Virtual reality for older users: a systematic literature review

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Abstract - **The use of technologies by the elderly is still restricted, especially concerning recent technologies. To better understand the older user experience, while using virtual reality technology, we performed a Systematic Literature Review. The databases selected for research were the digital libraries of ACM, IEEE, Science Direct and Google Scholar. During the literature review, we collected information about the characteristics of the participants of the studies selected, the experiences reported about the use of technology, the research method used, the technologies chosen for the tests, the results obtained and future work suggested. The main contributions of this work were to identify the state of art of virtual and augmented reality for older people, the possible applications of these technologies to them, the most used devices and also the considerations reported by previous experiences.**

Index Terms - **virtual reality; older people; systematic literature review; user experience.**

I. INTRODUCTION

Information and Communication Technologies (ICT) are impacting people's daily lives. There are cell phones, computers, bank terminals, payment boxes for parking in shopping centers among many others. Over the years, the number of technological options continues to grow. This is the case of Virtual Reality (VR) technology, which today allows people to have a new experience and to visit a different place with the use of smartphones, computers, or devices that resemble glasses.

This positive characteristic of VR is especially important for the older people, since many of them find it difficult to travel. Besides, the elderly is an audience that usually has less contact with ICT and at same time they suffer a decline of their physical and cognitive skills. VR technology is an option to help them in daily activities, to keep them up to date and to provide them the opportunity to have fun. For this, it's important to identify design elements and understand more about their VR experience in order to make virtual reality more suitable for them.

So, the purpose of this article is to present the results of a systematic literature review about user experience, research methods and suggestions of future work considering studies which were already performed with the use of virtual reality technology by older users.

This paper is organized as follows: in Section 2 we described some main characteristics of older people and also main concepts about user experience. Section 3 presents details about the adopted method of systematic literature review. Section 4 shows a quantitative summary of the search results. Section 5 highlights some answers to the research questions, and, finally, Section 6 presents the main conclusions about the results obtained.

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II. BACKGROUND

In this section we will present some characteristics of the audience of this study and fundamentals of user experience. Knowing characteristics of older people is important for evaluating if their needs are considered in the development of applications for them and also in the conduction of studies with their participation.

Aging-related physical impairments

People suffer changes during their lives. During old age, people face loss of their physical and cognitive abilities (Papalia and Feldman 2013).

The physical capacities that are reduced with aging are usually related to vision, hearing, motor control and dexterity.

Reduction of visual acuity is perhaps the best known impairment among the elderly problems. Other visual restrictions include the inability to focus on objects that are close (Vasconcelos et al. 2012), serious diseases such as glaucoma and cataract (NCBI 2014), reduced field of vision, reduced colour, depth and contrast perception, decreased adjustment to the dark (Ijsselsteijn et al. 2007; NCBI 2014). Because of that, it is difficult for the elderly to perceive and locate small elements on the screen (Lopez-Martinez et al. 2011) and to read text with small letters.

Concerning hearing impairments, many older people suffer from presbycusis, or reduced ability to hear sounds at very high frequency, which, for example, makes difficult listening to sounds of beeps (Vasconcelos et al. 2012). "Worldwide, more than 180 million people older than 65 years have hearing loss that interferes with understanding normal conversational speech" (World Health Organization 2015).

Ageing is also related with muscle mass decline, changes in bones mass, and strength decline. All these changes increase the risk of fracture. “Hip fractures are a particularly devastating type of osteoporotic fracture, and as a result of population ageing they will become more common, reaching an estimated annual global incidence of 4.5 million in 2050" (World Health Organization 2015).

Falls are another problem for the elderly. “Various reviews and meta-analyses have estimated that 30% of people older than age 65, and 50% of people older than age 85, who live in the community will fall at least once each year. Falls are, in fact, the main risk factor for fractures” (World Health Organization 2015).

Balance control maintains the body’s center of gravity on the basis of support during static and moving situations. It is up to the body systems to respond to variations in the center of gravity, either voluntarily or involuntarily. This natural process occurs effectively, mainly by the action of the visual, vestibular and somatosensory systems. With aging, these systems are affected and postural control may be ineffective in dealing with situations, thus reducing the compensatory capacity of the system, leading to increased instability (Maciel 2005).

In 2012, the top 10 health conditions associated with disability, in populations aged 60 years and older were (World Health Organization 2015): hearing loss, back and neck pain, chronic obstructive pulmonary disease, depressive disorders, falls, diabetes mellitus, Alzheimer’s disease and other dementias, refractive errors, osteoarthritis, cataract.

Aging-related cognitive impairments

“Not all cognitive functions deteriorate with age, and language features, such as comprehension, reading and vocabulary, in particular, remain stable throughout life" (World Health Organization 2015). However, in general, the aging process also causes cognitive constraints such as the reduction of attention to details and also of short-term memory (Lopez-Martinez et al. 2011; Vasconcelos et al. 2012).

