided into cognitive relearning, speech relearning and motoric relearning. Today with an aging population it it interesting to look at technology enhanced and game-based solutions that can facilitate independent living for older adults. The aim of the study was to identify and categorise recently conducted research in the field of virtual reality applications for older adults' relearning after stroke. This study was conducted as a systematic literature review with results categorised in a pre-defined framework. Findings indicate that virtual reality-based stroke rehabilitation is an emerging field that can renew after stroke rehabilitation. Most found studies were on stroke patients' motoric and game-based relearning, and with less studies on speech rehabilitation. The conclusion is that virtual reality systems should not replace the existing stroke rehabilitation, but rather to have the idea of combining and extending the traditional relearning process where human-to-human interaction is essential. Finally, there are no virtual reality applications that can fit all stroke patients' needs, but a thoughtful selection of exercises that matches each individual user would have a potential to enhance the current relearning therapy for older adults after stroke.

1 INTRODUCTION

Stroke is a serious and global health-care problem that has been identified as the most common reason for disability worldwide (Hoffmann, 2001; Langhorne, Bernhardt & Kwakkel, 2011; Gamito et al., 2017). For stroke survivors, rehabilitation is a crucial and long-term challenge that requires motivation and hard work from the patients and also extensive resources from the health care providers (Broeren et al., 2008). The way back to an independent and joyful life after stroke is often a long journey where patients as well as relatives together have to struggle for a successful relearning (Greveson & James, 1991; (Broeren et al., 2008). A stroke patient's disability could be divided into the categories of motor, speech and cognitive injuries, where the cognitive part of the rehabilitation is related to the motoric and speech aspects of a patient's relearning after stroke.

The motoric rehabilitation deals with problems using the body, while speech rehabilitation is related to problems with language and communication. Both impairments drastically reduce the ability to read, write, communicate and interact (Seniów, Litwin & Lesniak, 2009, Langhorne et al., 2011, Veerbeek et al., 2014, Pollock et al., 2014, Toussignant et al., 2018). Effective rehabilitation should be built around an everyday treatment, which is challenging to provide due to the high amount of human resources and running costs that are involved. On the other hand, several technology-enhanced alternatives have emerged that have a potential to complement the traditional long-term rehabilitation. This study had a focus on identifying and discussing virtual reality applications that have been part of post stroke rehabilitation.

1.1 Aim and Research Question

The aim of this study was to identify and categorise recently conducted research in the field of virtual reality applications for older adults' relearning after stroke. The main research question to answer was: *"Which are the lessons learnt in technology enhanced stroke rehabilitation for older adults using virtual reality applications?"*.

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2 EXTENDED BACKGROUND

Virtual reality has been an emerging trend in the 21st century, and the technical level is today far better than it was in the previous century. In tandem with the technical development, virtual reality systems have been implemented and tested in a huge number of areas, and quite frequently in health care.

2.1 Virtual Reality

Virtual reality has generally been defined as a computer-generated three-dimensional artificial environment that creates imitated reality (Pesonen et al., 2017). That imitated reality generates a feeling of a real-looking world which allows the user interaction as well; a user can interact by performing different kind of actions such as verbal commands, and different kind of physical and facial gestures (Glännfjord et al., 2017). Furthermore, virtual reality could be divided into several types of environments that can be immersive, semi-immersive and non-immersive. The full immersive could be a cave environment, whilst the semi-immersive type could be exemplified by a flight simulator. Finally, the non-immersive type consists of applications using the desktop system for viewing. Non-Immersive systems are the most basic ones offering a less powerful experience of being present than that the immersive virtual world systems can afford (Peters et al., 2016).

Virtual reality is considered an alternative for different types of physical and cognitive rehabilitation following stroke (Yamato et al., 2016). The use of virtual reality provides the possibility of strictly controlled user interaction (Brahnam & Jain, 2011), that might be used for different types of post stoke therapies such as cognitive training for re-learning of daily routine tasks (Gamito et al., 2017) and upper limb dysfunction therapy following stroke (Yates et al., 2016). Many of the stroke rehabilitation interventions involve intensive and highly repetitive exercises and the treatments involving virtual reality can be useful not only for the patients but it may also decrease the treatment costs and human resources for medical caregivers (Yamato et al., 2016).

