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A systematic review of gamification techniques applied to elderly care

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Abstract
The proportion of the world's population growing older is rapidly increasing over the last decades. With the recent progresses seen in information and communication technologies, there have been great concerns about developing personalized healthcare services that can ensure the living conditions and active aging of the elderly people. Among these technologies, we highlight and review in this work, the current state of gamification and related techniques applied to the elderly care context. Six research questions were defined to provide an overview on the current state in the development of gamified systems for elderly care through the identification of publication source types, research areas, target groups, game design elements and technologies employed and observed issues and benefits of using gamification in this context. Results have shown a great diversity in publication source types and research areas, even within the health domain. Different target groups were identified based on surrounding environment and physical and cognitive capabilities of the elderly person. Feedback, progression, rewards and social interaction enhancement are highlighted as the most relevant and frequently used game design elements for this context. Technological features observed include self-management systems, portable devices, physical robots, consoles and wearable technologies. The use of gamification techniques to support elderly people has proven to be beneficial to improve wellbeing as well as both physical, cognitive, social, and emotional state of the elderly person. Current challenges are most related with the need for traditional healthcare services to integrate gamification techniques to improve personalized healthcare and answer different necessities and adapt the support provided according to the individual capabilities of elderly people. The findings presented in this systematic literature review should be considered in the development of future personalized elderly care solutions by adapting the support provided according to interests, capabilities, necessities and contexts associated to the elderly person as a means to improve independence, health and wellbeing, capture interest and positive engagement, facilitate social interaction and decrease impact of many different medical conditions affecting older people.

Keywords Gamification · Serious games · Elderly care · Systematic literature review

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1 Introduction

We are currently witnessing an increase of the world's population which is growing older. According to United Nations's World Population Ageing Report (UN 2017), the global population aged 60 years or older has registered a total of 962 million in 2017 and this number is expected to double by 2050. With the increase of the number of older citizens living in today's society there has been a growing necessity to research and develop assistive technologies that can support elderly people (Durick et al. 2013; Roupa et al. 2010) specially in smart environments (Cook and Das 2004; Liu et al. 2016). Among many of the already available technologies it is highlighted the use of telecare devices (Botsis et al. 2008), persuasive technologies (Chatterjee and Price 2009), rehabilitation systems (Organization 2017) and digital games (Van Diest et al. 2013; Gerling and Masuch 2011; Gerling et al. 2011; Ijsselsteijn et al. 2007) in this type of context.

The use of games and game design elements in nongame contexts has sprouted the attention of many researchers from different areas and application fields such as digital marketing (Hofacker et al. 2016; Mishra and Dham 2018), finances (Wanick and Bui 2019), education (Rosyid et al. 2018; González et al. 2016), productivity (Korn and Schmidt 2015), sustainability (Alla and Nafil 2019; Paravizo et al. 2018) or even news (Deterding et al. 2011a, b). Nowadays, we associate this new use of games in more serious contexts to two main concepts described as serious games and gamification. Serious games are often regarded as games "designed to entertain players as they educate, train, or change behavior" (Stokes 2005). In this sense, a very common approach for developing serious games is the use of exergames or video games that provide encouragement to exercise, for groups of individuals that may be reluctant to engage in the more traditional forms of exercise (Whitehead et al. 2010). Gamification refers to the enhancement of services with features that can offer "gameful" experiences to its users and keep users motivated and engaged increasing their activity, social interaction, and the quality and productivity of their actions (Hamari et al. 2014). Companies are now extending (and 'gamifying') their existing services and much more investments are being made towards the development of gamified applications and/or serious games (Hamari et al. 2014). Likewise, recent research and advancements on gamification and serious games have been made in healthcare (Alahäivälä and Oinas-Kukkonen 2016; Carson et al. 2016; Dias et al. 2018; Konstantinidis et al. 2017a) with great focus on different health domains such as to promote both physical and cognitive activity (Anguera and Gazzaley 2015; Mullins and Sabherwal 2018; Wallace et al. 2014; Kappen et al. 2019; Sween et al. 2014), promote behavioral changes (Alahäivälä and Oinas-Kukkonen 2016; Hermens et al. 2014) and provide personalized healthcare services at all ages (Gerling and Masuch 2011).These services can bring innovative and cost-effective solutions and treatments to the most fragile and isolated groups in our society which correspond to elderly people and/or those suffering from chronic diseases (Kappen et al. 2019; Webster and Celik 2014). Furthermore, personalization becomes a key aspect for these kind of services as individual necessities and capabilities are even more impactful to this age group. The lack of personalized mechanisms could lead to a quick disinterest to keep using the healthcare service and in the context of elderly care this could easily result in the deterioration of health condition. In this context, the potential of gamification and the use of serious games is now being studied as a way to deliver more effective and personalized services to elderly people and to encourage and persuade them to undertake both physical, cognitive and social activities according to their individual capabilities and needs, thus contributing to their overall wellbeing and to motivate to pursuit more active and healthy lifestyles (Gerling and Masuch 2011; McCallum 2012; Brauner et al. 2013).

Although there is already a considerable amount of work proposed in the literature on the topic of gamification techniques applied to elderly care, comprehensive reviews of the most recent work done in this context are still very lacking. Therefore, the purpose of this work is to provide such needed overview of the advancements done in gamification and associated techniques applied to elderly care. For that, six different research questions were studied and discussed throughout this work to describe the current state of the art on the existing personalized elderly care services and their correlation with gamification technologies so that it can then be possible to establish a background for researchers to pursuit their research activities in this area. The selected studies were first revised in terms of publication source types, research areas and target audience. Then, each selected work was analyzed in more detail to understand what kind of game design elements and technological features were employed by authors in their proposals. Finally, the perceived challenges to overcome and the benefits to consider were explored to understand how gamification techniques can be successfully integrated in personalized elderly care solutions.

In the next section, it is exposed the research methodology used in this systematic literature review (SLR) which includes the formulation of different research questions and the definition of the search strategy to be applied. The results obtained are presented in Sect. 3 and discussed in Sect. 4. Finally, major conclusions are taken in Sect. 5 along with the work to be done hereafter.

2 Methodology

According to Budgen and Brereton (2006), Kitchenham (2004) a SLR is a means of gathering all available research related to a certain area or topic of study, research question, phenomenon or interest. To the best of our knowledge there are very few studies reviewing existing gamification techniques and serious games applied to elderly care. For this reason, we have conducted a systematic review of the works available in literature which approach the topic of gamification applied to personalized healthcare with focus on elderly care. We have followed Kitchenham's methodology (Kitchenham 2004) to execute this systematic review and we have developed a review protocol in which we define all the elements necessary to conduct a SLR: define a review protocol (and clearly define all research questions and search strategy), execute the review and then analyze and discuss the obtained results.

2.1 Research questions

In this SLR we define the main research question as follow: "What is the current state-of-the-art of gamification techniques applied to elderly care?". To answer this question the most recent literature should be revised according to six submain questions (see Table 1). In the first question the main source types of studies are revised to understand how diverse these studies are in terms of whether they were published in a journal, conference proceedings or another publication channel. Furthermore, this question may also allow to comprehend the impact of each publication (depending on the rank of the journal and conference). In the second question, the main related research areas of each published work are identified to understand if the use of gamification techniques applied to elderly care affects only the area of personalized healthcare or if there are other health domains where the use

Table 1 Research questions

	Research question
RQ1	What are the main source types of studies related to gamification in elderly care?
RQ2	In which research areas has gamification in elderly care been investigated?
RQ3	What are the main target groups of elderly people for gamified healthcare services?
RQ4	Which game design elements have been used on gamification in elderly care?
RQ5	What are the main technological features employed in the current existing systems?
RQ6	What are the current main challenges and benefits of using gamification techniques in elderly care?

of gamification could also be relevant. In the third question the target audience is studied and correlated to the context in which each published work was developed and what were the target groups for that study. Examples include elderly people living in a community, or elderly people living in a nursing home. In the fourth question, it is studied what game design elements are more frequently used in the development of gamified services to support elderly people. According to the literature (Zichermann and Cunningham 2011) it is known that a game design element corresponds to a game component that can be used to enhance user experience while using a certain service or application. The game design elements more frequently used not only in the healthcare context but also other areas of research (such as finance, industry, education, among others highlighted in the previous section of this SLR) include the use of points/score, badges, leaderboards, challenges, levels and feedback. With this question it is observed if those elements are also applied in considered works and if other less common elements are also considered. In the fifth question the main technological features are analyzed to identify which kind of software and hardware is more frequently considered in the development of gamified services for elderly care. In the sixth question the main benefits and challenges identified by the authors of each selected work are revised to understand what the current major limitations and obstacles are and the most advantageous features to consider to successfully develop gamified services for elderly care.

2.2 Definition of search strategy

The search conducted in this review considered works available in literature regarding current scientific knowledge about gamification and serious games applied to personalized healthcare with focus on elderly care. The search strategy is divided in three steps: definition of search sources, definition of search terms and study selection and data extraction process.

2.2.1 Definition of search sources

The first step of the search strategy was to identify and define which search sources would be considered while executing the SLR. For this work, searches were performed in four electronic databases (see Table 2) and considered the works published in journal articles, chapters, conference proceedings and books.

Table 2 Electronic databases

Identifier	Database	URL
ED1	PubMed	https://www.ncbi.nlm.nih.gov/pubmed/
ED2	Science Direct	https://www.sciencedirect.com/
ED3	IEEE Xplore	https://ieeexplore.ieee.org/Xplore/home.jsp
ED4	Web of Science	https://login.webofknowledge.com/

2.2.2 Definition of search terms

The second step of the search strategy was to define a set of search strings that reflected the research questions defined. Four search strings were defined according to a specific area of study. The search strings can be consulted in Table 3.

2.2.3 Study selection and data extraction process

The study selection and data extraction process include the definition of the selection and refinement methodology to filter undesirable results and then retrieve the most relevant findings that could answer the research questions defined in our SLR. For this, we defined both inclusion and exclusion criteria which can be consulted in Tables 4 and 5. The studies that satisfied at least one or more inclusion criteria were considered while the studies that matched one or more exclusion criteria were excluded.

After defining each necessary condition to include or exclude a certain finding, the study selection and data extraction process was performed using the PRISMA (Liberati et al. 2009) guidelines divided in four different phases: Identification, Screening, Eligibility and Inclusion.

