sustainability

Sustainable Technology and Elderly Life

Edited by

Ana Iglesias, Jorge Morato, Sonia Sanchez-Cuadrado and Carmen Fernández-Panadero

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Editors

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About the Editors

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Preface to ”Sustainable Technology and Elderly Life”

The ageing of the population is a global process, caused by the increase in life expectancy and the decrease in fertility rates. Between 2020 and 2040, the population over 65 years of age will double, while the population under 10 years of age will remain constant. The result will be that both populations will be practically equal in 2040. These demographic changes will have social and personal implications. The main social challenges are related to the maintenance of healthcare, pension and social security systems. In terms of their personal circumstances, this population will have an impact on the prevalence of certain diseases and on factors affecting personal well-being. The elderly, at this stage of their lives, face physical and cognitive deterioration, which in turn produces social isolation that aggravates their psycho-affective problems.

This Special Issue of the journal, titled “Sustainable Technologies for Older Adults”, collects six papers discussing current proposals that address these challenges. This Special Issue discusses ways to successfully manage the ageing population in a sustainable manner. Throughout this compilation, a systematic literature review is presented, followed by five relevant research studies on the topic. The papers presented pay special attention to approaches that are showing the most promising ways to tackle the problem, such as gamification, health monitoring or policies that avoid isolation of the elderly.

The Special Issue is aimed at different audiences. On the one hand, it aims to show the scientific community the state of the art of current research, with special interest for the areas engineering or e-health, working in areas such artificial intelligence, health monitoring or wearables and sensors. On the other hand, it is a resource of interest for the design of public policies that avoid the isolation of the elderly and help the development of smart cities. Finally, it is a valuable tool for companies designing technology for the elderly community, as it has been observed in the success that accompanies the devices when training, implementation and deployment costs are taken into account.

The systematic review “Sustainable Technologies for Older Adults” by Morato et al. analyses the literature published in the period from 2000 to 2021. This publication describes some interesting research projects that address different aspects affecting the elderly population. These aspects include e-health and the sustainability of the healthcare system, aspects related to the daily activities of the elderly and wellness policies to promote healthy ageing. The sustainability of these aspects is discussed throughout the articles. This bibliometric study also examines the technologies most commonly used for developments in these areas. The study indicates that there are a large number of applications related to the current Sustainable Development Goals (SDGs) adopted by the United Nations in 2015, and particularly to those SDGs listed under items 3 (good health and well-being), 4 (quality education), 5 (gender equality), 8 (decent work and economic growth), 9 (industry, innovation and infrastructure), 10 (reduced inequalities) and 11 (sustainable cities and communities). The paper discusses research trends to study factors that enhance healthy ageing, ensure social inclusion of the elderly through technology and prolong the time they can live independently thanks to smart environments.

The use of sustainable technologies has been shown to be very useful in later life (wearable devices for health, Internet of Things (IoT) and sensors to track the senior’s activity, socially assistive robots in residential homes, etc.). These technologies are especially beneficial when applied to health monitoring, with a consequent positive cost–benefit ratio. However, many elderly people are reluctant to use it, due to fears related to technology, lack of resources and access, low interest, lack of familiarity or security concerns. In relation to the e-Health category, mention should be made of the article written by Gaiduk et al, ”Digital Health and Care Study on Elderly Monitoring”. The article shows the pros and cons of using e-health monitoring techniques and how their application in hospitals and retirement homes is a suitable environment as long as public awareness is adequate to ensure their long-term use. The impact of the usability was analysed by means of surveys of the elderly. An interesting finding is that the elderly population, who are still in accessible technology, were hesitant to use the technology in the long term, as they were not clear about the added value it offers them. This finding underlines once again the importance of awareness and proper dissemination of the benefits that can be obtained by using these technologies.

Given that the decline in the younger population is very marked in some continents, it is foreseeable that the intergenerational gap will widen in the coming years. In relation to public policies to create more suitable environments for the elderly, an interesting paper is the article by Wen-Huei et al., ”Empirical Study of Virtual Reality to Promote Intergenerational Communication”. The design of an attractive framework to promote intergenerational communication is the purpose of the article. The purpose of the research is to study a way to improve communication between the elderly and the young in order to reduce the loss of culture and life experiences, while alleviating the isolation of the elderly. In this article, gamification and virtual reality are combined to promote the relationship and combination between generations.

Another example showing how assistive technologies for daily living can help prevent social isolation can be seen in the growing development of robots. Assistive robots are progressively moving towards social robots, which accompany the elderly to prevent cognitive decline and encourage the realisation of physical decline. This fact has been corroborated by the study published by Lukasic et al., entitled “The Role of Socially Assistive Robots in the Care of Older People: To Assist in Cognitive Training, to Remind or to Accompany?”. In their study, they performed 166 interviews dealing with preservation/improvement of cognitive functions. These studies on the impact of technology can be valuable for designing policies that allow for the sustainability of the system.

Many people over 60 are demanding more applications for leisure and free time. An interesting approach in this sense are the platforms and services to promote physical activity, showing an interesting proposal that interconnects the activity of everyday life with a healthy life. The study of a low-cost platform based on exergames is shown in the study by Gómez-Portes et al., “A Platform Based on Personalized Exergames and Natural User Interfaces to Promote Remote Physical Activity and Improve Healthy Aging in Elderly People”.

These platforms have great potential in telerehabilitation therapies and for improving physical activity at home. This finding has been corroborated by the study conducted by Corregidor-Sánchez et al., “Exergames to Prevent the Secondary Functional Deterioration of Older Adults during Hospitalisation and Isolation Periods during the COVID-19 Pandemic”. During the COVID-19 pandemic, isolation in the elderly increased markedly, both in those who lived alone and those who were hospitalised. Corregidor-Sanchez et al. have observed the positive impact of exergames in preventing physical decline and maintaining cognitive ability.

Throughout the various projects and research presented in this issue, some research gaps for elderly life are highlighted. On the one hand are the means to encourage and promote the degree of assimilation of this technology by the target population. In this sense, it is interesting to observe how the use of these technologies improves when inclusive and user-centred points of view are considered. Other aspects that favour the success of the project are training in the use of these technologies; the inclusion of implementation and maintenance costs in relation to the purchasing power of the users; and the maintenance and updating of the technologies developed.

This Special Issue presents challenges related to the sustainable use of technology to improve the lives of the elderly, with interesting reflections for researchers and, in general, for any reader interested in this field. Current and future lines of research that can address the many challenges in this area are shown. A respectful ageing with our elders using sustainable means and technologies can only be realised with a multidisciplinary approach, where technologies include social, cultural, environmental, educational, health or financial aspects: aspects that will become increasingly essential as the sociodemographic profile of the population changes as a result of the future increase in the proportion of older people worldwide.

Ana Iglesias, Jorge Morato, Sonia Sanchez-Cuadrado, and Carmen Fernández-Panadero

Editors

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Systematic Review

Sustainable Technologies for Older Adults

Jorge Morato [1,*], Sonia Sanchez-Cuadrado [2], Ana Iglesias [1], Adrián Campillo [1] and Carmen Fernández-Panadero [3]

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Abstract: The exponential evolution of technology and the growth of the elderly population are two phenomena that will inevitably interact with increasing frequency in the future. This paper analyses scientific literature as a means of furthering progress in sustainable technology for senior living. We carried out a bibliometric analysis of papers published in this area and compiled by the Web of Science (WOS) and Scopus, examining the main participants and advances in the field from 2000 to the first quarter of 2021. The study describes some interesting research projects addressing three different aspects of older adults' daily lives—health, daily activities and wellbeing—and policies to promote healthy aging and improve the sustainability of the healthcare system. It also looks at lines of research into transversal characteristics of technology. Our analysis showed that publications mentioning sustainability technologies for older adults have been growing progressively since the 2000s, but that the big increase in the number of research works in this area took place during the period 2016–2021. These more recent works show a tendency to study those factors that improve healthy aging, ensure the social inclusion of the elderly through technology and prolong the time in which they can live independent lives thanks to smart environments. Current research gaps in the literature are also discussed.

Keywords: older adults; sustainability; technology; readability; Internet of Things; sustainable development goals; smart cities; robotics; gerontology; health care

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1. Introduction

Globally, life expectancy is increasing and society is aging. In 2019, there were 703 million people aged 65 years and it is estimated that in 2050 there will be 1500 million [1], representing 16% of the total population. Forecasts predict that in 2050, for the first time in history, the population over 65 years of age will outnumber the population under 10 years of age (Table 1). The reasons for these demographic changes vary, although the principal explanations are the reduction in the fertility rate and improvements in the probability of survival at advanced ages. This population aging will transform age-patterns of production and consumption and constitute a challenge for the sustainability of public pension systems. It is also estimated that the adult population will become a vulnerable group, being affected mainly by two of the 17 Sustainable Development Goals enacted by the UN General Assembly for 2030 [2]: Goal 1—No poverty and Goal 5—Gender equality.

Table 2 shows the poverty levels of older adults in the most populated OECD countries according to the OECD report Pensions at a glance: OECD and G20 Indicators [3]. People are considered to be in poverty if they have an income that is less than half of the national mean equivalized disposable household income. The data show how poverty is more frequent among the elderly and the gap is wider when we consider gender. Older women are poorer than older men.

Table 1. World population trends for under 10 s and over 65 s. Bold data indicates the outnumbering of the young population (source: [1]). Figures are expressed in thousands.