The reaction response time also increases and this, together with reduction of psychomotor skills, such as motor coordination, makes difficult actions that require a lot of precision (Vasconcelos et al. 2012).

Another problem that older people face is the natural decline of their spatial cognition, even if they are healthy. This “human capacity of orienting oneself in and to cope with everyday environments” impacts on “the capacity to explore new environments, execute way finding in familiar contexts and use landmark for orienting themselves in complex situations”(Morganti et al. 2009).

These impairments can be even worse, especially in case of some diseases, such as dementia and Alzheimer.

Despite all these difficulties, older people often wish to expand their skills and to have interesting options of leisure (Papalia and Feldman 2013). These possibilities can help them to slow down the impact of aging on their physical and cognitive abilities, which often determines their emotional state.

User experience

As one of the research questions of this study addresses the experience of older users while using virtual reality, it is important to discuss the concept of user experience.

There are many different definitions of User eXperience (UX). ISO 9241-210 defines UX as “a person’s perceptions and responses that result from the use or anticipated use of a product, system or service”. In UX, perceptions and responses can be presented in different aspects, each representing different characteristics of the user experience such as usability, emotion, engagement and flow (Tcha-Tokey et al. 2016).

One of the main goals of interaction design is to reduce the negative aspects of the user experience, such as frustration and annoyance, while at the same time improving aspects such as fun, commitment, loyalty and trust.

The aspects that affect the user experience can be categorized into four types (Zarour and Alharbi 2017). The first type is user needs, which can be pragmatic (related to usability) or hedonic (related to stimulation). The second type is the brand, which is related to marketing and communication between the user and the organization. The third is the technological aspects, that is the development and production of technologies that impact the experience. Finally, the context includes any property that is not related to one of the previous aspects, but also impacts the experience (Zarour and Alharbi 2017).

Another important feature in user experience studies is evaluation metrics. In order for a coherent identification of perceptions and evaluations, it is necessary to use metrics that allow a parameterized evaluation to make an equivalent review of all responses resulting from the process (Tullis and Albert 2008).

There are several metrics that can be used, among them, some reveal aspects about the user experience or about the personal experience of the human being using a product or service. For instance, a usability metric reveals something about the interaction between the user and a product, bringing the aspect of effectiveness or efficiency to complete a task or the degree of users satisfaction concerning their experience in performing a task. As people are very diverse and adaptable, sometimes the challenge of choosing or using metrics can be great (Tullis and Albert 2008).

III. Method

The systematic literature review was conducted in order to identify studies and their results related to older user experience while using virtual reality.

Based on the guidelines proposed by (Kitchenham and Charters 2007), we performed the following activities: specifying the research questions, setting of a search strategy, selection of primary studies, assessment of study quality, data extraction and monitoring, data synthesis. These activities are detailed in the next subsections, except the last one, which is detailed in Section 4.

Research questions

For this study, three research questions were defined. The first and second ones have three and two specific questions, respectively, as follows:

RQ 1 Which are the characteristics of the studies about the use of virtual reality by older users?

- **SQ 1.1** What are the objectives of the studies?
- **SQ 1.2** What were the data analysis procedures?
- **SQ 1.3** Which virtual reality technology was applied?

RQ 2 How VR impacts on the experience of older users?

- **SQ 2.1** What design characteristics should be considered for this target audience?
- **SQ 2.2** What was the experience of the older users regarding the use of VR?

RQ 3 What are the suggestions for future work?

Search strategy

The research began in December 2018. Because VR is recent technology, no publication date restriction was set.

The major search terms were "virtual reality"and "VR", together with "older users" and similar terms, such as: elderly, senior, older people, older adult, old people, old person, old adult. This resulted in the following search string: "("virtual reality" or "VR") and ("older users" or "elderly" or "senior" or "older people", "older adult" or "old people" or "old person" or "old adult")".

These terms were looked at in the abstract of articles published in the digital libraries of ACM Digital library, IEEE Digital Library, Science Direct and Google Scholar.

Selection of primary studies

The inclusion criteria were:

- article must be written in English or Portuguese;
- article must present the results of a study involving older users (60 years or more) while using virtual reality technology.

The exclusion criteria were:

- duplicate articles – when similar articles were published in more than one source, it was considered the most recent or most complete one;
- literature reviews, because they do not detail the characteristics of a specific study and therefore they go against the inclusion criterion.

The selection process was based on the use of the following filters:

1. reading of the title: the article is selected if the title indicates a study that is related to virtual reality or the elderly;
2. reading of the abstract: the article is selected if the abstract presents a study that involves older people using a virtual reality technology;
3. reading of the full article: the article is selected if it answers at least two of the three research questions.

Doubts were solved by discussions involving all the authors of this paper, during face-to-face meetings.

Quality assessment

In order to be approved, an article must answer at least two of the three research questions. In general, every scientific article presents the purpose of the study. So, to ensure that at least SQ1.2 or SQ1.3 was answered, we considered RQ1 answered if at least two of its specific questions were answered. RQ2 was considered answered if at least one of its specific questions was answered.