2.2 Theoretical Framework

Stroke rehabilitation could primarily be divided into the categories of: cognitive relearning, speech relearning and motoric relearning (Ahmad, Mozelius & Ahlin, 2019). Furthermore, technology enhanced stroke rehabilitation might be sub-classed into a category of game-based relearning (Mozelius, Ahlin & Ahmad, 2019). These four categories described below, was used as a theoretical framework for the deductive thematic analysis in this study.

2.2.1 Cognitive Relearning

A fundamental part of the rehabilitation after stroke is the cognitive relearning, therefore, it is important to carefully examine the patient's cognition status before the rehabilitation starts (Skidmore et al., 2010, Heruti et al., 2002). The vast majority of stroke rehabilitation exercises need basic cognitive abilities for a successful memorising and relearning. Various cognitive deficiency can make it difficult to perform the rehabilitation exercises (Heruti et al., 2002). Therefore, a patient's cognitive skills determine the overall strategy of different types of rehabilitation and relearning following a stroke. The vast majority of stroke survivors are reported to have some kind of cognitive impairment that can have a negative impact on the patients' daily life activities (Palmcrantz et al., 2017).

Most stroke patients are depending on long-term cognitive rehabilitation process to recover (Cogollor et al., 2018). Even mild cognitive impairments after stroke can affect things such as a patient's independent living, the quality of life and the occupational effectiveness (Jokinen et al., 2015). Due to brain damage, the cognitive impairments can also cause issues such as attention deficits, memory loss, spatial neglect and perceptual disorders. There exist various exercises that can improve the attention and alertness for patients with attention deficiencies (Langhorne et al., 2011, Jokinen et al., 2015), and several types of therapies can be suggested for relearning and cognitive improvements. However, the type of rehabilitation is always depending on each patient's specific impairments.

2.2.2 Speech Relearning

Language and speech related dysfunctions have been classified as a condition called aphasia. Aphasia is a common stroke impairment phenomenon where patients' cognitive ability might not be decreased, but that parts of their speaking, reading and/or writing skills are damaged (Tousignant et al. 2018). Close to a third of stroke patients suffer from some kind of aphasia (Tousignant et al. 2018; Greener, Enderby & Whurr, 1999) In the first weeks after a stroke, many speech and language impairments recover, but the rest of the relearning can take years of repeated training with speech and language therapy as an important part of the recovery process (Gerstenecker & Lazar, 2019). Several research studies indicate that

the quality of life for aphasia patients is severely affected, and linked to emotional suffering, communication disorders and social limitations (Hilari et al., 2003; Ross & Wertz, 2003; Øra et al., 2018).

Moreover, aphasia patients often suffer from anomia, where the word retrieval fails and the person cannot express what they want they want to say. This creates major problems in a patient's daily life with misunderstandings and a reduced social life (Tousignant et al. 2018). Due to the speech and language issues suffer from to not be able to express emotions and to share thoughts and knowledge. A constant lack of expressions that can lead to isolation and to states of deep frustration (Johansson, Carlsson & Sonnander, 2012). Another consequence of speech inability the increased uncertainty, where patients become uncertain about what has been said and what has been understood. This also leading to doubts about what was planned, which also affects the patient's relatives and friends (Øra et al., 2018).'

2.2.3 Motoric Relearning

Almost all stroke patients experience some motor impairments that limit their physical activity and the ability to carry out daily routine tasks (Langhorne et al., 2009, Palmcrantz et al., 2017). To support motoric relearning and to increase the quality of patient's life, intense and long-term physical training is required. This is a long-term process that should be started as early as possible after a stroke (Ehn et al., 2015). Many of the currently most used treatments for motoric relearning involve physiotherapy and guided physical exercises, and the perceived benefits are obvious (Veerbeek et al., 2014).