Location	Age	2015	2020	2040	2050
World	<10	1,315,380	1,342,381	1,362,524	1,376,017
	>65	607,548	727,606	1,300,516	**1,548,854**
Africa	<10	346,678	381,403	496,260	545,328
	>65	39,729	47,096	97,501	143,103
Asia	<10	731,698	726,754	653,233	622,039
	>65	331,498	411,604	**802,394**	**954,680**
Europe	<10	80,088	79,821	68,157	69,258
	>65	**130,515**	**142,905**	**188,280**	**199,896**
Latin America	<10	105,561	103,887	91,447	85,470
	>65	48,356	58,651	**113,560**	**144,623**
North America	<10	44,857	43,706	46,069	46,153
	>65	**52,787**	**61,901**	**89,894**	**96,278**

Table 2. Percentage of income poverty in older adults in the most populated countries in the OECD (source: [3]).

Country	Percentage of Total Population Living in Poverty	Older Adults Poverty (All)	Older Adults Poverty (Male)	Older Adults Poverty (Women)	Difference Total vs. Older Adults	Genre Difference
China	28.8	39	37.9	40.1	10.2	2.2
Mexico	16.6	24.7	23.3	25.9	8.1	2.6
United States	17.8	23.1	19.6	25.9	5.3	6.3
Japan	15.7	19.6	16.2	22.3	3.9	6.1
United Kingdom	11.9	15.3	12.5	17.7	3.4	5.2
India	19.7	22.9	21.9	24	3.2	2.1
OECD	11.8	13.5	10.3	15.7	1.7	5.4
Russia	12.7	14.1	8.4	17	1.4	8.6
Turkey	17.2	17	14.9	18.5	−0.2	3.6
Germany	10.4	9.6	7.4	10.6	−0.8	3.2
Brazil	20	7.7	7.5	7.8	−12.3	0.3

To mitigate the macroeconomic impact of this population aging, the UN proposes promoting lifelong learning systems, extending health care to the entire population, encouraging healthy lifestyles, advocating savings, improving the employability of the elderly, avoiding the gender gap, delaying the retirement age and improving family reconciliation [1].

The United Nations defines sustainability in a broad sense, as actions to meet the needs of the present without compromising the ability of future generations to meet their own needs. Under this premise, the UN proposed the sustainable development goals as actions and priorities to be carried out in order to reduce poverty, improve health and education, reduce inequalities, grow economically, preserve nature and reduce the risk of climate change [2]. Achieving sustainable development goals requires addressing three essential challenges: economic, social and environmental. Tables 1 and 2 show data concerning sustainability problems. It is clear not only that the elderly will in the future take on greater sociodemographic importance, but also that there is a problem of economic insufficiency, especially in relation to the female gender. Technologies to tackle these problems should thus address the aspects of population growth, poverty and gender.

One factor that cannot be ignored is the impact of aging on health. Low fertility and mortality rates have not only a demographic but also an epidemiological impact. In the coming years, diseases will be more closely linked to aging populations with greater resources. By 2030, the WHO [4,5] has predicted increases in heart disease, cancer and diabetes, and decreases in perinatal mortality, parasitic infections and malnutrition. Mobility impairment and dementia will follow a pattern of growth, especially in countries with fewer resources. According to the aforementioned report, in developed countries 30% of the elderly over 85 and 50% of those over 90 suffer from dementia. Older adults face conditions that may have been acquired during the course of their lives, such as brain injuries or dementia. Aging increases the risk of dementia, the most common cause of which is Alzheimer's disease (70%), with symptoms such as forgetfulness, temporal and spatial disorientation and communication difficulties. According to the Ageing Report, in 2050 one third of the European populations will be over 65 years old. The WHO [6] estimates that 5–8% of this population will suffer from dementia. In this regard, ageism (discriminatory attitudes towards certain age groups) is growing. The data show that ageism has a negative impact on the health of older adults. In [7], prevalence of this prejudice was estimated to affect 50% of the population.

The economic impact of declining health and decreasing retirement ages is a growing concern. Deteriorating health coupled with increased longevity requires long-term care. The experience gained, the existence of less strenuous jobs and the likelihood of reaching old age while maintaining good health mean that retirement policies must be evaluated. Another aspect worthy of consideration is loneliness; support for families would benefit both families and older adults. Despite this fact, the number of people living alone, in institutions or alone with their spouse has increased in recent years. All these aspects can be improved by keeping the elderly healthy for longer. The UNO report on "Ageing, Older Persons and the 2030 Agenda for Sustainable Development" raised the question of why ageing and older adults matter for development. The report highlighted the importance of the elderly in economic development as a workforce in roles which include unpaid care work in support of their families, political and associative participation and active volunteering in their communities.

This article reviews technological initiatives aimed at the older adult population. The technological proposals identified are addressed from the point of view of sustainable technologies and how they can prolong older adults' health for longer, promote their social and work participation, facilitate independent living for longer, provide onsite medical care and remote medical surveillance and improve well-being, and the extent to which older adults can contribute, with their experience, to the community. Even though, in this regard digital divide should be studied in his group. Digital divide problems are related to different factors: on the one hand, digital skills and the degree of literacy of the elderly, on the other, the way information is published (issues of web design, text readability, legibility, etc.).

The rest of the paper is structured as follows. In the next section, the materials and the method followed are described. A quantitative analysis is then presented, explaining the evolution of this field of study and the progress made. This section also details the network of documents and the citation analysis. In the next section, the main projects and lines of research in the different subfields of the subject are summarized, and finally there is a discussion of the main findings.

2. Materials and Methods

We conducted a systematic literature review based on Kitchenham's procedures [8] and adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis Statement) guidelines [9]: identification, screening, eligibility and inclusion. To perform the review, it was necessary to determine the research questions, the data source, the analysis process and the study's limitations.

2.1. Research Question

First, we identified the research question. The main research questions addressed by this study were:

RQ1: What are the main patterns observed in the publication of research in this area?
RQ2: What topics and research areas are addressing older adults?

RQ3: How have sustainable technologies for older adults evolved?
RQ4: What research topics require further attention?

2.2. Resources

To answer these questions, a search for sustainable technologies for older adults was performed in the WoS and Scopus databases. The Clarivate Analytics Web of Science (WoS) database was created by the Institute for Scientific Information (ISI) in the fifties. Scopus was launched in 2004, although it had been compiling papers prior to that year. These resources complement each other insofar that their coverage is different. Some countries, such as Spain or India, have larger coverage in Scopus. In 2016, Mongeon and Paul-Hus [10] analyzed the overlap, showing relevant different levels of overlapping in different fields. Both resources represent the main data sources used in bibliometric and bibliographic studies. The search strategy was unaffected by temporal, geographical or subject limitations. The two databases cover different resources, including disciplines from different fields such as social sciences, technology, natural sciences, medicine or humanities. Scopus and WoS are the largest databases of abstracts and citations of peer-reviewed literature.

2.3. Search Process

The search process, to identify articles relevant to our study, was designed focusing on words related to the three main areas (Table 3), with "older adults", "sustainability" and "technology" being searched for in abstracts. Specific words, synonyms and near words were selected. For "older adults", the following words were searched for: (old * NEAR adult *) OR (old * NEAR people) OR (elder * OR "senior citizen *" OR geriatric * OR gerontology). For "technology", the words selected were: (technol * NEAR sustaina *) OR (digital * NEAR sustaina *) OR (ICT NEAR sustainab *) OR (greentech OR cleantech OR cybernetics OR robotics OR "artificial intelligence" OR "big data" OR informatics OR computer OR software OR IOT). Finally, terms related to "sustainability" were searched for in titles, abstracts, sources or categories. These words were Sustainab *, "foot print", CSR, Greentech, cleantech or "corporate social responsibility".

Table 3. Search queries (SQ) performed in WoS and Scopus. Asterisks are used as wildcards, replacing zero or more characters at the end of the word.

Objective	Query Scopus	Query WoS	Justification
SQ1: Identify topics and related research areas addressing older adults	(ABS (old * W/5 adult *) OR ABS (old * W/5 people) OR ABS (elder * OR "senior citizen *" OR geriatric * OR gerontology) AND NOT ABS (elderberry * OR elderflower *))	(AB = (old * NEAR adult *) OR AB = (old * NEAR people) OR AB = (elder * OR "senior citizen *" OR geriatric * OR gerontology) NOT AB = (elderberry * OR elderflower *))	Terms such as ederberr and elederflower has been discarded to avoid retrieving irrelevant documents.
	AND	AND	
SQ2: Identify how technology is used in this group and for what purposes	(ABS (technol * W/5 sustaina *) OR ABS (digital * W/5 sustaina *) OR ABS (ICT W/15 sustainab *) OR ABS (greentech OR cleantech OR cybernetics OR robotics OR "artificial intelligence" OR "big data" OR informatics OR computer OR software OR IOT))	(AB = (technol * NEAR sustaina *) OR AB = (digital * NEAR sustaina *) OR AB = (ICT NEAR sustainab *) OR AB = (greentech OR cleantech OR cybernetics OR robotics OR "artificial intelligence" OR "big data" OR informatics OR computer OR software OR IOT))	Terms have been selected based on common technologies used in this group. Technologies such as greentech and cleantech are sustainable.