As can be seen in Fig. 1, in the Identification phase a total of 905 results were retrieved from the selected databases. In the Screening phase, 59 duplicate records were first excluded (with exclusion criterion EC5). 699 records were next excluded after reviewing

Table 3 Search strings

Scope	String
Software	(App OR framework OR System) **AND**
Elderly	(Elderly Person OR Older Adult OR Senior) **AND**
Healthcare	(Health* OR Care*) **AND**
Gamification	(Gamification OR Game)

Table 4 Inclusion criteria

	Inclusion criterion
IC1	The source focuses on the use of gamification in elderly care
IC2	The source explores different gamification mechanisms applied to elderly care
IC3	The source evaluates gamified applications in elderly care
IC3	The source clearly identifies current benefits and challenges in the use of gamification in elderly care

Table 5 Exclusion Criteria

	Exclusion criterion
EC1	Sources not written in English
EC2	Sources published before 2010
EC3	Sources besides journal articles, chapters, conference proceedings and books
EC4	Sources that do not present studies related to the use of gamification techniques in elderly care
EC5	Duplicated sources

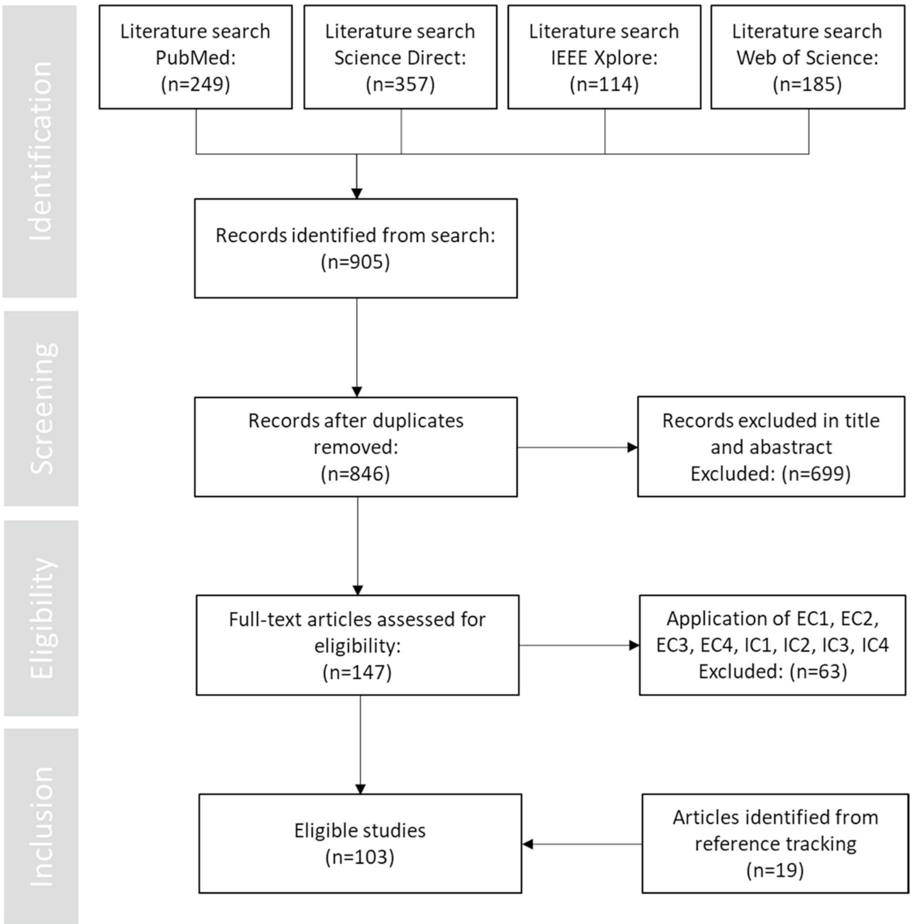

Fig. 1 PRISMA flow diagram

the titles and abstracts of the retrieved works. In the Eligibility phase, a full-text analysis was done on the remaining records according to the Inclusion and Exclusion criteria that were defined. Only 84 studies were eligible for the Inclusion phase. Finally, in the Inclusion phase, 19 further studies were included through reference tracking. After this phase, the total number of eligible studies was of 103 retrieved works. Each eligible study undertook a quality appraisal assessment and was ranked so that this SLR would only consider the most relevant works among these studies. For that, a set of four quality appraisal questions was formulated which can be consulted in Table 6. Regarding the fourth quality appraisal question, each study was ranked based on the the latest ranking provided by CORE and JCR rankings depending whether the study referred to conference proceedings or a journal publication.

The eligible studies and their quality appraisal results can be consulted in "Appendix 1". The best possible score for each study was of 5 (in case the study referred to a journal article ranked as Q1 by JCR) or 4.5 (in case the study referred to conference proceedings ranked as A in CORE). All the studies ranked with a score greater than 2, and which had at least a positive score on three of the four quality appraisal questions were finally considered for the SLR. In the end, among the 103 eligible studies previously identified, only the 42 most suitable studies were selected for the SLR.

3 Results

This section describes the results of the SLR and how each research question was answered according to the information available in each selected study.

3.1 Research question 1

3.1.1 What are the main source types of studies related to gamification in elderly care?

The selected papers have been published mainly in journal articles (59% or 25 of the selected papers) and the remaining publications refer to conference proceedings (41% or 17 of the selected papers). Three works have been published in Games for Health Journal (Li et al. 2017; Whyatt et al. 2015; Borghese et al. 2013) and three works have also been published in IEEE Journal of Biomedical and Health Informatics (Konstantinidis et al. 2016, 2017b; Ofli et al. 2016). All the remaining studies have been published in different journals or conference proceedings indicating great publishing diversity in this area. Each selected study was also evaluated based on the publication channel ranking. In conference proceedings, it was observed that two studies were published in a CORE A conference proceedings (Liu et al. 2014; Kappen et al. 2016), three studies were published in CORE B conference proceedings (Pisan et al. 2013; Khosla et al. 2013; Li et al. 2018), two studies were published in a CORE C conference proceedings (Lange et al. 2011; Mocanu et al. 2016), one study was publish in CORE Australasian (Garcia and Felix Navarro 2015) and nine studies were published in conference proceedings without a CORE rank (Gerling and Masuch 2011; Stutzel et al. 2016; Kostopoulos et al. 2018; Cornejo et al. 2012; Li and Chen 2017; Korn et al. 2019; Dell'Acqua et al. 2013; Buchem et al. 2015a; Chao et al. 2017). In journal articles, six studies were published in Q1 journals (Alahäivälä and Oinas-Kukkonen 2016; Konstantinidis et al. 2016, 2017b; Ofli et al. 2016; Hoshino and Mitani 2018; Saenz-de-Urturi and Soto 2016), twelve studies were published in Q2 journals (Li et al. 2017; Whyatt et al. 2015; Borghese et al. 2013; O'Connor et al. 2018; Malwade et al. 2018; Manera et al. 2017; Alloni et al. 2017; Kitakoshi et al. 2017a; Gamecho et al. 2015; de Vette et al. 2015; Boquete et al. 2011; Vaziri et al. 2017) and eight studies were published in Q3 or Q4 journals (Devos

Table 6 Quality appraisal questions

	Question	Answer	
QA1	Does the study present a detailed description of the game design elements used?	Yes (+1); no (0)	
QA2	Does the study explicitly refer to existing challenges, barriers or limitations in the use of those or/and other game design elements in elderly care?	Yes (+1); no (0)	
QA3	Does the study explicitly refer to existing benefits or advantages in the use of those or/and other game design elements in elderly care?	Yes (+1); no (0)	
QA4	Has the study been published in a relevant journal or conference proceedings?	CORE2018	JCR2018
		A (+1.5)	Q1 (+2)
		B (+1)	Q2 (+1.5)
		C (+0.5)	Q3 or Q4 (+1)
		No rank (0)	No rank (0)

et al. 2015; Hsiao and Rashvand 2015; Liukkonen et al. 2015; Proffitt et al. 2015; Ona et al. 2018; Money et al. 2019; Meza-Kubo et al. 2014; Gschwind et al. 2014). Among the selected studies published in Q1 journals it is highlighted the work published in IEEE Journal of Biomedical and Health Informatics in 2018 (Konstantinidis et al. 2017b) which had the highest Journal Impact Factor (4.217).

3.2 Research question 2

3.2.1 In which research areas has gamification in elderly care been investigated?

The 10 main research areas related to the use of gamification in elderly care according to the selected results are Computer Science, Medical Informatics, Engineering, Healthcare Sciences, Geriatrics Gerontology, Rehabilitation, Mathematical Computational Biology, Telecommunications, Public Environmental Occupational Health and Psychology (see Fig. 2).

Among these results it is highlighted the 3 areas with most selected works which are Computer Science (20 selected works), Medical Informatics (12 selected works) and Engineering (10 selected works). Computer Science and Engineering show a greater focus on the development of serious games; however Medical Informatics, Healthcare Sciences and Geriatrics Gerontology show a more even distribution in the development of both serious games and the use of gamification. For example, Devos et al. (2015) developed a personalized gamified application to record the medication intake, log physiological parameters and perform cognitive assessment. Kostopoulos et al. (2018) developed a gamified application to assist elderly in their daily activities and to improve their compliance to medical instructions (diet, medication intake, etc.). Other authors propose the development of serious games to improve both physical (Gerling and Masuch 2011; Borghese et al. 2013; Konstantinidis et al. 2017b; Pisan et al. 2013; Lange et al. 2011; Hoshino and Mitani 2018; Gamecho et al. 2015; Liukkonen et al. 2015) and cognitive (Gerling and Masuch 2011; Liu et al. 2014; Manera et al. 2017; Alloni et al. 2017) capabilities of the elderly.

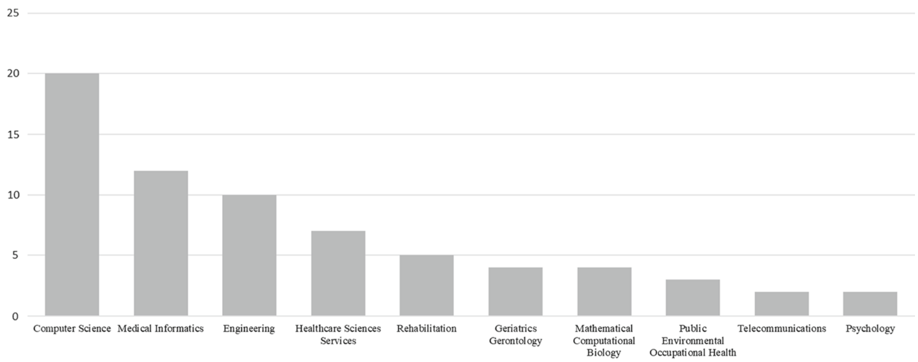

Fig. 2 Research areas of gamification in elderly care

3.3 Research question 3

3.3.1 What are the main target groups of elderly people for gamified healthcare services?

To answer this research question, each selected work was classified according to the target end user and the purpose of the proposed system. It was possible to identify six target groups of elderly people as can be seen in Table 7.