Data extraction

The information was extracted from the articles exactly as written by the authors. The data extracted from each article were: publication year, title, publication title (journal or conference), keywords, full reference, answers to the research questions.

IV. Results

This section presents the results after applying the search filters described in Section 3. Table 1 presents an overview of the search results, after using each of the SLR filters. The first filter ("Search String") returned 264 articles from ACM Digital Library, IEEE Digital Library, Science Direct, and Google Scholar. As a final result of the search, 63 articles were obtained from the bases selected for the research. Many of these articles were related with rehabilitation and health. Tables 2, 3, 4, 5 and 6 show the lists of selected articles as well as some information extracted from them: objective, technology and year.

In the following subsections, we present the answers to our research questions.

Which are the characteristics of the studies about the use of virtual reality by older users?

The following subsections describe the information collected for the first research question.

What are the objectives of the studies? In general, the studies were related to subjects such as health, rehabilitation and well-being. Some studies were related to the mobility or bodily aspects of the elderly, including falls (Giotakos, Tsirgogianni, and Tarnanas 2007; Mirelman et al. 2011; Singh et al. 2011; Mirelman et al. 2016; Lim et al. 2017; Suárez, Suárez, and Lavinsky 2006; Nyberg et al. 2005; Kamińska et al. 2018), balance (Anson et al. 2018; Kim et al. 2013; de Vries et al. 2018; Park and Yim 2016; Hsieh et al. 2013; Park, Kim, and Lee 2015; Cho, Hwangbo, and Shin 2014; Lee and Song 2012), exercise (Bruun-Pedersen et al. 2014; Eisapour et al. 2018; Sáenz-de Urturi and Santos 2018; Lee et al. 2015; Tsuda et al. 2016; dos Santos et al. 2015; Klinger et al. 2012), postural control (Chang et al. 2016; Bourrelier et al. 2016; Arias et al. 2012), motor learning (Mendes et al. 2012), rehabilitation on upper extremity function (Lee et al. 2016), and kinematic responses (Gurses, Kenyon, and Keshner 2011).

Many studies were related to psychological or cognitive issues, including shifting of attention (Carelli et al. 2008), memory (Chapoulie et al. 2014; Plancher, Nicolas, and Piolino 2008; Ouellet et al. 2018; Plancher et al. 2012;

Table 1: Number of selected articles

Filter	Number of Articles				
	ACM	**IEEE**	**Science Direct**	**Google Scholar**	**Total**
Search String	28	65	90	81	264
Title	26	63	30	75	194
Abstract	20	45	18	31	114
Full Reading	9	15	16	23	63

Table 2: ACM Digital Library – list of selected articles

Objective	Technology	Year	Ref
Improvement of kitchen environment usability	AR and VR based technologies	2012	(Ceccacci, Germani, and Mengoni 2012)
Wayfinding design in healthcare facilities	Video projector	2010	(Lee 2010)
Episodic memory assessment	Video projector	2008	(Plancher, Nicolas, and Piolino 2008)
Cognitive training game with participatory design	VR for mobile devices	2015	(Votis et al. 2015)
Compare the risk and fear of falls pre and post intervention using virtual reality games	Wii balance board	2011	(Singh et al. 2011)
Design serious games for older adults with dementia	HMD	2018	(Eisapour et al. 2018)
Investigate the design and use of virtual avatars among older adults	HMD	2018	(Carrasco Zuffi 2018)
Virtual reality exercise for older adults living with dementia	HMD	2015	(Eisapour et al. 2018)
Develop a personalized exergame aimed to engage older adults	Kinect	2015	(Sáenz-de Urturi and Santos 2018)

Optale et al. 2010; Jebara et al. 2014; Mohammadi, Kargar, and Hesami 2018), improve cognition (Park and Yim 2016; Serino et al. 2014; Klinger et al. 2012; Intraraprasit, Sunhem, and Jinjakam 2018), spatial orientation (Morganti and Riva 2011), psychomotor performance (Tarnanas, Mouzakidis, and Schlee 2013), executive functions (Yeh et al. 2012), deterioration in perceptual and cognitive function (Mitobe, Suzuki, and Yoshimura 2012), dementia (Liappas et al. 2018), and cognitive training game with participatory design (Votis et al. 2015). There were also a study about Positive mood induction (Baños et al. 2012) and decision-making procedure (Lin, Jeng, and Yeh 2018).

There are also studies about technological inclusion to "empower senior citizens to gain more control over their personal well-being" (Fernández et al. 2017), technology rejection criteria (Coldham and Cook 2017), and other studies about driving (Lithfous et al. 2014) and safe street-crossing (Maillot et al. 2017).