Table 3. *Cont.*

Objective	Query Scopus	Query WoS	Justification
SQ3: Identify the extent to which the use of technology contributes to sustainability in a broad sense (technology, people and systems).	AND ((TITLE-ABS-KEY (SUSTAINAB *) OR SUBJAREA(SUSTAINAB *) OR SRCTITLE(SUSTAINAB *)) OR (ABS ("foot print" OR "corporate social responsibility" OR CSR OR greentech OR cleantech)))	AND ((TS = (SUSTAINAB *) OR KP = (SUSTAINAB *) OR SO = (SUSTAINAB *)) OR AB = ("foot print" OR "corporate social responsibility" OR CSR OR greentech OR cleantech))	The generic term "sustainability" has been used in a broad sense to encompass mainly sustainability applied to technology, but also people's standard of living and the sustainability of the global systems that support them.

In the screening process, we checked the query until results were obtained which included as little document noise as possible. The study targeted all types of documents, including papers, conference papers and book chapters. We excluded duplicated papers.

2.4. Data Collection Analysis

The publications found in WoS and Scopus were analyzed in two different phases. First, a descriptive analysis was performed, showing how the topics and areas in this domain had evolved and identifying the main actors involved in the research. Secondly, those papers which, in our opinion, better described the advances made and current proposals were subject to a content analysis. This phase concentrated on advances in the main fields that make up this area of study. In the first phase, bibliometric features, subjects and keywords were analyzed. From each paper, the following data were extracted and tabulated:

- Type of document (book chapter, paper, conference paper).
- Author: full name and affiliation (in order to identify institutions and countries conducting research into sustainable technologies for older adults).
- Title and abstract (to explore technological trends and methods).
- Keywords assigned (to explore topics and subjects).
- Research area categories (to identify emerging areas).
- Source title (to determine what journals are significant in this area).
- Publication year (to learn about how research in the area has evolved over time).
- Number of citations (to identify relevant studies).
- Funding organization (to identify organizations that fund this type of research).

2.5. Study Limitations

The technologies discussed in this article are currently widely used not only with the elderly but also with other population groups. Our search focused on those articles in which the authors expressly stated in the abstract that sustainability was improved through the application of their technology to the elderly. In other words, we excluded articles which, despite describing applications of technologies to older adults, did not mention or relate the research to sustainability. The query was executed in both databases in English, and the results obtained therefore contained text in that language. No other restrictions related to document type, publication period or geographical location were applied in the search.

3. Results

In this section, we summarize the results of the study.

First, we show the results of the search process, which will allow the partially detection of the main patterns observed in the publications of the research in this area (RQ4). Then, the results of the data analysis are shown, allowing to answer the RQ1–RQ4 research questions.

3.1. Search Process Result

As a result of the search in databases, 207 resources were identified in WoS, and 246 studies in Scopus. In total, the two databases analyzed provided 330 different articles. Of the total number of documents, 122 (37%) were found only in Scopus, and 84 (25%) were found only in WoS, while 124 (38%) were shared by both. From the results of the query, 7% of the publications in the dataset were rejected due to noise.

3.2. Data Analysis Results: Timeline and Publication Sources

The timeline for publications about sustainability technologies for older adults began to increase in the 2000s. The number of publications increased steadily from 2008 to 2016, and then significantly from 2016 onwards. Figure 1 shows the distribution of the scientific works published during the period 1999–2020. The number of documents collected from WoS and Scopus is different, because each database is fed by different research sources. However, the trend is similar in both databases.

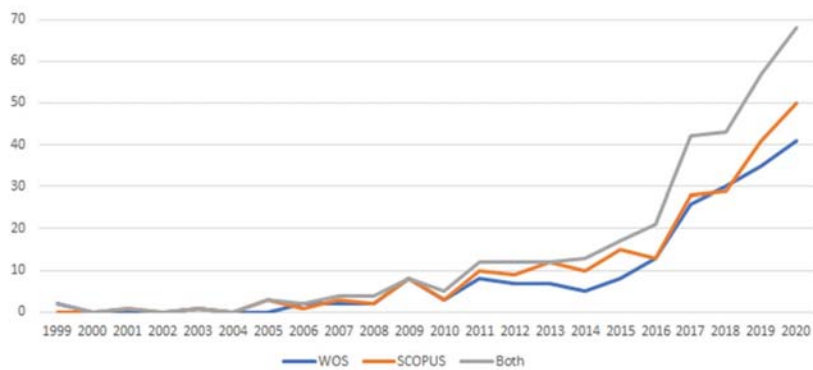

Figure 1. Distribution of research works during the period 1999–2020.

Regarding publication sources, many papers have been published in research journals, 43.1% of them appearing in 106 journals in Scopus and 46.4% of them appearing in 95 different journals in WoS. The main two journals of each database are shown in Table 4, including the number of papers published. The journal Sustainability is one of the top publication sources and it stands out in both databases for its number of publications related to sustainable technologies for older adults. Other representative publications are associated with the areas of information technology and health, although the results reflect a wide variety of publication sources.

Table 4. Top publication sources (≥4 papers) in Scopus and WoS.

Source	Scopus	Source	WoS
Lecture Notes in Computer Science	15	Sustainability	16
Sustainability	13	BMC Geriatrics	4

3.3. Data Analysis Results: Countries, Institutions and Organizations

Figure 2 shows the countries associated with the authors' affiliations. Differences in geographic coverage can be seen between the two databases. The largest contributions come from the United States, the United Kingdom and China, each with 25 papers on the subject. In addition to the United Kingdom, other Western European countries feature prominently. Other geographical areas contributed much fewer publications.

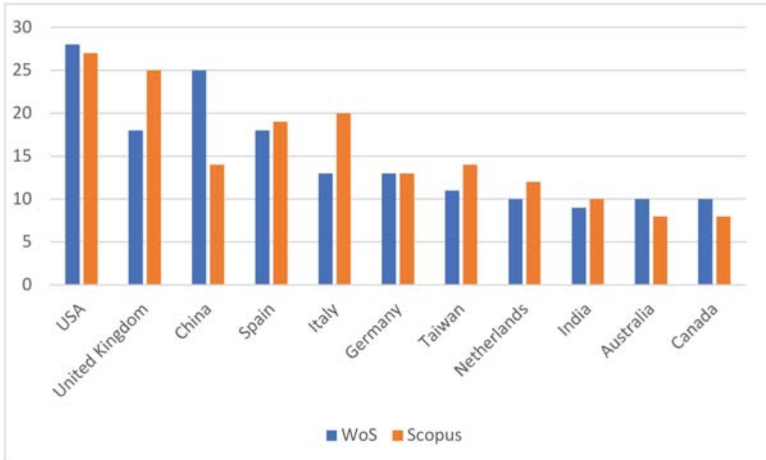

Figure 2. Countries associated with authors and publications from WoS and Scopus.

The relationship between each author and each country is determined by affiliation. In this regard, it is interesting to note which organizations are more prevalent in the two databases. One interesting feature is the large number of authors (researchers) who appeared in both databases. In WoS there were 885 different authors for 207 publications. Only 24 had authored two items, the rest just one. The same pattern can be seen in Scopus, with 992 different authors, of whom only 29 had authored more than one publication. The average number of authors per paper was 4.4 (SD 4.24) in WoS, and 4.1 (SD 3.88) in Scopus. The maximum number of authors per article was 29. Table 5 shows an example of the top institutions that have conducted research in this field, with at least 3 papers published. A total of 13 institutions in Scopus, and a total of 10 institutions in WoS. Note the prominence of Italian research institutions (U. Pisa, CNR) in both databases.

Table 5. Top affiliations in Scopus and WoS.

Affiliation Scopus	#	Affiliation WoS	#
Università di Pisa	4	CNR	4
Loughborough University	3	Univ New South Wales	4
Cumming School of Medicine	3	Arizona State Univ	3

Regarding the organizations funding this research, it is important to mention that not all projects are funded, and that the two repositories (Scopus and WoS) differ in their geographic coverage and their ways of organizing the data. This explains the differences shown in Table 6. The data from Scopus highlight programs funded by the European Union or promoted by European countries. Furthermore, noteworthy is the amount of research carried out under the auspices of the Chinese and Taiwanese governments, the National Health and Medical Research Council of Australia, and the United States. In the WOS database, the main funding programs correspond to the European Union, although institutions from the United States, China, Australia and Japan also play important roles (Table 6).

Table 6. Top funding organizations in Scopus and WoS.

Funding Sponsor—Scopus Corpus	# Scopus	# WoS
Horizon 2020 Framework Programme	7	-
United States Department of Health and Human Services	-	6
European Commission	5	9
National Natural Science Foundation of China	4	5
Engineering and Physical Sciences Research Council	3	3
National Institutes of Health	3	5

3.4. Data Analysis Results: Subjects and Keywords

Analysis of the keywords linked to the scientific documents reflected different research issues or domain applications (in blue and squared in Figure 3) and technologies applied (in blue in Figure 3) in the period 1999–2020. The average number of keywords per paper was 4.94 in WoS and 12.53 in Scopus. Figure 3 shows the keywords and technologies with at least 3 occurrences. Prominent subject trends in research into sustainable technology and older adults included Ambient Assisted Living (AAL), mHealth (Mobile Health), IoT (Internet of Things), BigData, Smart Cities, RFID (Radio-frequency identification), etc. Scopus also included some keywords related to methods, the most cited terms including surveys and questionnaires (12), behavioral research (7), qualitative research (7), decision making (5), treatment outcome (5), randomized controlled trial (5), interview (4), clinical study, (4) and prospective study (4).