In the 21st century, several types of technology-enhanced systems have been tested in motoric rehabilitation of stroke patients. The various systems have their various identified benefits, drawbacks and limitations (Rizzo & Kim, 2005, Broeren et al., 2008, Palmcrantz et al., 2017). In the rich number of novel relearning therapies that has been developed and tested there are also many examples that use virtual reality techniques. Some early 21st century examples using ankle and wrist devices for stroke rehabilitation have been described by Deutsch et al. (2001) and Jack et al. (2001). Finally, as pointed out by Porras et al. (2018), motor rehabilitation techniques involving virtual reality is an emerging field that has had a rapid and promising development during the last decade.

2.2.4 Game-based Relearning

At the same time as the variety of digital games has increased and reached a wider audience (Juul, 2010), games have been frequently involved in several aspects of learning. A game-based learning approach has been tested in a wide range of areas such as computer programming (Malliarakis, Satratzemi & Xinogalos, S. (2014), history education (Mozelius et al., 2017) and melanoma recognition (Maganty et al., 2018). The combination of virtual reality and games has been found to increase patients' interest and enthusiasm in the rehabilitation process (Brahnam & Jain, 2011).

Different types of VR based gaming systems such as Xbox Kinect and Wii seem to have some potential benefits in terms of accessibility, usability, and affordability (Yates et al., 2016). Deutsch et al. (2011) studied how exergames were used on the Nintendo Wii platform to improve balance and mobility for post-stroke patients. An interesting setup, but a lesson learnt was that a game-based setup for stroke patients also requires a careful pre-evaluation of the involved games (Deutsch et al., 2011). Finally, an interesting and more specalised approach to rehabilitation after stroke, could be to develop and use task-specific game-based virtual reality systems (Shin, Ryu & Jang, 2014).

3 METHOD

This study was carried out as a systematic literature review according to the step-by-step approach for health science research presented by Parahoo (2006) and Cronin, Ryan and Coughlan (2008). First step was to select a topic and to formulate the research question that is presented in the end of the introduction. Second step was to define inclusion and exclusion criteria for a set of articles that represent the status quo of the chosen field. The second step is closely aligned to the third step of selecting and accessing the literature, where the recommendation is to combine pre-defined keywords in a search string (Ely & Scott, 2007). Fourth step then is to assess the quality in the found articles and select the ones that contain appropriate and related information. Finally, the fifth step of analysing and synthetisising the findings was conducted following the preview, question, read, summarise (PQRS) system that is recommended by Cronin, Ryan and Coughlan (2008).

To retrieve a result set that represents the-state-of-the-art of the chosen field the selection criterion was to exclude articles that are older than 2018, and that

articles should preferably have been published in peer-reviewed research journals. The rationale for building on articles no older than 2018 was to look at state-of-the art solutions in this field. However, some articles were selected in a backward search, a technique that has been defined as "reviewing older literature cited in the articles yielded from the keyword search" (Vom Brocke et al., 2009). The pre-defined search string for retrieving a relevant result set was "stroke rehabilitation" AND "virtual reality" AND "older adults", where AND is the Boolean operator for combining keywords to a search criterion to find articles that must include all the chosen keywords (Ely & Scott, 2007; Cronin, Ryan and Coughlan, 2008). Finally, the review was framed with the frequently used approach of dividing the literature into categories. An approach that allows an integration of themes and patterns from both theoretical and empirical studies in the answering of the research question (Carnwell and Daly, 2001). In the fourth step an assessment of the chosen research methods was an important part of the quality assessment, and research methods for the selected articles are briefly described below in Table 1. Articles without a detailed description of a sound research method were excluded. Out of the initial 594 articles that were retrieved with the search string and the exclusion criteria the articles listed below in Table 1 were selected for further analysis after the quality assessment step where articles were skimmed with a focus on abstracts, method chapters, findings and conclusions. The two main criteria in the quality assessment were firstly to examine the used research methods, and secondly to look for findings that could answer the research question.