Among the selected works four environments were distinguished depending on whether: the elderly person would make use of the proposed system on their own (home environment) in his/her home; or if the system would be used by several elderly people simultaneously (community environment); or if the elderly person would make use of the system

Table 7 Target group

Group	Study
Home environment	Korn and Schmidt (2015), Carson et al. (2016), Borghese et al. (2013), Konstantinidis et al. (2016), Ofli et al. (2016), Liu et al. (2014), Khosla et al. (2013), Lange et al. (2011), Garcia and Felix Navarro (2015), Stutzel et al. (2016), Kostopoulos et al. (2018), Dell'Acqua et al. (2013), Hoshino and Mitani (2018), Malwade et al. (2018), Manera et al. (2017), Alloni et al. (2017), Gamecho et al. (2015), Boquete et al. (2011), Devos et al. (2015), Liukkonen et al. (2015), Proffitt et al. (2015), Ona et al. (2018), Money et al. (2019), Meza-Kubo et al. (2014), Gschwind et al. (2014), Billis et al. (2011)
Community environment	Li et al. (2017), Whyatt et al. (2015), Khosla et al. (2013), Li et al. (2018), Kostopoulos et al. (2018), Vaziri et al. (2017), Proffitt et al. (2015), Money et al. (2019), Gschwind et al. (2014)
Outdoor environment	Kostopoulos et al. (2018), Korn et al. (2019)
Nursing home environment	Gerling and Masuch (2011), Khosla et al. (2013), Saenz-de-Urturi and Soto (2016), Manera et al. (2017)
Physical rehabilitation and stimulation	Gerling and Masuch (2011), Korn and Schmidt (2015), Alahäivälä and Oinas-Kukkonen (2016), Li et al. (2017), Whyatt et al. (2015), Borghese et al. (2013), Konstantinidis et al. (2016), Ofli et al. (2016), Liu et al. (2014), Kappen et al. (2016), Pisan et al. (2013), Li et al. (2018), Lange et al. (2011), Mocanu et al. (2016), Garcia and Felix Navarro (2015), Kostopoulos et al. (2018), Cornejo et al. (2012), Dell'Acqua et al. (2013), Buchem et al. (2015a), Hoshino and Mitani (2018), Saenz-de-Urturi and Soto (2016), O'Connor et al. (2018), Malwade et al. (2018), Manera et al. (2017), Kitakoshi et al. (2017a), Gamecho et al. (2015), Vaziri et al. (2017), Hsiao and Rashvand (2015), Liukkonen et al. (2015), Proffitt et al. (2015), Ona et al. (2018), Money et al. (2019), Gschwind et al. (2014), Billis et al. (2011)
Cognitive rehabilitation and stimulation	Gerling and Masuch (2011), Korn and Schmidt (2015), Liu et al. (2014), Stutzel et al. (2016), Hoshino and Mitani (2018), Manera et al. (2017), Alloni et al. (2017), Boquete et al. (2011), Devos et al. (2015), Hsiao and Rashvand (2015), Ona et al. (2018), Meza-Kubo et al. (2014)

outside of his/her home (outdoor environment); or if the elderly person would make use of the system while being taken care of (nursing home environment). As can be seen in Table 9, most of the proposed systems were intended to be used under home-based and community settings while systems developed towards outdoor and nursing home environments were less observed in the literature.

All the selected works were then categorized according to the main goal of the proposed system whether: the system goal is to improve physical condition of the elderly person; or the system goal is to improve the cognitive condition of the elderly person; or both. In this sense the number of selected works targeted towards physical rehabilitation and stimulation was far greater than the number of works only focusing on cognitive rehabilitation and stimulation. Furthermore, these results show a strong interest in the literature to develop exergame-based systems with the aim of motivating the practice of physical exercise and at the same time reduce the sedentism of the elderly person.

3.4 Research question 4

3.4.1 Which game design elements have been used on gamification in elderly care?

To answer this question, we considered the game design elements suggested by Marczewski and colleagues (Tondello et al. 2016; Marczewski 2015) in which they enumerate different game design elements and additionally correlated those elements with different types of users and their gaming motivations (Philanthropist, Socializer, Free Spirit, Achiever, Player and Disruptor). For this SLR, the analysis of the selected papers was performed based on only the set of game design elements suggested by Marczewski and colleagues and not based on their correlation with different types of users as it is not a goal of this research question to identify different types of elderly users but instead just study the use of game design elements in the development of gamified elderly care solutions. Therefore, in Table 8 is presented the game design elements most frequently employed in each selected study.

Among the selected studies there is a clear preference to incorporate some sort of mechanism that can provide feedback to the user. In fact, more than half of selected studies have incorporated or suggested this game design element. For example, in Hoshino and Mitani (2018) it is proposed a personal rehabilitation system which provides preventive care using a rehabilitation game with touch, visual and audio feedback. In Konstantinidis et al. (2017b) it is proposed a exergaming platform with a hiking and fishing game and feedback is provided using messages and images to promote proper execution of the game functionalities. After the game is played, further feedback is provided to show user game performance. In Kostopoulos et al. (2018) it was developed a gamified application which tracks the number of kilometers walked per day by the elderly person and informs him towards daily miles. Daily and weekly history of the number of steps walked in each day can also be visualized with the application. This way the user could keep track of the progress and be motivated to improve his/her physical activity. In Ofli et al. (2016) a Microsoft Kinect-based coaching system was developed to guide users through a series of video exercises which would track and measure movements, provide real-time feedback, and record performance over time. Feedback is received in form of video instructions on how to correctly perform the exercise and performance is measured in real-time using the Kinect full body skeleton representation while various corrective alerts are provided by the system via textual and computer-generated audio cues. In Dell'Acqua et al. (2013) a

Table 8 Game design elements

Game design element	Study
Collection	Konstantinidis et al. (2016, 2017), Lange et al. (2011), Garcia and Felix Navarro (2015), Saenz-de-Urturi and Soto (2016), Vaziri et al. (2017), Hsiao and Rashvand (2015), Liukkonen et al. (2015), Money et al. (2019), Gschwind et al. (2014)
Sharing knowledge	Borghese et al. (2013), Kitakoshi et al. (2017a), Devos et al. (2015)
Administrative role	Borghese et al. (2013), Konstantinidis et al. (2016), Lange et al. (2011), Alloni et al. (2017), Gamecho et al. (2015)
Social interaction	Gerling and Masuch (2011), Li et al. (2017), Borghese et al. (2013), Konstantinidis et al. (2016), Khosla et al. (2013), Kostopoulos et al. (2018), Cornejo et al. (2012), Li and Chen (2017), Buchem et al. (2015a), Kitakoshi et al. (2017a)
Social competition	Khosla et al. (2013), Cornejo et al. (2012), Buchem et al. (2015a), Kitakoshi et al. (2017a)
Unlockable content	Kostopoulos et al. (2018), Hsiao and Rashvand (2015)
Creativity tools	Devos et al. (2015)
Customization	Konstantinidis et al. (2017b), Kostopoulos et al. (2018), Hoshino and Mitani (2018), Manera et al. (2017), Kitakoshi et al. (2017a), Hsiao and Rashvand (2015)
Quests/goals	Borghese et al. (2013), Liu et al. (2014), Lange et al. (2011), Kostopoulos et al. (2018), O'Connor et al. (2018)
Sense of progression/levels	Li et al. (2017), Whyatt et al. (2015), Borghese et al. (2013), Konstantinidis et al. (2016), Li et al. (2018), Mocanu et al. (2016), Garcia and Felix Navarro (2015), Kostopoulos et al. (2018), Li and Chen (2017), Hoshino and Mitani (2018), Saenz-de-Urturi and Soto (2016), Manera et al. (2017), Alloni et al. (2017), Kitakoshi et al. (2017a), Boquete et al. (2011), Vaziri et al. (2017), Hsiao and Rashvand (2015), Liukkonen et al. (2015), Money et al. (2019), Gschwind et al. (2014)
Points/scores	Whyatt et al. (2015), Konstantinidis et al. (2017b), Konstantinidis et al. (2016), Li et al. (2018), Lange et al. (2011), Mocanu et al. (2016), Garcia and Felix Navarro (2015), Stutzel et al. (2016), Cornejo et al. (2012), Li and Chen (2017), Hoshino and Mitani (2018), Saenz-de-Urturi and Soto (2016), Boquete et al. (2011), Vaziri et al. (2017), Money et al. (2019), Gschwind et al. (2014)
Prizes/rewards/trophies/badges	Konstantinidis et al. (2017b), Liu et al. (2014), Garcia and Felix Navarro (2015), Stutzel et al. 2016, Kostopoulos et al. (2018), Buchem et al. (2015a), Manera et al. (2017), Hsiao and Rashvand (2015)
Leaderboards/high scores/ranks	Gerling and Masuch (2011), Borghese et al. (2013), Cornejo et al. (2012), Kitakoshi et al. (2017a), Vaziri et al. (2017), Gschwind et al. (2014)
Achievements	Gerling and Masuch (2011), Konstantinidis et al. (2017b), Konstantinidis et al. (2016), Kostopoulos et al. (2018), Vaziri et al. (2017), Gschwind et al. (2014)
Virtual economy	Liu et al. (2014)
Lotteries	Khosla et al. (2013)
Time record/constraint	Li et al. (2017), Liu et al. (2014), Garcia and Felix Navarro (2015), Cornejo et al. (2012), Hoshino and Mitani (2018), Saenz-de-Urturi and Soto (2016), Boquete et al. (2011), Money et al. (2019)
Restart/replay tasks	Konstantinidis et al. (2016), Manera et al. (2017), Gamecho et al. (2015), Proffitt et al. (2015)
Flow	Borghese et al. (2013), Ofli et al. (2016), Liukkonen et al. (2015)

Table 8 (continued)

Game design element	Study
Feedback	Whyatt et al. (2015), Borghese et al. (2013), Konstantinidis et al. (2017b), Konstantinidis et al. (2016), Ofli et al. (2016), Liu et al. (2014), Khosla et al. (2013), Li et al. (2018), Mocanu et al. (2016), Garcia and Felix Navarro (2015), Kostopoulos et al. (2018), Cornejo et al. (2012), Li and Chen (2017), Korn et al. (2019), Dell'Acqua et al. (2013), Hoshino and Mitani (2018), Saenz-de-Urturi and Soto (2016), Manera et al. (2017), Kitakoshi et al. (2017a), Gamecho et al. (2015), Boquete et al. (2011), Vaziri et al. (2017), Hsiao and Rashvand (2015), Liukkonen et al. (2015), Proffitt et al. (2015), Money et al. (2019), Gschwind et al. (2014)