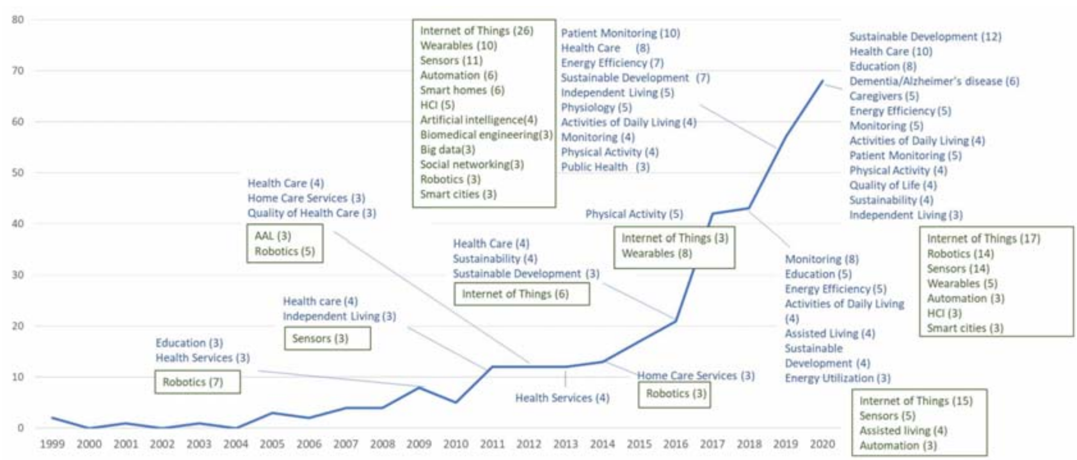

Figure 3. Main concerns and technology based on keywords in the papers (≥3 occurrences) in Scopus.

Network analysis of the keywords showed the relevance of each node. Figure 4 shows the clusters. The font size is larger when the number of inbound links, the degree, is higher. Inbound links are the number of papers that mention the keyword. In the figure, the clusters are identified with a number and labeled with the most relevant keyword in the node.

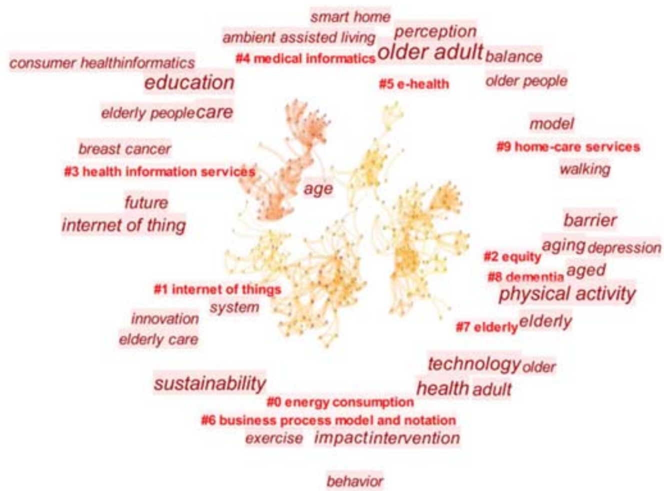

Figure 4. Relevance and clusters of keywords related to sustainability technology and older adults in the WoS collection.

Figure 5 shows the distribution of the documents by subject according to the classification defined in the WoS and Scopus databases. The categories and assignment criteria differ in the two databases, but their organization is similar. In both cases, the main category is Computer Science. They also agree in the Engineering, Environmental Science and Business, but not in other categories. Other categories, such as Science Technology, seem to be underrepresented in Scopus, undoubtedly due to the application of different allocation policies, and other categories of Scopus are underrepresented in WoS, such as Social Sciences.

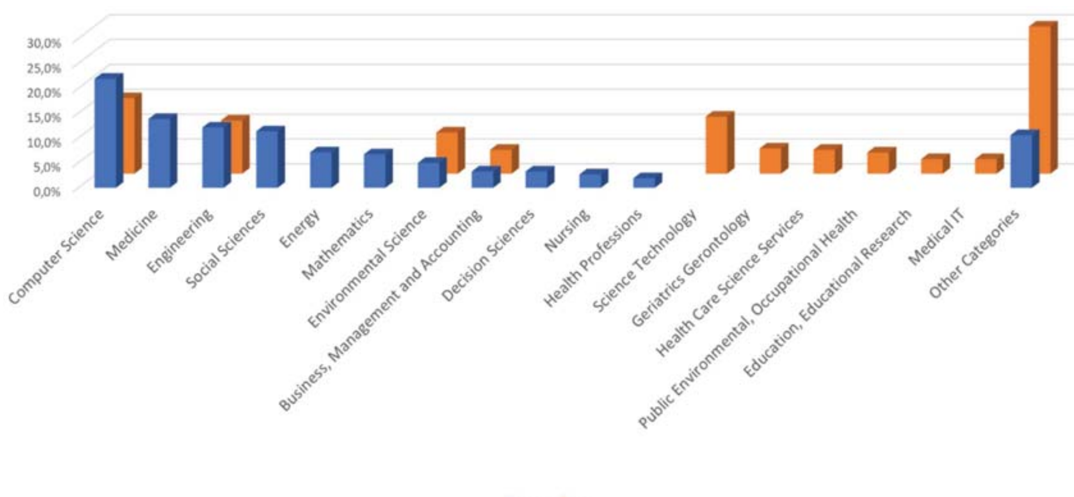

Figure 5. Distribution of the documents by subject in WoS and Scopus.

3.5. Data Analysis Results: Citation Report

Regarding the citation process, 1150 papers were referenced in the documents from the Scopus dataset, while 1156 references were mentioned in the WoS dataset. In Scopus, each document was cited on average 4.63 times, while each document in WoS was mentioned 5.61 times. Both databases have an H-index for these documents of 17. Figure 6 shows the number of citations per year for documents retrieved from Scopus and WoS. The data thus confirm the upward trend in studies related to sustainable technologies for older adults over the last 15 years. The main subjects treated in these documents are summarized in Figure 6.

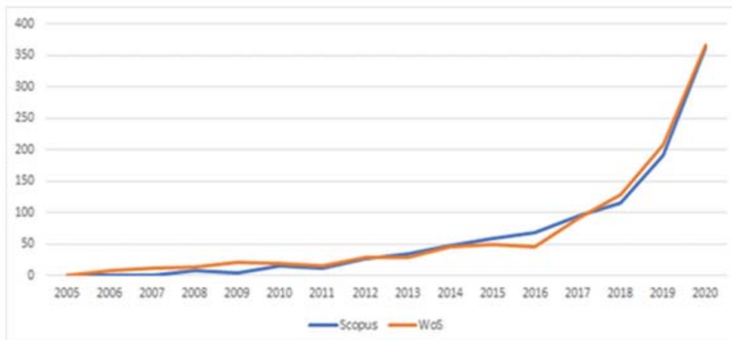

Figure 6. Publication year of the references cited in the documents retrieved from Scopus and WoS.

The references citing the 207 documents in WoS were published in 162 different sources. Table 7 shows the main journals cited. The largest number of papers were published in Sustainability, followed by the International Journal of Environmental Research and Public Health.

Table 7. Main sources in the citation report.

Source Titles	#	%
Sustainability	41	3.53%
International Journal of Environmental Research and Public Health	23	1.98%
Sensors	21	1.81%
IEEE Access	18	1.55%
Journal of Cleaner Production	13	1.12%
Multimedia Tools and Applications	13	1.12%

3.6. Content Analysis Results. Sustainable Technology and Older Adults

The papers analyzed described different sustainable technologies. They could be grouped into three different categories dealing with different aspects of the daily life of older adults: (1) eHealth, which includes papers related to disease prevention, detection and treatment, tele-health and health applications, among other issues; (2) daily activities and wellbeing, which includes different kinds of activities performed by older adults in their daily lives, such as education and training, leisure time, social communication and physical and emotional well-being; (3) policies and strategic plans, which includes technology related to global and systematic strategies affecting older adults, such as environmental or financial sustainability, sustainable living and transport.

There was also a cross-cutting category encompassing different projects such as usability, the study of behavioral patterns in the target population, design methodology and iterations of the different types of actors involved in conducting the projects.

The sustainable technologies applied to each of these categories are summarized below for each category, referencing the main research projects and systems found in the literature and showing, at the same time, the main trends and strengths of using this technology in a sustainable way. The categorization is based on the main component, as these are not disjoint categories. In fact, the projects have some highly cross-cutting components such as usability design, system accessibility and communication between stakeholders that we summarize in Section 3.6.4. On the other hand, technology is mixed at some points to build sustainable applications for each category. In the sections below, in order to give a structure to the large amount of data, we have organized the information according to the major technology applied in each project, which is the main focus of the article to which it refers.

3.6.1. eHealth

Next, the main research projects and works in eHealth are summarized and organized by the main technology applied. Moreover, Table 8 summarizes the main trends, strengths and weaknesses of using sustainable technology for eHealth and elderly life, answering to the Search Questions (SQ) that the paper defines in Table 3: main research areas addressing older adults, how technology is used and for what purposes, and extent in which technology contributes to sustainability.

eHealth and Information and Communication Technologies

In the field of medicine, Information and Communication Technologies (ICTs) are used to create sustainable conditions aimed at improving the quality of life of older adults and mainly related to illness prevention, detection and treatment. Information and Communication Technologies include mobile or desktop applications. Improvements in healthcare have significantly benefitted the population, above all older adults and their families.