4 FINDINGS AND DISCUSSIONS

Several studies recommend that technology enhanced solutions involving virtual reality should be more frequently used in after stroke rehabilitation to increase motivation and to better meet the needs of the patient (Hashim et al., 2018; Langan et al., 2018, Yeh, Pai & Jeng, 2019). The largest part of the selected articles had studied motoric relearning (Langan et al., 2018; Zafar, Malik & Masood, 2018; Howes et al, 2019), and surprisingly many studies involved the concept of game-based learning (Zafar, Malik & Masood, 2018; Sheehy et al, 2019; Yeh, Pai & Jeng, 2019). There are also several interesting studies on cognitive relearning (Gamito et al., 2017; (Yeh, Pai & Jeng, 2019), while there were few findings of speech rehabilitation studies. The four categories are presented one by one here below.

4.1 Motoric Relearning

A promising area of motoric relearning seems to be balance and gait exercises where a virtual reality application also can eliminate the risk of falling (Zafar, Malik & Masood, 2018; Kamińska et al., 2018). Several studies stress the importance of exercises that are adapted to the target group, and the recommendation in a study on balance and strength exercises by Howes et al. (2019), was to involve the end users at an early stage. An interesting finding in this study was that the older adults preferred to view the balance exercises on a flat screen rather than in headsets (Howes et al., 2019). The study by Porras et al. (2018) points out that virtual reality-based rehabilitation is rapidly developing, but that the best results for balance and gait rehabilitation were achieved when virtual reality exercises are combined with conventional rehabilitation.

Another part of motoric relearning where virtual reality is frequently used is for upper and lower limb exercises (Kamińska et al., 2018). As highlighted by Wang et al. (2017), most of the virtual reality exercise systems are only developed to train the upper limbs. However, there are several existing hybrid systems that can provide motoric training for both upper and lower limbs (Poli et al., 2013; Khor et al., 2014). To avoid muscle contraction, it is important for patients to have a continuous training after stroke (Poli et al., 2013), where the idea of a game of virtual football seems like a joyful lower limb exercise (Kamińska et al., 2018).

The study by Laver et al. (2017), found that the use of virtual reality and interactive games was not more beneficial than the conventional therapy approaches to improve upper limb functionality. On the other hand, Wang et al. (2017) found that virtual reality exercises combined with traditional therapy made greater improvement than just conventional methods. Kamińska et al. (2018) reported that game exercises based on virtual reality increased the possibilities of efficient and joyful motoric rehabilitation. Finally, a phenomenon in motoric relearning that needs attention is the displacement of the centre of pressure that is an identified result from some types of rehabilitation exercises (Sheehy et al., 2019).

Table 1: Selected articles after the quality assessment.