Table 9 Technological features

Technology	Study
Portable devices	Konstantinidis et al. (2017b), Liu et al. (2014), Stutzel et al. (2016), Kostopoulos et al. (2018), Li and Chen (2017), Korn et al. (2019), Gamecho et al. (2015), Boquete et al. (2011), Devos et al. (2015), Hsiao and Rashvand (2015), Ona et al. (2018), Meza-Kubo et al. (2014), Buchem et al. (2015b)
Robots	Khosla et al. (2013), Kitakoshi et al. (2017a), Gamecho et al. (2015)
Console devices	Li et al. (2017), Whyatt et al. (2015), Borghese et al. (2013), Konstantinidis et al. (2017b), Konstantinidis et al. (2016), Ofli et al. (2016), Pisan et al. (2013), Li et al. (2018), Lange et al. (2011), Mocanu et al. (2016), Garcia and Felix Navarro (2015), Cornejo et al. (2012), Dell'Acqua et al. (2013), Saenz-de-Urturi and Soto (2016), Vaziri et al. (2017), Liukkonen et al. (2015), Proffitt et al. (2015), Money et al. (2019), Meza-Kubo et al. (2014), Gschwind et al. (2014)
Touch panels	Hoshino and Mitani (2018), Meza-Kubo et al. (2014)
Wearable technologies	Kostopoulos et al. (2018), Korn et al. (2019), Buchem et al. (2015a), O'Connor et al. (2018), Malwade et al. (2018), Gamecho et al. (2015)
Adaptative interfaces	Mocanu et al. (2016), Devos et al. (2015)
Recommendation systems	Konstantinidis et al. (2016), Mocanu et al. (2016)
Rule-based systems	Borghese et al. (2013), Liu et al. (2014)
Multi-agent system	Kitakoshi et al. (2017a)
Virtual reality	Korn et al. (2019), Hsiao and Rashvand (2015), Ona et al. (2018)
Machine learning	Kitakoshi et al. (2017a)
Self-management systems	Li et al. (2018), Dell'Acqua et al. (2013), Alloni et al. (2017), Vaziri et al. (2017), Ona et al. (2018), Gschwind et al. (2014), Buchem et al. (2015b)

Microsoft-Kinect based system was developed to capture body movements and provide feedback to the elderly person regarding activities performed (such as jumping, standing or walking) as well as to identify and record falls and then alert medical staff. In Boquete et al. (2011) a television gamified system was develop to provide cognitive training programs to elderly people. This system offers a wide range of games to improve cognitive condition divided by three groups of cognitive activities (arithmetic, memory and association of ideas), using sums, ordering of numbers, letter memorization, image recognition, word association among others. The elderly person had to use a television remote control to answer different questions that were presented with different difficulty levels depending on his/her cognitive capabilities. In Vaziri et al. (2017), Gschwind et al. (2014) a Microsoft Kinect-based system was developed including three different exergames to support balance training and falling risk assessment. The authors expressed a great care for developing effective feedback mechanisms such as providing training results immediately after the training sessions and controlling activities over a period time as effective motivational factors for elderly people to stay interested in using the system. In Konstantinidis et al. (2016) authors proposed a exergaming platform using Wii Remote Control and Wii Balance Board composed by aerobic, strength balance and flexibility computerized exercises embedded in several proposed games (Hiking/ Cycling, Sky Jump, Arkanoid, Apple Tree, Fishing and Minig-Golf). While playing each game, the elderly person would receive automatic feedback in the format of auditory signals (such as whistling and clapping) and visual feedback (with rewarding and motivational pop up messages upon completing a significant event). In Proffitt et al. (2015) the authors studied how elderly people experienced balance exercises while interacting with both real and virtual environments. A task was performed in both real and virtual environments using different feedback mechanisms. In the virtual environment, the elderly person could see the visual of the full body skeleton representation on the television screen and had to use his/her hands to collect different gems and jewels. Furthermore, the elderly person would also receive visual and sound feedback whenever they collected gems successfully. In the real environment, the elderly person could only view the full body skeleton on the television screen and was given the task to grab a tennis ball. After performing the comparison study the authors concluded that elderly people were more focused and enjoyed performing the given task in the virtual environment compared to the real environment.

The second most observed game design element was the sense of progression or the use of different difficulty levels to represent different stages of progression. This element was included in 20 studies and is mainly used with the goal to improve either or both cognitive and physical condition of the elderly person. For example, in Alloni et al. (2017) it is proposed a cognitive rehabilitation system using 2D and 3D stimuli in an ontology that represents concepts, attributes and a set of relationships among concepts. The system then offers different cognitive exercises such as coupling words, unscrambling sentences and images, etc. The difficulty of these exercises can be specified by a therapist or adjusted automatically over time according the user performance. In Mocanu et al. (2016) the authors developed a Microsoft Kinect-based exergame using two avatars (user and virtual therapist) to instruct the elderly person to perform different exercises whose difficulty increases progressively as the user performance improves. In Kitakoshi et al. (2017a) it is proposed a preventive care system wherein the elderly can perform physical exercise without getting bored while communicating with robots through match-up games. The system adapts the difficulty and play time automatically according to the user's proficiencies and physical capabilities. In Borghese et al. (2013) it is proposed a game engine to support rehabilitation at home and suggests different postural exercises to the elderly person. This system adapts the difficulty of each exercise through a Bayesian framework by observing patient's success rate over time. In Garcia and Felix Navarro (2015) a Microsoft Kinect-based system is proposed in which the elderly person can play a gamified game to travel through different countries representing different challenges with different difficulty levels and collect exotic fruits by stepping on them. In Saenz-de-Urturi and Soto (2016) another Microsoft Kinect-based system was proposed with a similar concept where the elderly person must collect falling objects such as cakes and bottles of wine using his/her arms. The game uses three different levels with different difficulties and the main purpose is to capture and process the posture of the elderly person and provide feedback on correct and incorrect trunk and limb movements throughout gameplay. In Money et al. (2019) a first-person 3D exploration game was developed to educate older adults regarding fall risks in which the elderly person must identify potential hazards that might lead to a fall in a given home section. Each home section corresponds to a level with increasing difficulty. In Whyatt et al. (2015) a gamified system was developed using a Wii Balance Board and which provides four games (Apple Catch, Bubble Pop, Avoid the Shark and Smart Shrimp) that target different components of balance and in which the elderly person must control his/her center of pressure by performing different actions, such as catching falling apples, bursting bubbles, avoiding sharks and answering cognitive questions. The difficulty of each game is increased depending on the performance of the elderly person by increasing the speed and complexity of the movements of the objects which interact with the elderly person. In Li et al. (2018) a digital fitness game is proposed in which a personalized exercise plan can be configured by the medical staff to provide exercises with different difficulty levels. The elderly person can then access the exergame through the Microsoft Kinect and perform the suggested exercises with virtual demonstrations for each exercise. In Liukkonen et al. (2015) authors presented an Extreme Motion-based system using two exergames to improve physical well-being. One of the exergames had the main goal to practice different physiotherapeutic gymnastic exercises while providing feedback after performance to keep the player focused on the exercise instead of current performance. In the second exergame, the elderly person had to move in front of the camera and collect raspberries while avoiding obstacles. The difficulty and speed of the game increased in case the elderly person was able to perform the task correctly and avoid obstacles successfully. In Manera et al. (2017), the authors presented a study on the development of serious games adapted to elderly people with mild cognitive impairments and referred that the designing training aspect was a crucial aspect for serious games to be effective. This aspect could be exploited by designing an adaptative game challenge which "becomes more difficult as the player progresses, but steps back to an easier level when the player is tired or show a decline in performance". Furthermore, the authors also referred to the importance of a well-designed game reward system for the correct development of serious games.

In fact, another game design element considered in many of the selected studies was the use of some sort of rewarding mechanism for each exercise or task performed correctly. For example, in Kostopoulos et al. (2018) it is used an achievement system that unlocks trophies and rewards that can bring back nostalgic memories, events and entertainment to the elderly person. These rewards depend on the elderly person's interests and can be related to music videos, world events, old objects or personal events which are uploaded into the system by the elderly person's family. In Liu et al. (2014) it is used a virtual economy system in which the user collects virtual money depending on how well each given task is performed which can then be exchanged for virtual rewards. In Hsiao and Rashvand (2015) it is proposed a mobile augmented reality system with downloadable embedded learning exercises for both physical and cognitive rehabilitation and awards virtual tickets which users can use to advance to higher difficulty levels. In Buchem et al. (2015a) a gamified system was proposed to support elderly people retain and improve their physical condition using badges as digital achievements. These badges enhance user activity and represent the elderly person current training plan, number of daily steps and social interactions with other elderly people.

The use game mechanics as a means of enhancing social interaction between elderly people should also be highlighted. For example, in Li et al. (2017) five Microsoft Kinect based exergames were developed including a volleyball game that can be played simultaneously by elderly people and which capture upper limbs' movements to lift a falling volleyball. In Khosla et al. (2013) it was designed a social robot to play different games (such as Bingo game) in a residential care facility with groups of 8 to 30 elderly people. Furthermore, authors in Kostopoulos et al. (2018) referred to the usage of different elements like sharing photos, video calling and involving family so that the elderly person can be more social. Also, authors in Gerling and Masuch (2011) explore the potential of gamification for social interaction and express that "the presentation of playful activities and the integration of game elements such as game metrics offer the possibility of fostering social interaction between senior citizens living in nursing homes". In Li and Chen (2017) a mobile cognitive system was developed with an implementation of the Gomuku/Five in a Row game for elderly people to play alone or together with other people. Besides that, the game offers some features to enhance social interaction by allowing the elderly person to record screenshots and send them directly to his/her contacts or share in social media applications. All the screenshots are stored in an embedded browser which can then be easily accessed within the system. In Cornejo et al. (2012) two exergames were developed for Microsoft Kinect with enhanced social interaction features. In the first game, missions can be defined and submitted by the elderly person for his/her to take and upload photos within a given time. The elderly person must then access and rank each photo using physical exercises commands. Arm raise exercises are performed to navigate through photos while circular arm raise exercises are performed to rank a certain photo. The second game uses the same concepts presented in the first game however in this case the content is provided though the Facebook account of the elderly person and from his/her Facebook contacts. Three photos are selected randomly as well as one of the captions of those photos. The elderly person must then identify the correct photo for the given description using the same body actions of the first game.

3.5 Research question 5

3.5.1 What are the main technological features employed in the current existing systems?

Another goal of this SLR was to study the technological features employed by authors in their proposals. This allowed us, from a computer science point of view, to understand which approaches are the most successful and which are not. Therefore, among the selected studies we have identified different technological features (See Table 9).

The technological features most frequently observed among the selected studies include the use of self-management systems, portable devices, physical robots, consoles and wearable technologies.