One example of using technology for illness prevention is the initiative to implement immunization triage programs in an emergency department to achieve a sustainable system, reported in [11]. This work examined whether information technology provided a viable, sustainable method for increasing vaccination rates in an adult emergency department. The computerized reminder system produced positive results by increasing vaccination rates.

Along the same lines, Graham's work [12] proposed an integrated digital/clinical approach to reducing tobacco dependence. This was accomplished by leveraging the digitization of clinical information to proactively connect smokers to smoking cessation treatment. The treatment involved digital interventions such as web-based and text messages. The main finding of this study was that when used in lung cancer screening programs digital interventions are a feasible, scalable, sustainable method for engaging more patients in smoking cessation treatment.

In addition, Drobics et al. propose an ICT platform to promote healthy activities for everyone (including older adults) [13]. The platform allowed people to take control of their health, harmonizing medical, care and lifestyle services. It promoted, supported and monitored health related activities, enabling older adults, for example, to monitor exercises prescribed by their doctors.

Other proposals addressed illness detection. A research project carried out by [14] focused on detecting pathologies such as cardiovascular events. Other initiatives were treatment-oriented. For example, Smith's work [15] proposed a method for treating adult thoracolumbar spinal deformity. Another initiative, the Let's Chat project [16], used software development to detect dementia and cognitive impairments in primary care clinical settings.

Table 8. Sustainable Technology in eHealth.

Domain of Application	SQ1 Main Research Areas Addressing Older Adults	SQ2 How Technology Is Used and for What Purposes	SQ3 Extent in Which Technology Contributes to Sustainability	# Papers	References
e-Health Actions related to illness prevention, detection and treatment	Monitor patients to detect clinical conditions or send messages to improve treatment adherence Data mining, ML and LA with different purposes: detect patterns globally or automate alarms and personalized messages to patients in key situations for their health. Medical assistance, emergency support and disability support	IoT to sensor and monitor patients in different situations: (1) monitor specific parameters for detection and control of specific pathologies such as diabetes, heart problems. (2) monitor emergency situations such as falls, heart attacks or stroke. Digitalization of medical records ML and LA to analyze data and provide alarms that trigger services based on data from IoT devices or medical records. Assistive robotics to support physical problems derived from an acquired disability or mobility limitations typical of aging (e.g., wheelchair, exoskeleton or robotics arms).	Big data techniques improve pattern detection and personalization of services and allow the application of ML and LA techniques on a larger scale. Improving communication among professionals from different services allow the attendance of pluri-pathological patients Improving the accessibility and usability of HW and SW (computers, mobile phones and specific devices) allows its application to larger groups with special needs, such as the elderly.	27	[11–38]

With regard to the treatment of illness, Information and Communications Technology is one of the most successful technologies for facilitating home healthcare and telemedicine. The aging population impacts all areas of society, putting pressure on social expenditures and public health services and raising the number of challenges in medical care and rehabilitation. In [17], e-health is presented as a promising concept supporting the idea of independent living for patients with chronic diseases. In regions with older populations that have to travel long distances to hospitals or medical centers, services are improved by technology, but each patient needs personalized treatment.

Another aspect worthy of consideration is the application of ICTs to communication between different health care providers and the elderly population. The underlying motivation here is the lack of professionals in gerontology, nurses and long-term care professionals—a problem discussed in many papers. In ambulatory care scenarios, it has been proven that facilitating communication between pharmacists and patients and giving the latter an active role in the management of their medication has its benefits [18].

Some of the difficulties posed by chronic disease self-management tools are discussed in [19]. One of the biggest problems is that such tools are usually designed for a single disease and do not take into account the fact that elderly people usually have multiple pathologies. Another issue is usability: most tools have not been designed with the specific needs of the elderly in mind. Kastner presented an eHealth self-management application called 'KeepWell' capable of supporting seniors with complex care needs in their homes and proposed a trial to validate its efficacy, cost and acceptance.

Finally, the COVID-19 pandemic has accelerated the use of ICTs as an alternative form of consultation, especially for elderly people with multimorbidity belonging to high-risk groups for which in-person visits are discouraged. Lee [20] took this opportunity to propose a study into the potential of video consultation and to evaluate the sustainability of such a service after COVID-19. The study used the NASSS (Non-adoption, Abandonment, Scale-up, Spread and Sustainability) framework and its main findings are to be shared with administrators in the healthcare sector to enhance quality and safety in video consultations.

eHealth and the Internet of Things

Sensor-enhanced health information systems play an important role in creating sustainable conditions for self-sufficient and self-determined lifestyles [21]. This section looks at the use of sensors in wearable devices, among other technologies.

Healthcare providers are turning to sustainable technological solutions capable of facilitating information exchange for mobile geriatric care [22]. The use of IoT devices with multiple sensors allows doctors to perform medical check-ups regularly, receiving data directly from the devices and analyzing it accordingly even when they are not in the same building as the patient.

Guo [23] proposed a model for improving the connectivity of personal wearables with community and hospital environments, using an IoT architecture. However, is this technology accepted by everyone? The study carried out by [24] in India examined the factors influencing the adoption of smart wearable devices and IoT in society for health monitoring. Intrusiveness, comfort, perceived usefulness and perceived ease of use were all studied.

One major concern is the early detection of dementia in elderly people living alone. Javed [25] proposed an IoT-based solution involving the monitoring of daily activities to detect early stages of dementia and its evolution. This technique is called Cognitive Assessment of the Smart Home Resident (CA-SHR).

eHealth and Smart Living

Smart living technologies can facilitate interaction between health personnel and older adults. This category of technologies includes things such as Ambient Assisted Living and smart homes or cities. Of particular interest is the development of spoken language-based applications, which provide an intuitive, accessible interface for both the elderly and their home care providers [26]. In this type of AAL technology, it is recommended that informal caregivers, as experts in the matter, be taken into account when designing such tools [27].

Several studies focused on improving the life quality of older adults in their own homes, avoiding the need to travel to healthcare centers by using different devices to monitor their needs and medical parameters [28]. Some researchers are developing devices using machine learning which can track health parameters through urine tests, measure blood pressure etc. [29,30].

eHealth and Artificial Intelligence and Big Data Technology

Fuzzy-semantic systems have been developed to evaluate the physical state of patients during the rehabilitation process [31]. These kinds of systems are used in mobility/rehabilitation therapies, where the relationship between older adults' mobility and their quality of life is well documented.

eHealth and Robotics and Cybernetics

Robotic solutions are now being designed to provide support for daily activities performed by older adults. Ref. [32] proposed a taxonomy of social robotics, identifying 3 main categories: (i) Assistive Robotics (AR), which gives aid or support to a human user (rehabilitation, wheelchair and other mobility aids, companion robots, manipulator arms for the physically disabled and educational robots). (ii) Socially Interactive Robotics (SIR), the main goal of which is to develop close, effective interactions with a human for the sake of interaction itself. (iii) Socially Assistive Robotics (SAR), which also aims to create close, effective interaction with humans but in this case in order to assist and achieve measurable progress in convalescence, rehabilitation, learning, etc.

Different robots have been successfully used in caring for older adults to prevent dementia. The study carried out by [33], for example, described a robot programmed to play chess to combat brain degeneration.

A complementary analysis related to the treatment of dementia was conducted by [34]. This study, which looked at the engagement and acceptability of people with dementia in residential care for older adults, had older adults interact with a SAR called Matilda for 3 years (from 2010 to 2013). Another project, by [35], evaluated which features enhance patient interaction with robotic pets.

Simonov and Delconte [36] used humanoid robots in rehabilitative exercises, reducing the need for human care. Exercises to rehabilitate COPD patients were coded to program the robot and the human-robot interactions were compared using dynamic time warping (DTW). Other studies have focused specifically on the acceptability of robotic systems among older adults. Ref. [37], For example, analyzed older adults' engagement considering the lack of capacity for socioemotional interactions in the robotics systems then available, and also the price, a big barrier to the more widespread adoption of robots in society.

eHealth and Serious Games and Gamification

Health care associated with leisure time has brought important benefits to the population. One interesting proposal is that of gaming platforms. In 2018, Valenzuela [38] reported how gamification was applied to increase engagement and effectiveness. The author conducted a literature review to show that persistence and participation in the use of fitness games (or exergames) increased when they were more enjoyable.

3.6.2. Daily Activities and Well-Being

Unfortunately, there comes a time when the elderly are no longer able to perform everyday actions on their own. Prior to this situation, long-term care services can use technology to help older adults live independent, safe lives for longer. In this section we will discuss the main innovations that seek to facilitate a more sustainable quality of life for older adults in their daily activities. Table 9 summarizes the main trends, strengths and weaknesses of using sustainable technology for daily activities and wellbeing.

Table 9. Sustainable technology for daily activities and wellbeing.