Other studies dealt with more diverse subjects involving user interface, behavior and design. For example, an evaluation of "the use of an immersive virtual reality (VR), a mouse and a touchscreen for one directional pointing, multi-directional pointing, and dragging-and-dropping tasks involving targets of smaller and larger widths" (Chen and Or 2017), an improvement of kitchen environment usability (Ceccacci, Germani, and Mengoni 2012), serious games design (Eisapour et al. 2018; Ahmed et al. 2018; Levy et al. 2016), design and use of virtual avatars (Carrasco Zuffi 2018), satisfaction in 360°travel media (Srifar 2018), evaluation of complex environments exploration capacity (Morganti et al. 2009), and examine the usability of a newly designed virtual reality environment (Fong et al. 2010).

What were the data analysis procedures? Among the 63 selected studies, 59 presented the adopted method of data analysis.

The majority of the studies used statistical methods in their analyzes. 35 studies used only statistical analysis (Chang et al. 2016; Gurses, Kenyon, and Keshner 2011; Fernández et al. 2017; Mirelman et al. 2011; Mitobe, Suzuki, and Yoshimura 2012; Morganti and Riva 2011; Yeh et al. 2012; Singh et al. 2011; Sáenz-de Urturi and Santos 2018; Intraraprasit, Sunhem, and Jinjakam 2018; Ahmed et al. 2018; Liappas et al. 2018; de Vries et al. 2018; Kim et al. 2013; Mendes et al. 2012; Lee et al. 2016; Ouellet et al. 2018; Maillot et al. 2017; Mirelman et al. 2016; Tsuda et al. 2016; Park and Yim 2016; Morganti et al. 2009;

dos Santos et al. 2015; Lithfous et al. 2014; Serino et al. 2014; Hsieh et al. 2013; Klinger et al. 2012; Levy et al. 2016; Benoit et al. 2015; Suárez, Suárez, and Lavinsky 2006; Kamińska et al. 2018; Park, Kim, and Lee 2015; Cho, Hwangbo, and Shin 2014; Fong et al. 2010; Lee and Song 2012).

Some authors specified the specific statistical analysis used. For example, Giotakos, Tsirgogianni, and Tarnanas (2007) and Tarnanas, Mouzakidis, and Schlee (2013) used MANOVA (multivariate analysis of variance). Lim et al. (2017), Plancher et al. (2012) ,and Lee et al. (2015) used ANCOVA (analysis of covariance). Ten studies used ANOVA (analysis of variance) (Chen and Or 2017; Lee 2010; Plancher, Nicolas, and Piolino 2008; Bourrelier et al. 2016; Anson et al. 2018; Baños et al. 2012; Optale et al. 2010; Jebara et al. 2014; Mohammadi, Kargar, and Hesami 2018; Arias et al. 2012).

Seven studies used only qualitative evaluation (Bruun-Pedersen et al. 2014; Caggianese, Gallo, and Pietro 2014; Carrasco Zuffi 2018; Coldham and Cook 2017; Eisapour et al. 2018; Srifar 2018; Lin, Jeng, and Yeh 2018). Other two studies used used both qualitative and statistical approaches in their analyses (Carelli et al. 2008; Chapoulie et al. 2014).

Which virtual reality technology was applied? This section presents the technologies used in the selected studies, which varied a lot. Many of the studies used some motion capture technology (Caggianese, Gallo, and Pietro 2014; Chang et al. 2016; Chen and Or 2017), (Gurses, Kenyon, and Keshner 2011), (Mirelman et al. 2011), (Mitobe, Suzuki, and Yoshimura 2012), (Tarnanas, Mouzakidis, and Schlee 2013), (Yeh et al. 2012), (Mirelman et al. 2016), (Maillot et al. 2017), (Ahmed et al. 2018). Wii balance board was used in four studies (Singh et al. 2011; Lim et al. 2017; Mendes et al. 2012; de Vries et al. 2018), while other five studies used Kinect (Sáenz-de Urturi and Santos 2018; Ahmed et al. 2018; Lee et al. 2016; 2015; Kim et al. 2013).

Two of the studies used computer monitors to display virtual environments: (Caggianese, Gallo, and Pietro 2014) and (Carelli et al. 2008). There were also many works that considered projectors as a virtual reality technology to display the virtual environments (Chapoulie et al. 2014; Chen and Or 2017; Lee 2010; Mirelman et al. 2011; Mitobe, Suzuki, and Yoshimura 2012; Plancher, Nicolas, and Piolino 2008; Plancher et al. 2012; Maillot et al. 2017).

Head mounted displays (HMD) were used in 15 studies (Yeh et al. 2012; Fernández et al. 2017; Tarnanas, Mouzakidis, and Schlee 2013; Yeh et al. 2012; Eisapour et al. 2018; Carrasco Zuffi 2018; Eisapour et al. 2018; Intraraprasit, Sunhem, and Jinjakam 2018; Liappas et al. 2018; Ahmed et al. 2018; Coldham and Cook 2017; Ouellet et al. 2018).

Several other technologies can be found in the selected articles: chair-based exercise bike (Bruun-Pedersen et al. 2014), touch screen (Baños et al. 2012), TV screen (Anson et al. 2018), and NVidia 3D Vision Pro with special 3D glasses (Bourrelier et al. 2016).