The most observed technological feature employed by the selected studies was the use of gaming console devices such as the Microsoft Kinect (https://developer.microsoft.com/en-us/windows/kinect), Nintendo Wii Balance Board (http://www.wiifit.com/) and Tyromotion Tymo (https://tyromotion.com/en/produkte/tymo/). The intelligent game engine proposed in Borghese et al. (2013) can be integrated with the devices mentioned above and includes a rule-based engine using fuzzy logic to identify the most appropriate exercises defined by clinicians to be recommended to users. The system first schedules and adapts the difficulty to each user capacity and then monitors and supervises gaming sessions and their activity (capturing his/her movements with the console devices and comparing with the rules defined) and provides feedback to the user using a virtual therapist/avatar (VT). According to the authors, by using a fuzzy rule-based recommender system it will be possible to substitute the therapist (to a limited degree) and the VT will provide the user a feel of presence and that he/she is being supervised by a more experienced entity. In Lange et al. (2011), it is also proposed a system which recommends activities and uses Microsoft Kinnect embedded sensors to capture user movements and adapt the difficulty of the rehabilitation exercises according to the user's capabilities. However, in their proposal they do not mention how the captured movements are processed and compared so that the system can then identify whether a movement was performed correctly or not and how the system adapts the difficulty of each exercise to the user's capabilities. In Pisan et al. (2013), a similar system is proposed using Microsoft Kinnect, but in this case the authors reveal which metrics they consider to measure user performance: decision time, which corresponds to time elapsed before the user moves his/her legs to perform the exercise; movement time, which corresponds to the time elapsed while the leg is moving; response time, which corresponds to the sum of the movement time with the decision time; and the validation, which corresponds to whether the user moved to the right position or not. The work proposed in Konstantinidis et al. (2017b) also uses Microsoft Kinnect, however the authors also combined with the Google Street View API so that the user can move inside a virtual environment reflecting the real world.

Regarding the use of portable devices, we have noticed different proposals with applications adapted to smartphone or tablets. Furthermore, in two studies it was identified the use of different components or sensors embedded in these devices. In Hsiao and Rashvand (2015), it is proposed an application which makes use of the smartphone rear camera, microphone and gyroscope to detect body gestures and activate sensor areas while the user performs different exercises. For this, the authors have divided the smartphone operation in three different parts: using lightweight core processing to increase the durability of the smartphone battery; using augmented reality specific Input/ Output device control functions; and using a front-end application to optimize the inputs and outputs of the user interface. In Stutzel et al. (2016), it is proposed an application to monitor elderly patients with chronic degenerative diseases using a caregiver component to receive and send information regarding the elderly patient's condition. For this the application uses the smartphone's GPS sensor to track the patient's location and allow the patient and caregiver to access daily reports of the patient's location history.

The use of wearable technologies has been studied and proposed by different authors. In Kostopoulos et al. (2018), the proposed system makes use of the MiBand smart fitness bracelet to track user activity and shows feedback regarding daily and weekly goal progression. In O'Connor et al. (2018), it is discussed the use of neuromuscular electrical stimulation electrodes. The authors discuss the benefits and limitations to integrate these electrodes in wearable devices and how they can be used to improve physical condition and muscle strength of elderly people. In Korn et al. (2019) an augmented reality-based system was developed with a micro projector worn in the user's belt which provides instructions to the user using LEDs that project gamified training exercises on the floor. In Gamecho et al. (2015), the proposed system collects Electromyographic and Accelerometer signals in real time using the BITalino biosignal acquisition platform. The system monitors the performance of the user while performing different exercises in conjunction with the use of a mobile robot. The authors proposed two different algorithms to detect muscle contraction and limb tilt and motion using collected data which can indicate interruptions while the user performs different exercise and in turn trigger different actions on the developed robot. For example, if the user folds the arms, a command will be sent for the robot to move forward. If the user tilts the wrist to the left or right, the robot will rotate in the corresponding direction. In the end, the user will be able to perform different exercises such as controlling the robot to grab different objects placed in an area.

The use of robots to improve user health condition has also been studied in two other works. The robot developed in Khosla et al. (2013) promotes social interaction between elderly people while performing different functions such as: monitoring and recognizing facial expressions which translate to different emotions and adapting the interaction with each elderly person; playing different games with elderly people so they keep interested to interact with the robot; personalizing care with flexible communication features like speech recognition and voice vocalization; and promote mental activity while running a set of short or long quizzes which depend on the alertness and medical condition of the elderly person. In Kitakoshi et al. (2017a), three robots were developed for a preventive care system which interact and compete against each other through different match up games that are based on a traditional Japanese game. One robot would play the role of the opponent and incorporates a Microsoft Kinect sensor, and a motion sensor to detect movements of other robots. Besides that, the robot could express different voice and gesture-based emotions depending on both the relationship with the user and the current state of the game (for example if the opponent robot won or lost the match it would express happy or sad emotions). Another robot would play the role of avatar and would represent the user. It operates according to different exercises performed by the user (for example if the user performs a stepping exercise the avatar robot would walk forward). The system adapts the exercise load according to the feedback provided by the user (the user reports the fatigue level in a questionnaire presented in a tablet device). The third robot developed plays the role of a rival robot and competes directly with the avatar robot and its performance level is adjusted to a similar level as the avatar robot using a reinforcement learning mechanism. This robot is also aware of the incoming actions of the opponent robot so that it never performs an incorrect action and therefore never loses the game. According to the authors, the main goal of including such kind of robot in this system is to motivate the user to improve their performance and consequently perform better and more frequent exercises.

3.6 Research question 6

3.6.1 What are the current main challenges and benefits of using gamification techniques in elderly care?

In the last phase of the SLR we analyzed each selected paper in terms of benefits and challenges encountered to implement gamification techniques in elderly care. Among the selected results, it was possible to identify benefits in 38 of 42 selected studies and challenges in 31 of 42 selected studies. All benefits and challenges identified are presented in Tables 10 and 11 respectively.

From a general standpoint, in all considered studies it is emphasized the importance of using gamification and gaming applications to promote user health condition and well-being. The first and most discussed benefit by authors is how gamification techniques can improve user health condition and wellbeing. In this sense, different solutions were proposed using systems with exergames that incorporated mechanisms to interact with the user and then assess and improve user current mental condition. Related to this benefit, three other inherent benefits were identified by author which include increasing the interest and enjoyment of elderly people while using this kind of systems, decreasing

Table 10 Benefits of gamification in elderly care

Benefit	Study
Improve health and wellbeing	Gerling and Masuch (2011), Alahäivälä and Oinas-Kukkonen (2016), Whyatt et al. (2015), Borghese et al. (2013), Konstantinidis et al. (2017b), Konstantinidis et al. (2016), Ofli et al. (2016), Kappen et al. (2016), Pisan et al. (2013), Khosla et al. (2013), Lange et al. (2011), Mocanu et al. (2016), Stutzel et al. (2016), Kostopoulos et al. (2018), Cornejo et al. (2012), Li and Chen (2017), Korn et al. (2019), Dell'Acqua et al. (2013), Buchem et al. (2015a), Hoshino and Mitani (2018), Saenz-de-Urturi and Soto (2016), O'Connor et al. (2018), Malwade et al. (2018), Manera et al. (2017), Kitakoshi et al. (2017a), Gamecho et al. (2015), de Vette et al. (2015), Boquete et al. (2011), Vaziri et al. (2017), Devos et al. (2015), Liukkonen et al. (2015), Proffitt et al. (2015), Ona et al. (2018), Money et al. (2019), Meza-Kubo et al. (2014), Gschwind et al. (2014)
Capture user interest and positive engagement	Gerling and Masuch (2011), Alahäivälä and Oinas-Kukkonen (2016), Li et al. (2017), Whyatt et al. (2015), Borghese et al. (2013), Konstantinidis et al. (2017b), Konstantinidis et al. (2016), Ofli et al. (2016), Kappen et al. (2016), Pisan et al. (2013), Khosla et al. (2013), Lange et al. (2011), Mocanu et al. (2016), Garcia and Felix Navarro (2015), Stutzel et al. (2016), Kostopoulos et al. (2018), Cornejo et al. (2012), Li and Chen (2017), Korn et al. (2019), Buchem et al. (2015a), Hoshino and Mitani (2018), Saenz-de-Urturi and Soto (2016), O'Connor et al. (2018), Malwade et al. (2018), Manera et al. (2017), Kitakoshi et al. (2017a), de Vette et al. (2015), Vaziri et al. (2017), Liukkonen et al. (2015), Proffitt et al. (2015), Ona et al. (2018), Money et al. (2019), Gschwind et al. (2014)
Facilitate social interaction	Gerling and Masuch (2011), Alahäivälä and Oinas-Kukkonen (2016), Li et al. (2017), Konstantinidis et al. (2017b), Konstantinidis et al. (2016), Kappen et al. (2016), Khosla et al. (2013), Stutzel et al. (2016), Kostopoulos et al. (2018), Cornejo et al. (2012), Li and Chen (2017), Buchem et al. (2015a), Hoshino and Mitani (2018), Malwade et al. (2018), Manera et al. (2017), Kitakoshi et al. (2017a), de Vette et al. (2015), Vaziri et al. (2017), Proffitt et al. (2015), Meza-Kubo et al. (2014), Gschwind et al. (2014)
Decrease impact of medical conditions	Borghese et al. (2013), Khosla et al. (2013), Kostopoulos et al. (2018), Manera et al. (2017), Liukkonen et al. (2015), Ona et al. (2018), Meza-Kubo et al. (2014)
Allow personalized care	Alahäivälä and Oinas-Kukkonen (2016), Borghese et al. (2013), Khosla et al. (2013), O'Connor et al. (2018), Manera et al. (2017), Devos et al. (2015)

the impact of medical conditions (often associated to ageing population) and promoting social interaction by providing mechanisms to enhance group interaction and social contact between elderly people. The last observed benefit is the possibility to adapt the

Table 11 Challenges of gamification in elderly care

Challenge	Study
Require healthcare professional's assistance onsite	Borghese et al. (2013), Liu et al. (2014), Manera et al. (2017), Kitakoshi et al. (2017a), Ona et al. (2018), Meza-Kubo et al. (2014)
Elderly people are not used to new technologies	Gerling and Masuch (2011), Alahäivälä and Oinas-Kukkonen (2016), Konstantinidis et al. (2017b), Konstantinidis et al. (2016), Kappen et al. (2016), Khosla et al. (2013), Mocanu et al. (2016), O'Connor et al. (2018), Malwade et al. (2018), Alloni et al. (2017), de Vette et al. (2015), Proffitt et al. (2015), Ona et al. (2018)
Many traditional healthcare services are not personalized to Meza-Kubo et al. (2014) each user capabilities and necessities	Alahäivälä and Oinas-Kukkonen (2016), Whyatt et al. (2015), Borghese et al. (2013), Konstantinidis et al. (2017b), Konstantinidis et al. (2016), Ofli et al. (2016), Khosla et al. (2013), Li et al. (2018), Kostopoulos et al. (2018), Korn et al. (2019), Dell'Acqua et al. (2013), Manera et al. (2017), de Vette et al. (2015), Vaziri et al. (2017), Hsiao and Rashvand (2015)
Game mechanics are not tailored for all elderly people	Gerling and Masuch (2011), Alahäivälä and Oinas-Kukkonen (2016), Li et al. (2017), Whyatt et al. (2015), Konstantinidis et al. (2016), Li et al. (2018), Garcia and Felix Navarro (2015), Li and Chen (2017), Buchem et al. (2015a), de Vette et al. (2015)
Exergames lack of socialization features to help elderly people to engage in the game	Cornejo et al. (2012)

healthcare system and the associated gamification techniques to the capabilities of each person.