Domain of Application	SQ1 Main Research Areas Addressing Older Adults	SQ2 How Technology Is Used and for What Purposes	SQ3 Extent in Which Technology Contributes to Sustainability	# Papers	References
Daily activities and wellbeing Actions oriented to facilitate autonomy of elderly helping them to perform every day actions on their own.	Monitor patients in their daily routines: physiological needs, physical activity and nutrition. Mental wellbeing fostering communication, learning and gamification Digital literacy to use personal devices (mobile phones, computers and wearables) to support physical and mental wellbeing	IoT and big data to sensor and monitor patients in different situations to promote active and healthy aging Commercial wearables (wristbands, pedometer, mobile phones) with IoT sensors integrated to monitor patients and send them alarms Socially interactive or assistive robotics for emotional support or to prevent dementia. Even though there are many successful prototypes, the technology is not yet mature for mass and sustainable use Gamification with different purposes: learning, mental activity, physical activity or daily routines.	Interoperability and usability of IoT systems and battery duration still need substantial improvement to make some of these technical solutions sustainable. The maturity of educational platforms (MOOCs, LMS) has made it possible to bring education and serious games to this group despite their mobility problems. Increased use of social networking and videoconferencing tools have allowed elderly to stay connected with family and friends, support networks such as neighborhood centers and health services.	47	[23,37,39–84]

Daily Activities and Information and Communication Technologies

Pasalich [39] established the sustainability of a home-based physical activity and nutrition program, reporting a short-term improvement in diet and in physical activity, albeit with significant gender-related differences and a significant decline in the follow-up phase. In [40] the activity patterns of older adults were monitored with an IoT based system, detecting risky situations and variations in activity metrics. In a pilot study [41], authors analyzed how elderly people may benefit from technology in their daily lives, even though devices have not generally been optimized for their needs (e.g., their physiological or cognitive limitations). This study, which used scenario-based techniques, confirmed that older adults may accept technological artifacts when they perceive them to offer benefits in terms of well-being and health. Regarding daily activities, some technologies are designed to be used by older adults, while others are designed to be employed by their caregivers. Some such projects are summarized below.

With respect to technology oriented to older adults, Ref. [42] proposed habilitating the home or community environment to enable older adults to remain active and independent for longer through mind stimulation measures that included interactive television and personalized ICT support. This approach proposed the use of open standards, low-cost solutions and interoperable applications.

Carretero [43] demonstrated the benefits of employing ICT-based services for informal caregivers and attendants, in terms of sustainability and savings for the care system. This idea was supported by Leslie et al. [44], whose study focused on how technology can help family caregivers work more sustainably and aid resilience. These authors found that caregivers need improved computer systems capable of connecting them and providing information and support.

Daily Activities and the Internet of Things

Many authors highlight the importance of sensors for monitoring physiological signals and of the Internet of Things (IoT) as an aid to independent aging [23,45–49] compiled several IoT applications, protocols and methods for elderly people and people with special needs. With regard to IoT, the study by [50] addressed digital services for the 60–75 age group by digitally adopting wellness routines. This study found that in this group routines are not maintained over time and concluded that digital coaching can help users create good, effective, sustainable wellness routines. Prominent in this group of articles are those related to fall detection systems for elderly people [51,52]. These systems monitor and detect critical events such as injuries or dangerous environments, triggering immediate action and response.

One interesting work by Wang [47] proposed developing a smart bathroom that uses sensors to monitor physiological signals. Feng [53] suggested using sensor-based posture monitoring. In this regard, perpetual awareness systems [54] are essential for assisted living and healthcare (for instance, fall detection, falls being one of the major public health concerns in older adults [55]). One of the problems with the IoT approach is that there is a need to keep an eye on battery energy status. The study by [56] analyzed the effectiveness of iStoppFalls, an ICT-based prevention system. The same authors also incorporated video games for exercises and mobility monitors adaptable to different subgroups of older adults and their specific characteristics, reducing the risk of falls. Ref. [57] developed a framework to measure gait velocity and prevent falls, minimizing sensor errors caused by thermal noise and the overlapping of different sensors' regions.

The use of sensors to monitor older adults and the data generated require the implementation of techniques that facilitate their analysis. This process needs improved data interoperability and ontologies. Chien [58] studied the application of Fog architecture to a Cloud system intended for elderly care.

Daily Activities and Smart Living

As can be seen in the keyword analysis, smart cities and smart homes account for a large amount of research. Some authors [59,60] have proposed different approaches for implementing smart eldercare and sustainability. Ref. [61] proposed smart senior citizens' communities, using technology as a sustainable method with which to support the aged and incorporating the brand new "green" practice of modern communities. Ref. [62] created VIHO (Efficient Computer Support in Care for the Elderly), a project which explores how information technology could support the development of elderly care projects and improve the efficiency of elderly care work practice in the future. Hu et al. [63] discussed how technologies can help in the sustainability of retirement villages, while the SmartWalk project [64] looked at how smart cities can promote physical activity by doing things such as tracing walking routes in the city.

However, all these technologies do more than simply make it possible to monitor people's lives in order to improve living conditions and prevent problems associated with aging. They also help reduce the effect of adverse events such as falls. Ref. [65], for example, investigated how shock-absorbent flooring in wards for older adults reduces fall-related injuries.

Ambient Assisted Living is a sustainable, affordable solution that allows older adults to lead independent lives. Some studies have tried to identify the main challenges of applying AAL for independent living. In a survey carried out with specialists to learn more about the main problems of this approach, Ref. [66] found problems of reliability, robustness, security and data privacy.

Ambient Intelligence Living (AML) is a paradigm related to AAL. In AML, sensors and wearables are integrated into our everyday environment, the data being processed with Artificial Intelligence (AI). Older adults need constant monitoring to control their health status and quality of life. In this case, the main problem is to find the best way to interconnect devices. The paper by [67] presented a wearable ambient intelligence-based device that continuously monitors the emotional state of older adults in terms of sleepiness and stress. The CARDEA research project [68] included an AAL system, including wearable devices to detect falls, indoor localization and vital sign monitoring, allowing doctors and caregivers to manage the system's functions through their web applications. Other studies focus their efforts on developing tools to recognize older adults' postures, voices and needs in their homes [69,70]. A complementary strategy to those outlined above is to combine biophilia and smart home technology. This provides an optimal context for aging in place, and was the approach followed by Lee [71] to design a sustainable residential-natural environment for smart homes.

Awada [72] presented the results of the CAMI AAL project, which provided a solution consisting of an interface that helps elderly people to self-manage their daily lives and social interactions such as sharing knowledge, working, etc. The application can be customized according to the needs of the user and their social support network (family and friends) and has been partially validated in three different countries: Poland, Romania and Denmark. This project claims to provide flexible, scalable, individualized solutions to support elderly people in their daily lives. Ref. [73] implemented a smart mobile tutoring eco-social laboratory for assisted recreation, applying technologies such as Ambient Intelligent Architectures (AIA) to monitor the power supply, provide professional bio-feedback, etc.

Daily Activities and Artificial Intelligence and Big Data Technology

Human Activity Recognition (HAR) is a well-known problem when using technologies such as ICT or IoT for eldercare and healthcare. Activity is usually detected with the help of sensors, smartphones or imaging devices. However, the data acquired is meaningless if it is not analyzed. Jobanputra and colleagues [74] presented a survey of different operational Artificial Intelligence techniques and methods and compared their results. The technologies studied included Decision Trees (DT), K-nearest Neighbours (KNN), Support Vector Machines (SVM), Hidden Markov Models (HMM), Neural Networks as Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN).

Smart home IoT infrastructures supporting independent living for older adults have been developed in many research projects, as summarized in the previous section. Some of them provide artificial intelligence mechanisms for easy setup and testing of the installed equipment, as well as providing caregivers with advanced data and visual analytics to help them monitor older adults' health and activities efficiently and sustainably [75].

Daily Activities and Robotics and Cybernetics

One way to reduce caregiver dependency is to detect those repetitive daily tasks that can be automated, such as taking medications. Chen [76] designed a smart medication dispenser with a friendly human-computer interaction interface that prevents patients from forgetting their medication and also avoids other errors such as skipping doses. The interesting multidisciplinary project Robot Companions for Citizens [77] proposed an innovative design for more adaptive, behaviorally complex robotic systems capable of assisting older adults with their everyday needs. This initiative combined nanotechnology, biomaterials, neuroscience and human-robot and robot-robot interaction. In the social domain, one equally innovative application of robotics focuses on creating social networks between humans and robots (human-robot social interactions—HRSI). Lee [78] described a theoretical framework for effectively implementing a sociable robot in a healthcare or elderly care facility, promoting healthier, more active lifestyles among the social network members.

One of the key requirements for creating sustainable adult-robot relationships is to improve affective exchanges between humans and robots. Reference [37] proposed introducing a human-robot affective dimension to improve the acceptability of robotic systems. This included non-intrusive sensory interfaces that adapt robot's affective responses to the user's behavior, using verbal and non-verbal communication to enhance the empathic exchange of moods and feelings.

The application of robotics, however, goes beyond merely considering robots as isolated individuals that provide support at specific moments. Studies also exist in which the robot is integrated more closely with the user to provide support in certain activities. Ref. [79], for example, presented a robotic exoskeleton for gait assistance that facilitates active aging by reducing oxygen consumption in comparison with treadmill walking or self-paced overground walking at the same speed. One of the main drawbacks of such gait assistance exoskeletons is that they tend to be large and heavy. Studies such as [80] have worked to make these exoskeletons more wearable by reducing their weight and making them adjustable tor different sizes. All of these improvements allow the exoskeleton to be worn under clothing, thereby increasing their social acceptability.