Author(s), year, publication:	Method:	Interesting findings:	Category:
Zafar, A., Malik, A. N., & Masood, T. (**2018**). Effect of Virtual Reality Training on Dynamic Balance of Chronic Stroke Patients., JIIMC 2018 Vol. 13, No.1	Quasi interventional pilot study. Purposive sampling, 8 stroke patients	"improvement in dynamic balance after virtual reality training, indicating that virtual reality can play an important role in rehabilitation of balance impairment in chronic stroke" "VR provides a safe environment to the patient to perform real life task without the risk of fall which is an important factor in increasing patient's confidence in mobility."	*Motoric* *Game-based / Exergame*
Sheehy, L., Taillon-Hobson, A., Finestone, H., Bilodeau, M., Yang, C., Hafizi, D., & Sveistrup, H. (**2019)**. Centre of pressure displacements produced in sitting during virtual reality training in younger and older adults and patients who have had a stroke. *Disability and Rehabilitation: Assistive Technology*, 1-9.	Cross-sectional, observational pilot study Game-based learning	"Some virtual reality training games produce greater displacements of the centre of pr essure in sitting than others, suggesting that careful matching between game challenge and desired therapeutic outcome" Stroke survivors performed similarly to healthy older and younger adults in the gaming. "Older adults tend to lean more than younger adults while individuals with stroke move more or less than others, depending on the game."	*Motoric* *Game-based*
Yeh, T. M., Pai, F. Y., & Jeng, M. Y. **(2019**). The factors affecting older adults' intention toward ongoing participation in virtual reality leisure activities. *International journal of environmental research and public health*, *16*(3), 333.	Quantitative survey, Hypothesis testing	"experience of virtual reality leisure activities by older adults have a significant influence on their perception of its value" "virtual activities so that patients can move beyond the boring and monotonous rehabilitation methods in traditional medical treatment" "Through interaction in games, older adults can maintain close relationships with others" "firms or other organizations should study the needs and expectations of older adults toward virtual reality leisure activities in detail."	*Motoric* *Cognitive* *Game-based*
Langan, J., Subryan, H., Nwogu, I., & Cavuoto, L. (**2018**). Reported use of technology in stroke rehabilitation by physical and occupational therapists. *Disability and Rehabilitation: Assistive Technology*, *13*(7), 641-647.	Quantitative surveys distributed by mail, email and in online postings	"Conventional equipment such as stopwatches are more frequently used compared to newer technology like Wii and Kinect games." "The patient care experience is a priority in healthcare, so when patients report feeling bored and desiring greater fostering of autonomy in stroke rehabilitation, it is troubling" "Therapists should consider using technology in stroke rehabilitation to better meet the needs of the patient"	*Motoric* *Game-based*
Hashim, S. H. B. M., Ismail, M. B., Manaf, H. B. A., & Hanapiah, F. A. B. (**2018**). Framework of virtual reality game on dual cognitive task for stroke rehabilitation. In *2018 IEEE Symposium on Computer Applications & Industrial Electronics (ISCAIE)* (pp. 114-118). IEEE.	Framework designed based on a literature review and questionnaires	Proposed framework "VR is often designed to be more engaging, more interesting and more enjoyable than conventional stroke rehabilitation." "stroke patients that have problems with dual cognitive task could use virtual reality games as part of their rehabilitation programme. However, they need equipment that is in-expensive and are low health risk to them so that it would not burden them."	*Cognitive* *Motoric* *Dual cognitive* *Game-based*

Table 1: Selected articles after the quality assessment.(cont.)

Porras, D. C., Siemonsma, P., Inzelberg, R., Zeilig, G., & Plotnik, M. (**2018**). Advantages of virtual reality in the rehabilitation of balance and gait: systematic review. *Neurology*, *90*(22), 1017-1025.	Systematic Review and Meta-Analysis	VR-based rehabilitation is developing rapidly, VR improved balance and gait especially when combined with conventional rehabilitation.	*Motoric* *(balance and gait)*
Gamito, P., Oliveira, J., Coelho, C., Morais, D., Lopes, P., Pacheco, J., ... & Barata, A. F. (**2017**). Cognitive training on stroke patients via virtual reality-based serious games. Disability and rehabilitation, 39(4), 385-388.	Experiment Game development	"The results showed significant improvements in attention and memory functions in the intervention group, but not in the controls" "Overall findings provide further support for the use of VR cognitive training applications in neuropsychological rehabilitation."	*Cognitive* *Game-based*
Kamińska, M. S., Miller, A., Rotter, I., Szylińska, A., & Grochans, E. (**2018**). The effectiveness of virtual reality training in reducing the risk of falls among elderly people. Clinical interventions in aging, 13, 2329.	Functional testing Spring hand dynamometers	"One game that strongly activated the upper limbs was bowling" "VR training increases the possibilities of motor training and can help reduce the risk of falls by improving the static and dynamic balance"	*Motori* *(balance,upper limbs, lower limbs)* *Game-based*
Bevilacqua, R., Maranesi, E., Riccardi, G. R., Donna, V. D., Pelliccioni, P., Luzi, R., ... & Pelliccioni, G. (**2019**). Non-Immersive Virtual Reality for Rehabilitation of the Older People: A Systematic Review into Efficacy and Effectiveness Journal of clinical medicine, 8(11), 1882.	Literature study	"The level of realism of the virtual stimuli seems to have a crucial role in the training of the cognitive abilities. Nevertheless, semi-immersive or non-immersive VR systems have the advantage of being more accepted by the users, as they experienced less cybersickness after the training. Moreover, the integration of these devices in the health management systems are still lacking "	*Motoric* *Cognitive*
Howes, S. C., Charles, D., Pedlow, K., Wilson, I., Holmes, D., & McDonough, S. (**2019**). User-centred design of an active computer gaming system for strength and balance exercises for older adults. Journal of Enabling Technologies.	User testing of VR-systems based on Oculus Rift headsets	"Findings from this study suggested that active computer gaming was safe way to deliver strength and balance exercise to older people. No adverse events were reported during use of the system. Participants unanimously preferred viewing the system displayed on flat screen rather than using a VR headset."	*Motoric* *(strength and balance exercises)*
Saposnik, G., Teasell, R., Mamdani, M., Hall, J., McIlroy, W., Cheung, D., ... & Bayley, M. (**2010**). Effectiveness of virtual reality using Wii gaming technology in stroke rehabilitation: a pilot randomized clinical trial and proof of principle. Stroke, 41(7), 1477-1484.	Single-blind and randomised clinical trial with two parallel groups of stroke patients	"VR Wii gaming technology represents a safe, feasible, and potentially effective alternative to facilitate rehabilitation therapy and promote motor recovery after stroke." "it was possibly subject to bias in that patients using the 'new' technology may have been more motivated by the use of this treatment"	*Motoric* *Game-based*