Looking at the selected studies we have identified five main current challenges reported by authors in the literature while developing and using gamification techniques in elderly care. The most observed issue in the selected studies is how many traditional healthcare services do not consider the human factor and are not adapted to each user. Another observed challenge reported by authors comes from the fact that most existing game mechanics in healthcare services are not tailored towards elderly people. As a result, elderly people usually fail to understand and perceive the associated benefits of those services. Furthermore, most recent system makes use of new technologies (both digital and physical) which require additional learning that is often difficult to instruct to elderly people. As a result, elderly people will lose interest in such systems more easily. Authors also identify the issue related to the necessity to include the presence of the healthcare professional as an additional motivational factor and to train and instruct the elderly person to use the system correctly. Finally, authors in Cornejo et al. (2012) have also alerted to an issue in the context of exergames development related with the lack of features that can promote social interaction between elderly people and family members.

4 Discussion

In this section we take a closer look at the results presented in the previous chapter and discuss some of the ideas and main points that were observed so that we can outline new directions for research in the area of gamification techniques applied to elderly care.

Looking at the distribution of works throughout the years (since 2010), a steady growth in the number of publications was observed. In fact, and as can be seen in Fig. 3, nearly 75% of the works (31 selected works) were published within the last 4 years. These numbers may indicate a growing interest to perform research in this area, however this assumption can only be confirmed if we take a closer look at the results obtained in the SLR.

4.1 RQ1: What are the main source types of studies related to gamification in elderly care?

The first research question studied in this SLR was to analyze the distribution of works through different source types. It was observed that the two main source types of publication were journal articles and conference proceedings, with the first having most publications. Looking at the publications in journal articles, Q2 indexed journal publications had the highest number, followed by publications in Q3 indexed journals and finally by Q1 indexed journals. Likewise, the publications in conference proceedings followed the same order, with CORE B publications having the highest number of publications, followed by both CORE A and CORE C publications. With these results, we can say that the overall quality of publication sources is very good as more than 50% of the selected works (23 published works) have been published in either Q1 or Q2 indexed journals or with CORE A and CORE B rank.

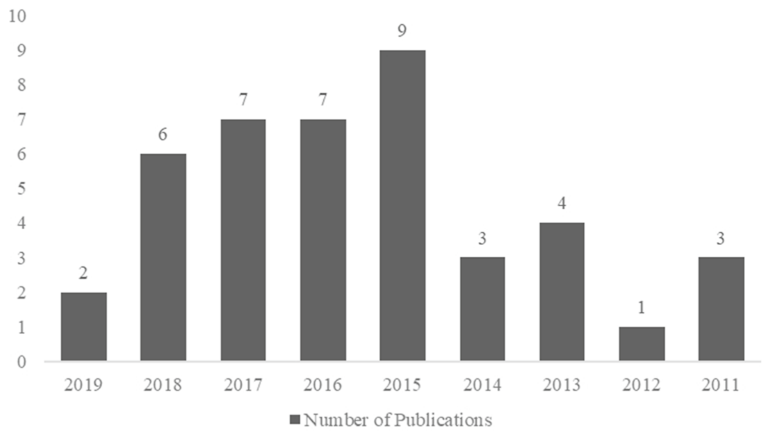

Fig. 3 Publication years

4.2 RQ2: In which research areas has gamification in elderly care been investigated?

In the second research question, it was studied the research areas in which investigation on gamification in elderly care was carried and three main areas were identified: Computer Science, Engineering and Medical Informatics. Specific elderly care and healthcare areas associated with the selected works are Medical Informatics, Healthcare Sciences Services, Rehabilitation, Geriatrics Gerontology and Public Environmental Occupation Health. These areas, alongside with the remaining identified areas such as Biology, Telecommunications and even Psychology show a diverse distribution of works and can explain the importance of this topic today.

4.3 RQ3: What are the main target groups of elderly people for gamified healthcare services?

The different groups of elderly people targeted by each proposal in the selected works were studied in the third question. Four environments were identified that describe the kind of users targeted by the proposed system: regarding home environment, the selected studies are intended for domestic and independent use; community environment targets elderly people living under community settings (if they have regular contact with other elderly people as in community dwelling or with family members or friends); outdoor environment targets elderly people who enjoy performing outdoor activities (walking, fishing, etc.); nursing environment targets elderly people who require the supervision or presence of a medical staff on daily basis to support him/her in his/her daily activities. Most of the selected works were developed for home environments and this result can be explained by the number of systems designed to improve the physical condition of the elderly person. Among these systems, there is a large preference to develop exergames using console platforms such as Microsoft Kinect or Nintendo Wii and which are targeted for home-based exercise programs. Authors refer to the main advantages of this kind of platforms which includes controlling movement through full body tracking capabilities (Mocanu et al. 2016; Dell'Acqua et al. 2013; Vaziri et al. 2017; Gschwind et al. 2014), affordability (Ofli et al. 2016; Saenz-de-Urturi and Soto 2016) or easier interactions without the use of remote controllers (Garcia and Felix Navarro 2015). Furthermore, several exergames proposed in the selected works have been developed with the main goal to help elderly people improve balance and muscle strength and then reduce the risk of falls (Whyatt et al. 2015; Ofli et al. 2016; Pisan et al. 2013; Garcia and Felix Navarro 2015; Vaziri et al. 2017; Proffitt et al. 2015; Money et al. 2019; Gschwind et al. 2014). Overall, the number of verified works targeted towards physical rehabilitation and stimulation of the elderly person was much greater than the number of works targeted towards cognitive rehabilitation and stimulation. In fact, over 85% of the selected works were developed for this purpose which indicates a strong research interest to develop exergame-based systems for elderly care. This does not mean, however, that researchers should refrain from studying and developing solutions to improve the cognitive condition of the elderly person. On the contrary, authors have also shown that the cognitive condition of the elderly person greatly affects his/her wellbeing and the development of solutions that can decrease the impact of cognitive decline and associated diseases is essential to assure healthier ageing (Anguera and Gazzaley 2015; Wallace et al. 2014; Navarro et al. 2013).

4.4 RQ4: Which game design elements have been used on gamification in elderly care?

In the fourth research question it was studied the game design elements used in the selected works. We considered the game design elements identified by Marczewski and colleagues in (Tondello et al. 2016; Marczewski 2015) hexad scale and distributed each selected study according to each identified element. We highlight the following game design elements which were verified in the selected works: provide feedback regarding user performance; indicate progression and improvement while the user is using the system though levels and increased difficulty; reward player while performing correct actions with badges, trophies and prizes; enhance and promote social interactions between participants and even between virtual or robotic entities. Overall, the selected works explained the benefits of using these kinds of elements, however we think some of the proposals could still be improved by extending the formulation of their models and explaining with more detail how they incorporated these elements in their proposals. In Kostopoulos et al. (2018), the authors have established a goal and achievement feature which would allow users to obtain different rewards after completing different goals and achievements. Despite the novel and very interesting approach, a further explanation on how these goals and achievements were generated for each user could be beneficial to understand different motivations that lead users to perform different tasks. Furthermore, the algorithms that were considered to adapt the difficulty of these goals and achievements to the capabilities of each user could be presented to better understand the proposed model. In Khosla et al. (2013), the authors present a five-layered architecture to develop a robotic system supporting different communication modules which would then allow to personalize the interaction done between the developed robot and the elderly person according to his/her capabilities. The proposed work could be improved

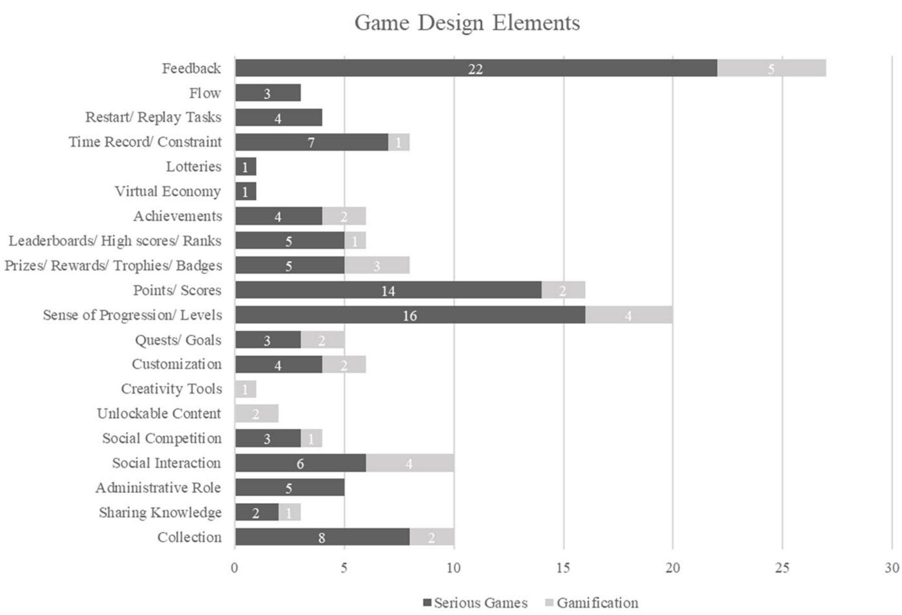

Fig. 4 Game design elements

by providing a more detailed explanation of each layer, such as the shared intelligence layer and the related intelligent algorithms and programs. In Devos et al. (2015), the authors propose a mobile-health personalized care application with different functionalities including a recognition test to assess short and long time memory degradation using content available on the personal device. The proposed model could be improved by describing with more detail how the content available on the personal device could be classified and filtered. In Liukkonen et al. (2015), the authors refer to the importance and use of both feedback and motivational support to the user to capture his/her interest while performing repetitive tasks. Although the authors were able to explain and detail how feedback can be provided to the user, they should also detail how intelligent mechanisms could be used to increase user motivation while using the application. Another point worth of mentioning still related with the results obtained in the fourth research question is the relation between game design elements and the type of system developed (See Fig. 4).

We observed that most of the serious games, which include all the selected exergame-based systems proposed by authors, made a strong use of feedback, progression, time constraints and score game design elements. Since most of these systems were designed to be played during training sessions it was possible to observe that these four game design elements combined could provide an effective and in real time performance indicator to the elderly person while holding a training session. At the same time, gamified systems also made use of feedback and progression elements, but other frequently used elements included use of badges, trophies and rewards and social interaction mechanisms. These results can be explained as many of the gamified systems were designed to potentiate relaxed gameplays without time constraints or score tracking but instead with entertaining features that could enhance both individual and collective gameplay.