Figure 1 presents the technologies used in the experiments reported in the selected articles.

How VR impacts on the experience of older users?

The following subsections describe the information collected to answer the second research question.

What design characteristics should be considered for this target audience? According to Bruun-Pedersen et al. (2014), the outdoor virtual environments for elderly should include more life and diversity, adding elements such as trees, wind, water, climate changes, animals, and events. These elements inspire exploration and help to avoid the feeling of static environment.

Metaphors are also important to make interaction more intuitive (Caggianese, Gallo, and Pietro 2014), such as using the same movements that are necessary in real life to interact with virtual objects.

Training and better virtual interaction design, such as more effective feedback, might improve older people's performance in using VR" (Chen and Or 2017). Besides, (Singh et al. 2011) concluded that "the environment and activities in the games should also be from daily life" and the "customization of physical parameters for each user" make the game intuitive and easy to play for the participants.

In Chapoulie et al. (2014), the authors stated that the physical setup they used for reminiscence therapy, such as a chair or a bench during testing, is well suited to the public with limited mobility. In addition, the authors mentioned the usefulness of VR for cognitive memory processes.

"Diminished capacity to attend to more than one task during postural demands has been cited as a causative factor for instability in the elderly" (Gurses, Kenyon, and Keshner 2011).

The participants of (Fernández et al. 2017) "perceived new VR technologies as interesting options through which to receive information more easily and in a more appealing format. The format was considered more appealing because video content and animations were used to complement written text".

The results presented in Morganti and Riva (2011) revealed that "only Alzheimer's patients require more time in the execution of wayfinding when an allocentric map of the environment was provided to them".

The findings of Eisapour et al. (2018) "contradict previous studies that suggested that older adults will prefer to create avatars different to their real bodies". Some participants wanted to create enhanced version of themselves and "two participants created avatars as companions that represented persons from their past".

Sáenz-de Urturi and Santos (2018) reported several recommendations: avoid tasks that requires head motion, keep visual targets in the front field of view, use verbal instructions, use a calibration process to adjust the required range of motion for each individual and interactions with virtual objects without using any buttons on the control interface.

Besides, the quality of the audio should properly match the rich 3D visual qualities of the VR environment (Liappas et al. 2018).

On its turn, Srifar (2018) showed that "the image displayed must not move too fast to prevent dizziness and improve comfort of the target consumers and is highly rec-

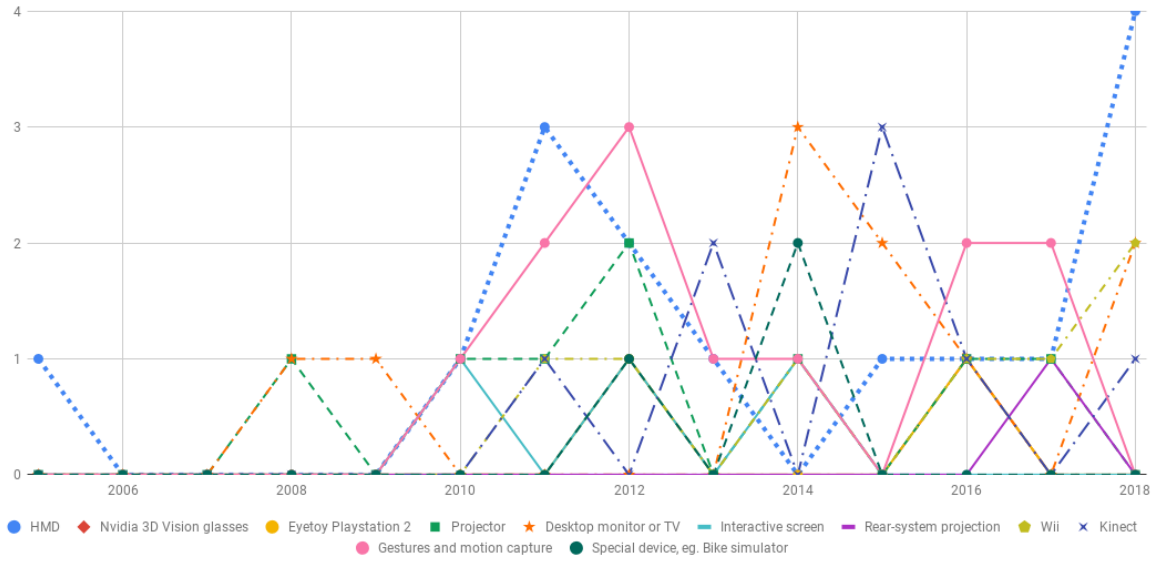

Figure 1: Technologies

ommended to implement a function to customize movement rate for the customer". Concerning image and sound quality, they stated that "the resolution of the display should be high and if the target consumers have visibility problems, they would use eyeglasses too to achieve best experience". The sound must be stereo so that the user recognize the direction of the sound.