Robots are also used in Smart Green City systems, where artificial intelligence helps physical systems to estimate the risk of environmental pollution, improve the travel time between different parts of the city, increase the quality of social life and ensure a greater degree of independence for older adults or people with disabilities. Pandelea and colleagues [81] proposed integrating anthropomorphic walking robots into Smart Green Systems to detect, monitor and control this process.

Daily Activities and Serious Games and Gamification

One of the purposes for which serious games have most frequently been applied as a means of enhancing the quality of life in active aging has been to improve cognitive function. Cognitive impairment and dementia are two of the main threats in this area. These types of interventions, referenced using the umbrella term Computerized Cognitive Training (CTT), consist of systematic, repetitive exercises performed on different platforms (computer games, mobile devices, gaming consoles and virtual reality) to improve specific cognitive domains. Even though much research has been carried out in this area, the studies vary greatly and are not very repeatable. Ref. [82] conducted a systematic review of the literature for interventions lasting 12 weeks or more. Among its main findings, CTT was found to slightly improve global cognitive function compared with other active interventions such as the viewing of educational videos, and there was evidence of a slight improvement in episodic memory compared to inactive control groups. However, no changes in processing speed were detected, nor was there any significant evidence that the cognitive improvements detected persisted over time. It is therefore important to point out that this is an open, active field of research and that more investigation, with more extensive and more in-depth studies, is needed to obtain conclusive results that will scientifically demonstrate the long-term benefits.

Other areas of concern are social welfare and skills management in the workplace. High-level skilled workers are a fundamental asset in organizations, and some studies have therefore analyzed how steps can be taken to promote a feeling of well-being. Gamification techniques have been used to analyze how employees can be helped to acquire experience. For older adults, the feeling of satisfaction is especially valued. The Active @ Work project [83] incorporated intelligent behavior to keep the user aware of their state of well-being, activating notifications to mitigate the risk of fatigue or stress at work.

Gamification has been also used to transfer knowledge from older adults to younger generations. For example, Ref. [84] presented a study in which batik artisans transferred their skills and knowledge using gaming technology as a learning medium, ensuring the sustainability of the industry. The game-based application proposed in the study transposed the physical process of batik production into a digital, interactive, visual space.

3.6.3. Policies and Strategic Plans

The increase in the elderly population has important implications for government policies and strategic plans, above all for the provision of health, wellbeing and care services. Ref. [85] argued that in order to preserve our health system and its sustainability, it is necessary to revise the current work retirement model, teach people to manage their own life, health, economy, etc., change people's activities during their lifetimes and rethink habits regarding the use of health systems. The authors also pointed out that automatic aid devices are needed in homes.

Table 10 shows a summary of the main policies and strategic plans of using sustainable technology for elderly life, similar to previous sections and answering to the Search Questions (SQ) defined in Table 3.

Some authors [86] analyzed the strengths of technology in a cross-European context, establishing that stakeholders should be involved in the definition of future health-care policies and priorities. To ensure a sustainable health-care service, an analysis of the contribution of technological innovation as opposed to that of social reorganization is also needed. Romanopoulou [87] analyzed the challenge posed by the growth of the elderly population in the context of the economic crisis in Greece and proposed the creation of LLM Care (Long Lasting Memories Care), a new health care ecosystem that will provide healthcare specially tailored to the elderly and vulnerable populations. The key to this model is that it is aligned with the European Innovation Partnership on Active and Healthy Ageing (EIP on AHA). Not only does it present the principal considerations governing the establishment of such ecosystems, but it also shows how they interconnect at policy, business, social, technological, organizational and individual levels to improve sustainability and how this exercise in alignment could be analyzed as best practice for similar organizations at European level.

Table 10. Sustainable Technology for Policies and Strategic Plans.

Domain of Application	SQ1 Main Research Areas Addressing Older Adults	SQ2 How Technology Is Used and for What Purposes	SQ3 Extent in Which Technology Contributes to Sustainability	# Papers	References
Policies and Strategic Plans Actions oriented to facilitate the provision of public health, mobility, education and wellbeing services in general and guarantee their sustainability over time.	Create ecosystems with smart facilities and ambient assisted living: smart cities, smart mobility, smart home. Empower users and focus on prevention rather than clinical intervention. Promote individual's autonomy, peer led and social support networks. Considering users, their needs and limitations and involving them in the design of services is key to achieving mass adoption of easy-to-use products and services.	Big data to monitor users, products, services and systems, detect patterns and make predictions. The massive use of cell phones and the increasing penetration of wearables have provided a large part of the population with tools that can be used for monitoring and communication, but it is necessary to make progress in the privacy and security of the data exchanged. One of the main challenges is the interoperability among platforms, devices and data to achieve common infrastructures for the whole ecosystem. It is also important to reduce cost and improve energy efficiency and device's lifetime. to provide low-cost products and services.	It is necessary not to focus on partial solutions to very specific problems but to create a global ecosystem that monitors, connects and informs the needs of different stakeholders: policy makers, healthcare providers, social services, technological industry and individuals using product-service-systems approach. Scale economy and TIC support in in the most disadvantaged areas, such as rural areas or developing countries. New ways of distance product and service delivery that considers usability issues in elderly collective.	46	[27,47,64,85–128]

However, few studies into the needs of the elderly have been carried out which take into account older adults' own points of view. The exceptions include two interesting initiatives in Ireland. The first, conducted by [88] as part of a European Union Northern Periphery Programme (EU NPP), focused more on the specific needs of the rural population, where population aging is even more significant. The second, conducted by [89] as part of the TILDA project, focused more on analyzing the use of formal home care vs. long-term residential care. Since the current situation is not sustainable in the long term, both initiatives were oriented towards collecting evidence to inform policy makers about new ways of improving service delivery. The older adults involved in the first study emphasized the importance of a systemic approach that would take into account an overall vision of different services, not only health but also transport, housing and personal support networks. They valued the closeness of the family mainly for its social and domestic support but considered it important that health, transportation and housing be provided as services to keep them autonomous for as long as possible. The second study revealed instrumental activities in daily life to be decisive factors for adequate health care. The need for residential care in adults with low to moderate levels of dependency can be reduced by providing them with formal home care. In general, older adults valued the existing health services and were concerned that the reorganization of services would prioritize technical efficiency over quality of service. More research and standardized assessment is necessary to support these findings.

For the provision of health services to be sustainable, however, it is necessary not only to focus on the service itself and its target public, but also to develop suitable policies for recruiting and retaining the human resources that provide the service. Ref. [90] discussed this problem in Lebanon, pointing out the importance of developing these kinds of policies at national level in order to make them sustainable. We believe that the use of technology can significantly improve the daily life of health professionals by minimizing travel, facilitating remote monitoring and establishing professional networks to support their work, as indicated in previous sections.

Ramanadhan [91] analyzed hybrid models based on community-clinical partnerships capable of increasing health equity and pointed out the main challenges facing these communities in terms of keeping their services sustainable. The study highlighted the need to take a long-term, infrastructure-oriented approach and emphasized the importance of the partnership's make-up, the alignment of all its members' efforts and a long-term funding structure as keys to success.

Similar conclusions were reached by [92] in a literature review on the Asia-Pacific region which explored the role health technology plays in shaping health care for aging populations. Whereas technology applications do offer a wide range of potential benefits to the elderly population, there are also issues related to surrounding infrastructures, funding and the acceptability of technology. These issues must be approached globally by creating frameworks for the implementation and monitoring of technologies to achieve robust, sustainable development in the long term. The authors [93] advocated using technology to empower older adults and people with disabilities, integrate them back into mainstream society, enhance their capabilities and give them a chance to compete in the real world. Kobayashi and colleagues [94] analyzed recent trends in medical ecology in Japan and proposed the development of high-quality, lightly structured technologies to provide low-cost, easy-to-access healthcare as a basis for safeguarding human dignity.

In addition, Cho [58] examined similar problems in the Caribbean countries, highlighting the need to rethink care models to include more sustainable health systems with new orientations in policy, service delivery, organization, training, technology and funding in response to the growth of the elderly population. As in previous studies, Chou emphasized the importance of interventions to ensure healthy aging, arguing that interventions need to focus on preventive actions that will improve older adults' autonomy in adapted self-care environments. Such policies will improve long-term care and reduce the incidence of the non-communicable diseases that account for 78% of deaths in Caribbean countries.

Policies and Information and Communication Technologies

The LivingLab PJAIT project [95] presented a sustainable ICT-based solution to improve senior citizen participation in urban life based on lowering ICT barriers, promoting social inclusion and engaging older adults in the process of developing ICT solutions.

Research into technology aimed at older adults has also explored energy efficient, friendly technologies for mobile and portable devices such as video transmission devices [96]. The aim is to increase such devices' lifetimes. Energy efficiency and user-friendliness are essential in technologies, so reducing power consumption in devices [52] and improving the lifetime and reliability of batteries [97] are key objectives. It is assumed that energy efficiency and resource sustainability will result in improvements in both the service provided by workers and the service received from citizens.

The concept of smart mobility understood as the use of ICTs to organize shared transport adapted to people's individual needs has traditionally been associated mainly with urban environments. However, there are some studies that have analyzed the benefits of adopting this approach also in rural areas. One of these, conducted by [98] in Heinsberg, a rural region in the west of Germany, revealed that smart mobility can help alleviate several disadvantages of rural living, including shortcomings in the provision of public transport supplies and restrictions in older adults' access to different amenities.