4.5 RQ5: What are the main technological features employed in the current existing systems?

In the fifth research question the different technological features most frequently used in this context were studied. Among these features, it is highlighted the use of portable devices, physical robots, consoles and wearable technologies. It was noticed that authors are trying to develop solutions which make use of the embedded sensors available in portable devices we use every day (such as smart-phones and tablets) in order to retrieve user activity data and to guide, provide feedback and recommendations, so that they can improve their lifestyles and be healthier. Another observed feature is the use of physical robots to interact with the user and performs tasks on his/her behalf. Regarding this feature, it is interesting to see that all authors sought to study the acceptance and interaction of users with robots and they were able to obtain very positive results. In Gamecho et al. (2015), authors referred that participants thought robots to be funny and less boring compared to a simple smartphone screen. In Kitakoshi et al. (2017a), the authors verified that participants enjoyment while using the system and interacting with robots was high. Their interest and sense of familiarity with the robots were encouraged by playing the game and interacting with the robots themselves rather than watching demonstrations of those interactions performed by other people. In Khosla et al. (2013), elderly users were questioned whether they enjoyed interacting with the developed robot or not and the results were very positive. Furthermore, the elderly users also expressed their satisfaction to play different group activities together with the developed robot. The use of console devices was also explored by authors in their proposals. In this context, authors opted to develop exergame-based systems for the reasons we expressed above in this discussion, and the data processing was mostly related with the detection of movement while performing different exercises. Similarly, to the use of physical robots, the acceptance of engagement with console devices was overall positive, regardless of having low or no experience at all with this kind of device and with video games. In Proffitt et al. (2015) participants expressed preference for performing tasks in a virtual environment instead of a real environment and expressed they would more likely keep performing tasks in the virtual environment in the future due to the fact this environment allowed them to perform low difficulty and not too demanding exercises. Furthermore, participants also expressed improvements in both eye coordination and cognition while performing the exercises. The improvement of physical condition using the exergame-based system was also expressed by other authors in their system evaluation. In Whyatt et al. (2015), the results demonstrated an increase in functional balance and decrease in fall risk. In Vaziri et al. (2017), Gschwind et al. (2014) participants with poor balance revealed balance improvements after using the proposed system. In Konstantinidis et al. (2016) authors evaluated their proposed system through a Senior Fitness Test and results revealed significant improvements on different physical activities such as chair standing, walking, chair reaching and back scratching. Despite the positive outcomes related to exergame-based systems and the use of console devices, the systems still faced some issues, such as the difficulty to calibrate the position of the elderly user (Lange et al. 2011), or the necessity to have more extended testing time periods in order to validate the effectiveness of the recommended exercises (Borghese et al. 2013; Konstantinidis et al. 2017b; Liukkonen et al. 2015). Some authors referred to the use of wearable technologies to collect user data and bio signals. This information is mostly related to user activity and information on user physical condition (Kostopoulos et al. 2018; Malwade et al. 2018; Gamecho et al. 2015). Besides that, some wearable devices can be used to provide electrical stimulation and manage ageing related complications associated to the decrease of the amount of daily exercise practiced by the elderly person (O'Connor et al. 2018). Although the use of these technologies seems promising and may indeed provide improved healthcare outcomes, it is important that the implementation and use of such technologies should always consider the limitations associated to ageing population such as cognitive and physical impairments. Furthermore, the success of these technologies will always depend on the acceptability and willingness of elderly people to them, so the motivational factor should not be discarded.

4.6 RQ6: what are the current main challenges and benefits of using gamification techniques in elderly care?

In the sixth and last research question of this SLR, it was studied the benefits and challenges associated to the use of gamification techniques in elderly care. Many of the studies express the benefits of using gamification to promote both physical, mental and emotional state of the user. The fact that gamification techniques can be integrated with other technologies already discussed such as mobile, wearable and console devices widens the range of possibilities of solutions that can be provided with this sole purpose. It should be noticed once more, the clear distinction between a gamified application and an exergaming application as the former refers to the use of "gameful" experiences in non-game contexts without creating a full game while the latter refers to a full game by itself.

Regarding gamification, authors in Kostopoulos et al. (2018) refer that it can "reinforce the elderly people to stay active and improve their well-being" and that "using gamification across every element of the service will provide a motivational element, ensuring that the older person enjoys and feels rewarded by their experience". Authors in Malwade et al. (2018) express that "gamification is one element that increases the mode of enjoyment among the elderly". This feeling of fun and enjoyment motivates the elderly person to pursuit a healthier lifestyle, leading to a decreased impact of certain medical conditions and to be more active and social.

Regarding the social context, authors in Khosla et al. (2013) refer that "social interaction promotes emotional health and can help maintain good cognition" and that "besides being a means of social engagement playing and winning games has therapeutic affect and also makes old people become active and useful". Furthermore, authors in Kostopoulos et al. (2018) suggest that gamification "will help older adults engage with their community, peers and families both socially and through active skill based engagement". Finally, authors in Manera et al. (2017) say that "social interaction, physical and cognitive activities, and motivation can have a major impact on the disease progression".

We have also identified in different studies the importance given towards personalization and user-centered design when developing gamified applications. Authors in Khosla et al. (2013) refer that personalizing the elderly care will enable elderly to be productive, useful and more resilient, thus contributing to their emotional well-being. Authors in Devos et al. (2015) explain that the usage of gamified applications with game-like aspects by healthy older people "depends on the level of personalization which has been realized". The fact that these technologies include and offer different game design elements such as sense of progression, customization, feedback allow to develop personalized healthcare services adapted to individual necessities and capabilities and that keep improving the more the elderly person makes use of the service throughout his/her daily routine. The reality, however, is that many traditional healthcare services will require further improvements and integration of gamification techniques to allow this personalized care since they do not consider ageing as a fundamental factor and often ignore the human variable which interacts and lives under different environments as it grows older and becomes more fragile with increasingly more individual necessities, capabilities, interests and backgrounds and instead ignore environment constraints and only provide the same features to every single user. For example, authors in Kostopoulos et al. (2018) express that applications focused on health and healthy living are aimed at active and fit adults instead of elderly people and that these applications should also be adapted to the needs of elderly people. Authors in Alahäivälä and Oinas-Kukkonen (2016) refer that most existing studies ignore the difference between different users and provide the same feature to all users. They add that "future health gamification should pay more attention to the User Context and provide tailored services for different needs". Authors in de Vette et al. (2015) discuss how elderly users are underrepresented as consumers of digital games "because the games offered are not in line with their accessibility and usability demands or their interests and needs". Furthermore, authors in Borghese et al. (2013) say that games should be "developed to take into consideration the cognitive and physical limitations of the population(s) for which they are intended". Authors in Vaziri et al. (2017) refer to "positive factors seem to have much to do with the availability of social elements" as elderly people expressed "desire for multiplayer games and features". In Ofli et al. (2016), authors concluded their study by expressing the necessity of interactive systems to be capable "to balance the attractiveness and effectiveness of the exercise systems in real-world settings while considering various factors, such as age and educational level of users, system and environmental constraints, type of feedback, level of gamification, incentives, and social interaction".

Other issues that were identified in half of the selected papers are connected and are the trouble that elderly people have to understand, accept and use new technologies and game mechanics that are available in the proposed systems and that result in a great difficulty to perceive the inherent benefits associated to those systems. As a result, they lose interest to keep using the system over the time. Authors in Alloni et al. (2017) express that elderly people are "less prone to the use of technology" and as a result feel "unprepared when put in front of something new and very likely never seen before". Authors in Gerling and Masuch (2011) refer that "While younger users are familiar with gaming systems and game elements can be integrated into regular applications based on common domain knowledge, this is not possible when designing for elderly users" and that "a lack of gaming experience may have a negative impact on the general understanding of metaphors derived from digital games, which is expected to further hinder the engagement of elderly persons with gamified applications". Authors in Khosla et al. (2013) say that "the present generation of elderly (65 years and older) in residential care facilities are not tuned in to the concept of technology in general" and prefer to receive care directly from the healthcare professional. This question leads to another verified issue which is the necessity to include the physical presence of the healthcare professional. While one hand this requirement might seem beneficial in some situations, for example, and according to Kitakoshi et al. (2017a) when they refer that "the existence of game-playing partners and facility staff surrounding the user will lead to improvement in the user's security and motivation to play the game.", on the other hand authors in Borghese et al. (2013), Liu et al. (2014) express that this element is missing in home rehabilitation and can lead to isolation and diminish the appeal for rehabilitation. Furthermore, governments have set different goals to promote initiatives and care projects and diminish the caregiver burden (Kostopoulos et al. 2018; Kitakoshi et al. 2017a). This way it will be possible to support elderly people so they can live more independently in the society and improve their quality of life (Kitakoshi et al. 2017a). Although it was observed that the presence of the healthcare professional could be beneficial to provide security and motivation, the fact that elderly people are too used to receiving feedback directly from the healthcare professional, it becomes very challenging to develop healthcare services using gamification techniques for home rehabilitation where this element is missing. Furthermore, this requirement affects significantly healthcare associated costs and the usability of the gamified solution if the user does not know how to use it independently.

Overall, according to our observations, the future of gamification in the area of elderly care is very promising and the use and application of gamification techniques on traditional healthcare services might be the key to overcome many of the mentioned and verified issues throughout this SLR. Among these issues we highlight motivation as a fundamental factor to draw the elderly person interest into the world of gamification and we think a compromise should be established between the amount of support provided directly by the healthcare professional and the mechanisms that should be incorporated to allow the elderly person to freely use the solution and still feel motived while doing so. In this sense, there is already a wide amount of proposals using innovative and effective features such as exergames with consoles devices and virtual reality which were capable of achieving very positive results in terms of user retention and adherence to physical exercise programs and the performance of other tasks by elderly people. The potential behind the use of such futures is therefore evident and should be considered in the development of future healthcare systems for elderly people. Furthermore, another determining factor also observed in the proposed works to motivate elderly people was to enhance social interaction between themselves and with other people and family. For many of the users this aspect as essential to keep being motivated to use the system. We believe these three aspects (motivation, independence and social interaction) should be at the forefront in the development of gamified solutions and as a result we will surely see the proposal of even more solutions using exergames, virtual reality and social interactive systems in the upcoming years.