Klinger et al. (2012) suggest "increasing the accessibility of the all application by improving contrasts by using raw colors and increasing the sizes of some elements" and "improve the motivation of users adding difficulty levels, and make the virtual environments living by adding people, animations (traffic flow for cities, people on the beach for seaside)". The authors also suggest that involving elderly people into the design process will allow the designers and developers to better fit their needs and expectations.

What was the experience of the older users regarding the use of VR? This section presents the experience of the older users regarding the use of VR in the selected articles. Even though user experience does not depend only on the hardware/device used, but also on the application, the information collected may be important for extracting values, perceptions and feelings from the elderly in relation to the use of virtual reality. This can help in the development of virtual reality applications for the older people.

Some studies presented notes from observations of older people and their familiar context. For example, the application developed for the study of Bruun-Pedersen et al. (2014) created several associations with past experiences. In addition, the study collected several feelings of the participants. One of them "described that the Virtual Environment (VE) provided a sense of accomplishment that she did not have with the conventional manuped exercise". The possibility of exercising while traveling through the VE provided a sense of purpose and happiness, which indicated to the authors an intrinsic motivation that was not present in the regular exercise.

Chapoulie et al. (2014) also noted that familiar environments have great emotional value for the elderly population. Besides, the participants of the study felt the experience as quite stimulating and interesting.

In the study conducted by Srifar (2018), the participants who have watched 360°virtual reality travel media have enjoyed the experience. They felt like actually traveling to another place. Although the dizziness made some of them refuse to watch the media again, almost all of them were interested and wanted to travel to other places too.

Some participants of the study (Fernández et al. 2017) "expressed the desire to once again attend cultural events or locations that they had already visited in their lives", which showed to the authors of the study that "the emotional impact of being able to take fully immersive digital journeys to these sites of interest was rated extremely highly by participants".

Other studies had more focused reports about the interactivity of their applications. The analysis of Votis et al. (2015) "showed that elderly people find it very useful to navigate" in the game "environments in a 'click-and-go' fashion through respective visual aids, given that the aids are adequately intuitive".

Singh et al. (2011) stated that all participants were willing to continue working with the HMD-VR game and no one experienced problems with accessibility or while observing objects, which for the authors meant that the goals of the game were clear to participants. The participants of the study (Ahmed et al. 2018) had high acceptance too, although some participants did not understand the capabilities

of VR in order to adopt it for everyday use.

In the study of Liappas et al. (2018), some participants stated that the headset was too heavy and expressed the view that VR was only for games and only for younger people.

The participants of Maillot et al. (2017) have been anxious before the experiment.

Besides, in the study of Park and Yim (2016), some participants felt dizzy from being exposed to the 3D environments.

Finally The authors of Lee and Song (2012) stated that "jumping and balancing on a beam in the boot camp game were tasks participants were unable to do in the real world, but they could follow the motions in a free and safe way in the virtual world".

What are the suggestions for future work?

Many of the selected works suggest improvements with the objective of increasing the accuracy of the method used and the validity of the research. For example, it was suggested to carry out studies with larger samples and with different configurations, to confirm previous results (Giotakos, Tsirgogianni, and Tarnanas 2007; Plancher, Nicolas, and Piolino 2008; Yeh et al. 2012; Jebara et al. 2014; Mohammadi, Kargar, and Hesami 2018; Arias et al. 2012; Lin, Jeng, and Yeh 2018; Levy et al. 2016; Optale et al. 2010). Other studies considered larger periods (Bruun-Pedersen et al. 2014; Eisapour et al. 2018; Intraraprasit, Sunhem, and Jinjakam 2018; Suárez, Suárez, and Lavinsky 2006), while some studies considered both larger periods and samples (Lee et al. 2015; dos Santos et al. 2015; Mirelman et al. 2016; Maillot et al. 2017; Anson et al. 2018; Park, Kim, and Lee 2015).

Several studies suggested enhancing their applications to be more suitable for elderly or get different results: (Caggianese, Gallo, and Pietro 2014; Chapoulie et al. 2014; Kim et al. 2013; Bourrelier et al. 2016; Nyberg et al. 2005; Carrasco Zuffi 2018; Lee et al. 2016; Ahmed et al. 2018). Coldham and Cook (2017) suggested interviews in other countries to take a broader view, Kamińska et al. (2018) wanted to conduct experiments with participants of different profile and Baños et al. (2012) proposed to identify appropriate dosage of training durations.

Finally, there were studies with different proposals for future work. In Chen and Or (2017), the authors stated that "given that the factors affecting user performance in basic operations with VR are not yet well understood, aspects such as subjective preference, perceived exertion or submovement should be further examined in future studies". Another is to "provide an analysis of senior citizens' perceptions of their mastery of technology and confidence when using technology against their actual mastery of the technology" (Fernández et al. 2017). Besides, Plancher, Nicolas, and Piolino (2008) suggested their tool "opens up a large field of future investigations into episodic memory evaluation as well as rehabilitation".