Table 1: Selected articles after the quality assessment.(cont.)

Amaya, A., Woolf, C., Devane, N., Galliers, J., Talbot, R., Wilson, S., & Marshall, J. (**2018**). Receiving aphasia intervention in a virtual environment: the participants' perspective. Aphasiology, 32(5), 538-558.	Semi-structured interviews two weeks before (and two weeks after (exit) an intervention	"intervention was strongly associated with fun and enjoyment" "Perceived impacts related to communication, activity, computer use and confidence."	*Speech*
Wang, Z. R., Wang, P., Xing, L., Mei, L. P., Zhao, J., & Zhang, T. (**2017**). Leap Motion-based virtual reality training for improving motor functional recovery of upper limbs and neural reorganization in subacute stroke patients. Neural regeneration research, 12(11), 1823.	Randomised controlled pilot study	"The Wolf Motor Function Test score for the experimental group (Leap Motion-based virtual reality training combined with conventional occupational therapy) indicated greater improvement than that attained by the control group"	*Motoric (upper limb)*
Khor, K. X., Rahman, H. A., Fu, S. K., Sim, L. S., Yeong, C. F., & Su, E. L. M. (**2014**). A novel hybrid rehabilitation robot for upper and lower limbs rehabilitation training. Procedia Computer Science, 42, 293-300.	Kinematic study	"development of a novel hybrid rehabilitation robot that able to perform rehabilitation training for both upper and lower limbs" "Stroke patients need to continue training after stroke to avoid muscle contraction, but due to large number of patients, they are not able to train frequently in the hospital."	*Motoric (upper limbs, lower limbs)*

4.2 Cognitive Relearning

A serious game for cognitive training was developed by Gamito et al. (2017), a game where attention and memory tasks in daily life activities were practiced in a virtual reality world. Results in the study showed significant improvements for participants in the intervention group, but not in the control group. As suggested by Bevilacqua et al., 2019), the quality of realism and stimuli in virtual worlds seem to be a crucial factor in the relearning of cognitive abilities. At the same time, multi-modal virtual worlds can help patients to move beyond the sometimes boring and monotonous traditional relearning methods, where the use of graphics and sound could stimulate older adults' cognitive functions (Yeh, Pai & Jeng, 2019).