As a final remark we express the many possibilities offered by gamification which are already perceived as fun, interesting and different by elderly people, so it is just a matter of defining the best approach adapted to the user and to his/her environment to convince elderly people to start using gamified healthcare services. Meanwhile we can question that as the years go by the technological aptitude may become less and less of an obstacle for gamified healthcare services targeted towards elderly people to succeed. In fact, if we think of people who were born in the 1960's which will be over 60 years old in just 5 years, those people experienced the dot-com bubble and the boom of Information Technology during their entire adulthood and have been in contact with technological advancements through most of their lives. For those people, it should be expected that as they grow older, they will be able to understand the benefits offered by this type of services more easily and they will hopefully be more open to rely on these services throughout their daily lives. Future studies on usability and user motivation will help to confirm (or not) this idea.

This discussion is concluded with brief remark on a point that was not part of the scope of this SLR but that should not be ignored: security and personal privacy constraints in the development and use of gamification techniques and subsequent usage and protection of user related data, specifically in the context of elderly care, are gaining more and more attention among authors and some have already discussed it in their works (Alahäivälä and Oinas-Kukkonen 2016; Stutzel et al. 2016; Manera et al. 2017; Alloni et al. 2017; Devos et al. 2015).

5 Conclusions and future work

This paper presents a systematic literature review related to the use of gamification techniques applied to the elderly care context. From an initial set of 905 selected studies, 103 were chosen for quality appraisal and among those, the 42 most relevant studies were selected and reviewed. These studies were then reviewed according to six research questions regarding source type, research area, target group, identified game design elements, technological features, challenges and opportunities of. It was possible to verify that the study related to gamification in elderly care is growing significantly over the last years, with nearly 75% studied being published since 2015 which indicates that the topic in question is very relevant and its research interest is also growing. There is a great diversity among the research areas related to each published work, also including different areas in the health domain, which shows the impact and importance of this topic today. Six target groups associated with the capabilities and the type of environment surrounding the elderly person were studied. Several game design elements were identified and used by authors in their proposals. The technological features most frequently used by authors include the use of portable and console devices, robots and wearable technologies. In this sense, a noticeable trend has been observed in most recent works to develop interactive and personalized systems targeted at each user capabilities and necessities. This includes the development of intelligent mechanisms and algorithms to adapt the interaction and support provided, ranging from exergames, with augmented reality and scalable difficulty till robots that play games and communicate with elderly people using different emotions. The game design elements highlighted include the use of mechanisms to provide feedback and rewards to the elderly person, the possibility to increase the cognitive/physical load as the user becomes more proficient with the system and the use of mechanisms which enhance and promote social interaction. The use of these elements and mechanics can result in more personalized elderly care solutions by adapting the support provided to the elderly person according to interests, capabilities, necessities and surrounding environment which will in turn contribute to improve health and well-being, capture interest and positive engagement, facilitate social interaction and decrease impact of many different medical conditions. Main challenges identified are related with the fact that the presence of the healthcare professional is often required, there is great difficulty to motivate and teach elderly people to use and understand the system and derived game mechanics and technologies and the lack of healthcare services that can provide personalized features according to the capabilities and necessities of the elderly person.

As future work we intend to consider all the results found in this work and apply them in the development of a personalized elderly care framework with the main goals to potentiate the support and the interaction with elderly people and consequently promote their wellness. It will be necessary to study how to capture and understand different environments and behaviors and adapt the interaction with the elderly person based on that knowledge. For this purpose, we will take advantage of the findings obtained in this SLR regarding most successful and employed game design elements as a means to engage and motivate the elderly person to perform different activities and drive him/her to stay social, healthy and active. Further support will be also provided to other stakeholders such as healthcare professionals, and family members, and for this a visualization tool will also be developed where they can receive feedback and observe daily activities and health information of the elderly person. This will allow a much closer monitoring of the user health status and even help detect and reduce the risks associated to certain diseases. Finally, by supporting the collaboration between different stakeholders it will then be possible to add and formalize domain knowledge that can be used to better support the elderly person.

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Appendix 1

See Table 12.

Table 12 Quality appraisal results

Study	Quality appraisal				
	QA1	QA2	QA3	QA4	Score
Gerling and Masuch (2011)	+1	+1	+1	0	3
Catala et al. (2014)	+1	0	0	+0.5	1.5
Gamecho et al. (2015)	+1	0	+1	+1.5	3.5
Liu et al. (2014)	+1	+1	0	+1.5	3.5
Okano et al. (2013)	+1	0	+1	0	2
Hoshino and Mitani (2018)	+1	0	+1	+2[a]	4
Codreanu and Florea (2015)	+1	0	0	+0.5	1.5
De Morais and Wickström N (2011)	+1	0	+1	0	2
Courtial et al. (2017)	+1	0	+1	0	1
Li et al. (2016)	0	0	+1	0	1
Khosla et al. (2013)	+1	+1	+1	+1	4
Kitakoshi et al. (2017a)	+1	+1	+1	+1.5	4.5
Mondellini et al. (2018)	+1	0	0	0	1
Ferland et al. (2018)	+1	0	0	0	1
Burdea et al. (2015)	+1	0	+1	0	2
Borghese et al. (2013)	+1	+1	+1	+1.5	4.5
Alloni et al. (2017)	+1	+1	0	+1.5	3.5
Bauer and Dey (2016)	0	0	0	+2	2
Hsiao and Rashvand (2015)	+1	+1	0	+1	3
Amritha et al. (2016)	+1	0	+1	0	2
Devos et al. (2015)	+1	0	+1	+1	3
Chao et al. (2017)	0	0	+1	0	1
Chromy et al. (2016)	+1	0	0	0	1
Agrigoroaie and Tapus (2016)	+1	0	0	0	1
Lange et al. (2011)	+1	0	+1	+0.5	2.5
Liu et al. (2017)	0	0	+1	0	2
de Vette et al. (2015)	0	+1	+1	+1.5	3.5
Kostopoulos et al. (2018)	+1	+1	+1	0	3
Lunardini et al. (2017)	+1	+1	0	0	2
Bieryla and Dold (2013)	0	0	0	+1	1
Madeira et al. (2012)	0	+1	+1	0	2
Pisan et al. (2013)	+1	0	+1	+1.5	3.5
Rabin et al. (2011)	+1	0	+1	0	2
Vartholomeos et al. (2014)	+1	0	0	0	1
Alkhushayni and McRoy (2016)	+1	+1	0	0	2
Malwade et al. (2018)	0	+1	+1	+1.5	3.5
Awada et al. (2017)	+1	+1	0	0	2
Liukkonen et al. (2015)	+1	0	+1	+1	3
Konstantinidis et al. (2017b)	+1	+1	+1	+2	5
Santos et al. (2015)	+1	0	+1	0	2
Hermens et al. (2014)	+1	0	0	+1	2
Louie et al. (2012)	+1	0	0	0	1
Chan and Nejat (2010)	+1	0	0	0	1

Table 12 (continued)

Study	Quality appraisal				
	QA1	QA2	QA3	QA4	Score
Manera et al. (2017)	+1	+1	+1	+1.5	4.5
Stutzel et al. (2016)	+1	+1	+1	0	3
O'Connor et al. (2018)	+1	+1	+1	+1.5	4.5
Caggianese et al. (2018)	+1	0	0	0	1
Ahmed et al. (2018)	+1	0	0	0	1
Alahäivälä and Oinas-Kukkonen (2016)	0	+1	+1	+2	4
Wargnier et al. (2016)	+1	0	+1	0	2
Fernandez-Cervantes et al. (2018)	+1	0	+1	0	2
Bieryla (2016)	0	0	0	+1	1
Yeo et al. (2018)	+1	0	0	+1.5	2.5
Wittland et al. (2015)	0	+1	0	+1.5	2.5
Whyatt et al. (2015)	+1	+1	+1	+1.5	4.5
Villani et al. (2017)	0	+1	+1	+0	2
Vaziri et al. (2017)	+1	+1	+1	+1.5	4.5
Thompson et al. (2017)	+1	0	+1	0	2
Smith et al. (2013)	+1	0	0	+0.5	1.5
Smaerup et al. (2017)	0	+1	0	+2	3
Shake et al. (2018)	+1	0	0	+1.5	2.5
Saenz-de-Urturi and Soto (2016)	+1	0	+1	+2	4
Proffitt et al. (2015)	+1	+1	+1	+1	4
Padala et al. (2017)	0	+1	0	+1.5	2.5
Ona et al. (2018)	0	+1	+1	+1	3
Ofli et al. (2016)	+1	+1	+1	+2	5
Navarro-Barrientos et al. (2015)	+1	0	+1	0	2
Navarro et al. (2013)	0	0	+1	+0.5	1.5
Money et al. (2019)	+1	0	+1	+1	3
Mocanu et al. (2016)	+1	+1	+1	+0.5	3.5
Meza-Kubo et al. (2014)	0	+1	+1	+1	3
Lu et al. (2017)	0	+1	0	+1.5	2.5
Lins et al. (2016)	0	0	+1	+0.5	1.5
Li and Chen (2017)	+1	+1	+1	0	3
Li et al. (2017)	+1	+1	+1	+1.5	4.5
Li et al. (2018)	+1	+1	0	+1	3
Leutwyler et al. (2012)	0	0	+1	+1.5	2.5
Leutwyler et al. (2014)	0	0	+1	+1.5	2.5
Lawrence et al. (2010)	+1	0	0	0	1
Kyriazis and Kiourti (2018)	0	0	+1	+2	3
Korn et al. (2019)	+1	+1	+1	0	3
Konstantinidis et al. (2016)	+1	+1	+1	+2	5
Kitakoshi et al. (2017b)	+1	0	+1	0	2
Kitakoshi et al. (2015)	0	+1	+1	0	2
Kappen et al. (2016)	0	+1	+1	+1.5	3.5
Jirayucharoensak et al. (2019)	+1	0	0	+1	2

Table 12 (continued)

Study	Quality appraisal				
	QA1	QA2	QA3	QA4	Score
Hansen et al. (2012)	0	0	+1	+0.5	1.5
Hanada et al. (2014)	+1	0	0	+0.5	1.5
Gschwind et al. (2014)	+1	0	+1	+1	3
Geman et al. (2019)	+1	0	0	+2	3
Garcia and Felix Navarro (2015)	+1	+1	+1	0	3
Fan et al. (2016)	+1	0	+1	0	2
Dell'Acqua et al. (2013)	+1	+1	+1	0	3
Deacon et al. (2018)	+1	0	0	+2	3
Cornejo et al. (2012)	+1	+1	+1	0	3
Codreanu et al. (2017)	+1	0	0	+0.5	1.5
Buchem et al. (2015a)	+1	+1	+1	0	3
Buchem et al. (2015b)	+1	0	0	0	1
Brox et al. (2016)	+1	0	0	0	1
Boquete et al. (2011)	+1	0	+1	+1.5	3.5
Boot et al. (2018)	0	+1	+1	0	2
Billis et al. (2011)	+1	0	0	0	1
Ahn et al. (2014)	+1	0	0	+1	2

[a]Last JCR update on 2010

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