V. Discussion

The Systematic Literature Review allowed us to identify a concentration of studies in the health area and a low number of studies in other areas, such as education and entertainment. Other issues that can bring great contributions are related to the requirements of virtual reality entertainment software aimed at the elderly, or hardware requirements so that devices can be adapted to the physical and cognitive needs of the elderly users.

The devices used in the studies were varied. Only 15 studies reported the use of HMD, the best known device for immersive virtual reality. In addition, projectors or computer screens were considered a virtual reality technology in some studies. Several studies used motion capture technology as a means of interaction within the game or to collect data.

We also retrieved a small number of studies using qualitative methods. Qualitative research is important to understand a question or phenomenon in more depth. In a more recent area such as virtual reality, qualitative research could bring good contributions for the development of applications for older people.

With the information about the design characteristics and user experience related to the selected studies, it was possible to identify some elements to consider in experiments and also in the development of virtual reality applications for the elderly:

- Use larger-than-usual visual elements in the interface
- Consider the use of lighter equipment
- Use interaction with the body
- Consider the mobility problems of older people
- Offer options for the application to adapt to the particular characteristics of each user (such as customization of physical parameters and customization of movement rate)
- Use familiar environments that could be associated with past experiences.
- Use same movements that are necessary in real life to interact with virtual objects
- Avoid tasks that require the user to move the head quickly or images that move too fast in order to prevent dizziness
- Keep visual targets in the front field of view
- Use verbal instructions
- Use a calibration process to adjust the required range of motion for each individual
- Use high resolution on the display
- Use stereo sound
- Match the quality of the audio properly with the rich 3D visual qualities of the VR environment
- Perform a preparation session with the participants before usage of VR equipment
- Improve contrast by using raw colors
- Provide landmark-based encoding instructions
- Involve elderly people into the design process

Table 3: IEEE Digital Library – list of selected articles

Objective	Technology	Year	Ref
Investigate the reduction of fear of falling	No information	2007	(Giotakos, Tsirgogianni, and Tarnanas 2007)
Rehabilitation of shifting of attention	Desktop monitor for VR	2008	(Carelli et al. 2008)
Evaluate executive functions and memory	HMD and motion capture technology	2012	(Yeh et al. 2012)
Investigate the use of VR technology as part of exercise experience	Chair-based exercise bike and interactive screen-based virtual environment	2014	(Bruun-Pedersen et al. 2014)
Presentation of cultural artefacts	High-resolution monitor and gestures sensor.	2014	(Caggianese, Gallo, and Pietro 2014)
Reveal the elderly people about their deterioration in perceptual and cognitive function	Projector and motion capture device	2012	(Mitobe, Suzuki, and Yoshimura 2012)
Determine what kind of cognitive and psychomotor performance is associated with functional impairment in activities of daily living	HMD and motion capture device	2013	(Tarnanas, Mouzakidis, and Schlee 2013)
Understanding the postural control	Motion capture device	2016	(Chang et al. 2016)
Reminiscence therapy	Projectors	2014	(Chapoulie et al. 2014)
Rehabilitation of spatial orientation	VR technology	2011	(Morganti and Riva 2011)
Investigate if VR can be applied to address the multifaceted deficits associated with fall risk	Projector and motion capture device	2011	(Mirelman et al. 2011)
Behavior analysis to design efficient cognitive training	HMD	2011	(Intraraprasit, Sunhem, and Jinjakam 2018)
Perceive technological barriers and needs of people suffering from dementia	HMD	2011	(Liappas et al. 2018)
Practical idea of serious games for elderly patients	HMD Oculus Rift, Leap Motion and Kinect	2011	(Ahmed et al. 2018)
Examine technology rejection criteria	HMD HTC Vive	2017	(Coldham and Cook 2017)

Table 4: Science Direct – list of selected articles

Objective	Technology	Year	Ref
Evaluation of interface and behavior of an immersive virtual reality	Projector, motion capture device	2017	(Chen and Or 2017)
Examination of time-varying kinematic responses	Motion capture device	2010	(Gurses, Kenyon, and Keshner 2011)
Empower senior citizens to gain more control to improve well-being	HMD	2016	(Fernández et al. 2017)
Treadmill training to reduce fall risk in older adults	motion-capture camera and large screen	2016	(Mirelman et al. 2016)
Comparison of individualized virtual reality and group-based rehabilitation	Kinect	2016	(Lee et al. 2016)
Design training program for prevention of falling in the elderly	Wii balance board	2017	(Lim et al. 2017)
Study the effect of virtual reality exercise on quality of life in older women	Kinect and monitor screen	2015	(Lee et al. 2015)
Evaluate the learning, retention and transfer of performance improvements	Wii balance board	2012	(Mendes et al. 2012)
Positive mood induction	Touch screen with integrated audio speakers	2012	(Baños et al. 2012)
Assessment of everyday memory	HMD	2018	(Ouellet et al. 2018)
Help older pedestrians make safer street-crossing decisions	Rear-system projection, 3D sound rendering system, and motion capture system	2017	(Maillot et al. 2017)
Determine whether trunk motion treadmill walking would improve over-ground balance	TV screen	2018	(Anson et al. 2018)
Assess the effects of exercise program on hip muscle strength and balance control	Kinect	2013	(Kim et al. 2013)
Engage Motor and Postural Abilities	NVidia 3D Vision Pro with special 3D glasses	2016	(Bourrelier et al. 2016)
Characterize episodic memory profiles	Video projector	2012	(Plancher et al. 2012)
Assess to which extent skiing games challenge balance	Wii balance board	2018	(de Vries et al. 2018)