4.3 Speech Relearning

Despite the feature of speech interaction with virtual reality systems (Chun et al., 2015), it was hard to find studies on speech relearning in virtual worlds. An explanation might be, as it was stated by, that "speech rehabilitation intervention options are few", but that there have been some tests where Aphasia scripts have been combined with speech training where the proper articulation was illustrated by the mouth of an avatar. Probably that the search strategy here should be to replace "stroke rehabilitation" with "aphasia scripts". However, the result might be the same, and as pointed out by Amaya et al. (2018), there is an increasing contribution of digital systems for aphasia therapy, but virtual reality applications still are rare. An interesting concept is to create virtual speech relearning exercises as multi-user environments where patients can interact with therapists, support staff and other patients. Many interviewed patients mentioned their appreciation for interaction, humour and social contact, and only one patient found the social interaction to be fatiguing (Amaya et al., 2018).

4.4 Game-based Relearning

Considering motoric relearning, virtual bowling was found to be the game that strongly activated the upper limbs, and that football and downhill skiing games are suitable exercises for the lower limbs (Kamińska et al., 2018). In the frequently cited study by Saposnik et al. (2010) the conclusion was that game-based virtual reality applications offer a safe, feasible, and potentially effective alternative for motoric relearning after stroke. On the other hand, some types of games need a careful matching between the desired therapeutic outcomes and the gaming impact on stroke patients (Sheehy et al., 2019).

To develop video games is often time consuming and costly, and a cost-efficient approach could be to collaborate or to work in parallel with the game industry (Gamito et al., 2017). The idea of a relearning process built on games that have not been

fully designed for rehabilitation (Gamito et al., 2011), might clash with the idea of a truly individualised and adapted relearning process (Ahmad, Mozelius & Ahlin, 2019). A recommended way to increase users' safety, usability and acceptability of the games is user-centred design where stroke patients are involved in the game development (Howes et al., 2019).

4.5 General Discussion

Another aspect of the discussion between high-end games with complex virtual reality worlds is the cybersickness phenomenon. Cybersickness that is an issue in virtual reality worlds resembles of motion sickness with symptoms such as nausea and cold sweating (Mazloumi et al., 2018). To avoid cybersickness among older adults the idea could be to choose semi-immersive or non-immersive virtual reality systems since they induce less cybersickness. However, the level of realism and immersion of the virtual world seems to have a crucial role in cognitive relearning. (Bevilacqua et al., 2019)

As in other fields where virtual reality games have been tested there seems to be a motivational effect also among older adult stroke patients (Hashim et al., 2018, Yeh, Pai & Jeng, 2019). Even if it might be the new technology itself that motivates, as remarked by Saposnik et al. (2010), motivation should not be underestimated in the long-term post stroke relearning struggle. Finally, as highlighted by Gilbert et al. (2013), participation in virtual worlds could have a general positive impact on patients with disabilities.

Finally, a drawback with VR solutions for stroke patients that was found by random in a backward search in this study is the cybersickness phenomenon. Cybersickness is sometimes also referred to as virtual reality sickness or simulator sickness, and is a syndrome that arises from the use of VR. The three main symptoms of cybersickness are oculomotor discomfort, disorientation and nausea (Vinson et al., 2012). This might be particularly problematic since nausea is an identified ailment among stroke patients (Canhao et al., 1997)

5 CONCLUSION

Virtual reality-based stroke rehabilitation is a rapidly emerging field opening up possibilities for all the four described categories. The greatest potential seems to be for stroke patients' motoric and game-based relearning, and with less applications for speech rehabilitation. The main idea should not be to completely replace the existing stroke rehabilitation with virtual reality systems, but rather to combine and extend the conventional relearning methods, and to keep the identified importance of human-to-human interaction (Loft et al., 2019). There are no virtual reality applications that fits all stroke patients', but a thoughtful selection of exercises that matches the user needs have a potential to enhance the current relearning therapy for older adults after stroke.

6 FUTURE WORK

A relevant and interesting follow-up study would be to test and evaluate various variations of the found virtual reality applications for stroke relearning. This should be carried out in a real world setting in close collaboration with a professional stroke rehabilitation team. The evaluation should mainly be based on stroke patient’s perceived use and their actual relearning progression. Furthermore, the use of games in stroke rehabilitation looks promising and could be interesting to investigate further in another separate literature review. Finally, for the category of speech relearning for stroke patients it would be interesting to further explore the combination of virtual reality and aphasia scripts.

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