Table 5: Google Scholar – list of selected articles – to be continued

Objective	Technology	Year	Ref
Study satisfaction of elderly in 360° virtual reality travel media.	HMD	2018	(Srifar 2018)
Investigate the feasibility and safety of virtual reality exercise intervention in patients with hematologic malignancies receiving chemotherapy	Wii Balance Board	2016	(Tsuda et al. 2016)
Improve cognition, muscle strength, and postural balance	No information	2016	(Park and Yim 2016)
Evaluate complex environments exploration capacity	Desktop	2009	(Morganti et al. 2009)
Analysis of virtual reality versus functional training in fitness	Kinect	2015	(dos Santos et al. 2015)
Improve spatial learning and driving abilities	Driving simulator	2014	(Lithfous et al. 2014)
Assess deficit in the mental frame syncing	Computer monitor	2014	(Serino et al. 2014)
Build an information platform of interactive scenarios, for practices and evaluation on balance ability	Kinect	2013	(Hsieh et al. 2013)
Lessen cognitive decline and improve memory functions	HMD and motion tracking sensor	2010	(Optale et al. 2010)
Design of virtual reality based physical and cognitive stimulation exercises	Bike interfaced with computer	2012	(Klinger et al. 2012)
Study effects of enactment in episodic memory	PC and large screen	2014	(Jebara et al. 2014)

Table 6: Google Scholar – list of selected articles (continued)

Objective	Technology	Year	Ref
Study efficacy of virtual reality associated with serious games in elderly people	EyeToy PlayStation 2 and video projector.	2016	(Levy et al. 2016)
Evaluate the acceptability of a VR experience using the image-based rendering virtual environment	Large screen	2015	(Benoit et al. 2015)
Assess postural control adaptation quantitatively in unsteady elderly patients at risk of falls in open spaces	No information	2006	(Suárez, Suárez, and Lavinsky 2006)
Development of a virtual reality system to study tendency of falling among older people	HMD	2005	(Nyberg et al. 2005)
Assess the effectiveness of virtual reality training in reducing the risk of falls among elderly people	Kinect	2018	(Kamińska et al. 2018)
Examine the effects of virtual reality game exercise on balance and gait of the elderly	No information	2015	(Park, Kim, and Lee 2015)
Determine the effects of virtual reality-based balance training on balance of the elderly	Wii Balance Board	2014	(Cho, Hwangbo, and Shin 2014)
Examine the awareness, decision-making procedure, and personal values of the elderly with regard to virtual reality leisure activities	Wii	2018	(Lin, Jeng, and Yeh 2018)
Examine the usability of a newly designed virtual reality environment for training in the healthy older persons	VR-ATM (interactive screen)	2010	(Fong et al. 2010)
Determine the allocentric and egocentric memory deficits	Desktop	2018	(Mohammadi, Kargar, and Hesami 2018)
Evaluate of repetitive rhythmic movements in the elderly and Parkinson's disease patients	HMD	2012	(Arias et al. 2012)
Investigate the effects of a virtual reality exercise program on the balance of elderly persons with type 2 diabetes	EyeToy PlayStation 2 and motion-tracking camera	2012	(Lee and Song 2012)

VI. Conclusions

In this article we present the results of a systematic literature review with the objective of identifying the studies related to virtual reality focusing older users. We also presented a list of some elements that we consider important for the development of virtual reality applications focusing on older people.

Several studies used sensors to collect data during the experiments. However, some studies presented different technologies in relation to other well-known technologies for use with virtual reality, which leads to the hypothesis that the concept of virtual reality is not yet consolidated.

Considering the objectives of the articles selected, it is possible to identify the main applications of virtual reality for the older people, now and in the near future: healthcare, rehabilitation, prevention of fall, physical activity engagement, cognitive exercises, fun and virtual travels to faraway places.

Finally, the research considered only articles of published in the ACM, IEEE, Science Direct, and Google Scholar. Then, for future work, we propose to carry out studies from other publications to address the failures resulting from these limitations.

The contribution of this work is to provide information about the methods conducted on previous research, user experience and future work on virtual reality with older adults as participants in the studies. This information can help researchers plan their research methods, improve the reliability of their work, and design virtual reality applications focused in the elderly.

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