The city of Jakarta (Indonesia) was the scenario for a project to implement sustainable e-government (web-based government) and m-government (e-government based on a mobile phone application) and thereby make it a Smart City [99]. Interaction between citizens and the government changed. One of the main results highlighted in the study was that the project enhanced the effectiveness of the public administration. The study also showed that citizens were happy with the applications, which satisfied their sense of self identity, enabled them to pursue their own interests and met their expectations. Senior citizens and conservative communities, however, preferred traditional real-life interaction and the authors concluded that regular training on ICT would be needed for them.

Policies and the Internet of Things

One efficient, sustainable way to help older adults live independently is the use of wearables. A literature review conducted by Godfrey in 2017 [100] on the use of wearables to track older adults' movement (or gait analysis) revealed a great variety of types but threw little light on how they work. Some studies have highlighted the potential energy saving advantages of certain disease prevention measures. Ref. [101], for example studied using the IoT to save energy in lighting while minimizing eye strain in smart homes.

Rich and colleagues [102] described peer-led physical activity interventions with 408 adults in 12 ethnically diverse senior centers in San Diego County. Wearables and sensors (pedometers, wrist activity monitors, blood pressure, GPS devices) were used to monitor individuals and tablets were used by peer health coaches to deliver and track the intervention. One of the main findings was that using a peer-led implementation strategy to deliver technologically monitored physical activities can enhance the adoption, implementation and sustainability of programs.

In Taiwan, the IoT was integrated into the Agricultural and Livestock Production Management System in order to achieve the goal of sustainable agriculture [103]. An agricultural product traceability system made it possible to check compliance with product quality requirements. However, many farmers in Taiwan are small-scale farmers and/or elderly citizens who do not habitually use computers and find it difficult to send the data required to the traceability system. The IoT system allowed the system itself to create real-time production data and send it directly to the traceability system, so the farmers did not need to learn to use computers to upload data to the quality system.

Policies and Smart Living

ICTs applied as part of a multidisciplinary approach to an area of knowledge such as this may have a greater impact, because they make it possible to respond to users' needs while at the same time providing information on users' daily behavior, thus helping to better manage the sustainability of the system as a whole. In this regard, Ref. [104] proposed a Product-Service-System approach for integrating ergonomics and sustainability competences in the development of Ambient Assisted Living, an initiative based on the research experiences of the Technology and Design for Healthcare (TeDH) research group in the INDACO (Industrial Design, Communication, Arts and Fashion) department at the Polytechnic University of Milan.

In the same field of information service management, Birmingham City Council is running the City4Age pilot project, funded by the Horizon 2020 Program of the European Commission [105]. This project focuses on data collection using wearable devices, outdoor sensors and other smart devices. Its urban system is designed to detect changes in daily life—physical activity and social patterns—early and to develop technology-based interventions to help reduce the risk of frailty.

In response to the difficulty of predicting occupancy, Ref. [106] studied sustainable, efficient living-rooms for residence-homes, or any other large-spaces, finding that the use of low-cost, low-resolution heat sensors allowed lighting, heating and air circulation to be automatized in large areas.

Policies and Artificial Intelligence and Big Data Technology

Urban planning can have both positive and negative effects on the health, well-being and social participation of a city's inhabitants. However, the decisions made by stakeholders involved in public services must be based on firm evidence. Advances in the IoT, LA and big data can contribute significantly to the collection and processing of such evidence. The INTERACT (Interventions, Research and Action in Cities) project [107] involved natural experiments in 4 Canadian cities. This project not only delivered timely evidence about how urban interventions influence health and wellbeing but also took a step forward in this direction by providing methods and tools to facilitate such studies. To address these challenges, the project team plans to collect around 100TB of sensor data on both location and physical activity over 5 years.

With regard to older adult mobility, smart card data from information systems have been used to study bus use patterns [108]. The characteristics analyzed with big data techniques include temporal distribution, the distance, duration and frequency of trips and the spatial distribution of travelers. The information about mobility thus obtained can directly contribute to public transport policy formulation, service and management.

Policies and Robotics and Cybernetics

Twenty years ago, there were great expectations about what ideal multitasking robots for assisting the elderly would appear in the future. Despite much research along these lines, however, their use today remains marginal. Reference [109] pointed out that one of the main reasons for this is the fact that research is carried out on imaginary scenarios or in small-scale trials. She also noted that for robotic solutions to be useful, affordable and sustainable from an ethical, social and ecological point of view, research proposals must be evaluated within the framework of existing care ecosystems, taking into account the real political and economic contexts in which care is provided and the provision of care when resources are limited.

Reference [110] provided a glimpse into the future of elder care, reinforcing Van Aerscot's idea of the need for a more comprehensive approach involving institutions. A transition in the elder care system was predicted, with robots ultimately being embedded in welfare services and society. The authors focused on the future of elder care and how it will be affected by the emergence of care robotics, taking the current use of robots in elder care as a point of departure. The study's results established that there is a shift towards the use of robots in care, but that socio-institutional and technological adaption is needed. These two areas are highly interrelated and both of them need to be taken into account for the successful integration of robots in society.

3.6.4. Transversal Aspects of Technology

The transversal aspects of technology affect all areas, including: (1) design methodologies; (2) the usability and accessibility of the applications implemented; (3) understanding of behavioral patterns in the target population; (4) interaction between the different stakeholders affected by applications; and (5) training in the use of technology. The main research projects carried out in these areas are summarized below.

1. Design methodology. User-centered, inclusive, co-creative design methodologies are recommended for developing successful, sustainable technologies. Reference [27] recommended engaging informal caregivers, as experts, in the design of AAL-related technologies. In the same vein, Ref. [111] studied how older adults can participate in the software development process, to produce more friendly, useful applications for this population. Reference [112] reported how an IoT for Seniors course led to the design of more suitable applications by developers [111].
2. Usability and accessibility features. To make technology sustainable, it must be developed taking into account characteristics such as usability (including efficiency, effectiveness, easy-of-use, user satisfaction, etc.) and accessibility (creating technologies—including mainstream and assistive solutions—that everyone, including older adults and people with disabilities, can use in a range of different contexts) [113]. The need to develop inclusive ICTs and to employ user-centered methodologies and co-creative methods is explained in [114], where inclusive technologies were designed for and with the help of older adults, balancing ease of use, subtlety and elements of Cognitively Sustainable Design. Human-centered design and methods, which take into account the needs of all the people involved in the care and assistance of the elderly, were also used in the Habitat project [115] to define the most inclusive and less intrusive design solutions for an IoT home assistance platform for elderly users. Co-creative methods are used also in other IoT projects and smart living environments for ageing well, such as the ACTIVAGE project [116]. Digital information and web services are being used increasingly by the population. In particular, the use of Internet to manage bureaucratic procedures (pay taxes, request appointments with the public administration, fill out service request forms, etc.) and access medical information (make medical appointments, consult medical data, etc.) is widespread. Unfortunately, digital barriers exist which impede adequate access by certain groups, such as older adults. This increases the digital divide [117]. Some proposals have been put forward aimed at tailoring health web information services to the needs of elderly and disabled user groups [118]. According to one Ahref report [119], 90.63% of active pages on the web are never visited. This implies a great waste of energy and resources, from the time invested in their creation and indexing to the cost of hosting them on web servers. One reason for the lack of visits is poor readability. This is a factor that especially affects the most vulnerable and isolated groups, such as the elderly. The effort to make effective, sustainable pages can improve such groups' standard of living and their inclusion in society, but there are still limiting factors caused by aging and a lack of computer skills. As a result, when information is required, more time must often be spent searching on the web. Readability can reduce the time spent locating and understanding information. Other studies have focused on analyzing the attitudes of older adults and people with disabilities towards the use of assistive technologies when they are in need of care. Reference [120], for example, helps us to understand the relationship between individuals' perceptions of care and the acceptance of assistive technology by different user groups.
3. Behavioral patterns. As part of the requirements acquisition phase in technology design methodology, it is important to consider users' behavioral patterns. Some papers have described surveys conducted to see how older adults relate to their environment and to technology, to allow the development of more accessible software and devices for use by this group [111,112]. In a project for smart cities, Ref. [105] identified social patterns of seniors in order to avoid accidents. In the same vein, the

SmartWalk project mentioned earlier identified safe routes in the city [64]. Knowledge of older adults' consumption and living habits is a prerequisite for the design of appropriate technologies. An interesting approach in this regard is the study of energy consumption in relation to elderly people's behavioral patterns, as exemplified in the work carried out by [108,121] on transportation habits. Similarly, Wang [47] analyzed the distribution of the elderly population with cell phones, allowing services to be tailored more sustainably. The study by Godfrey [100] showed that this population is very heterogeneous in its habits.

4. Stakeholder interaction. Interaction and communication between all the different agents involved can contribute to a technology's success. In [122] the design of a multidisciplinary clinical pathway to treat hip fractures reduced mortality rates and shortened hospital stays.
5. Training in the use of technology. ICTs offer many possibilities for improving the daily lives of adults, but the digital divide can also be a factor of social exclusion for them. Ref. [123] highlighted the importance of lifelong learning and, more specifically, digital literacy for improving the social integration of elderly people. As an example, the study reported the effective digital literacy of a group of 96 seniors in the Faculty of Human Sciences at the UABC in Mexico. Ref. [124] analyzed the impact of ICT policies on social inclusion in several regions with the lowest GDP per capita in Spain using the model developed in the IMPOLIS project. The results of this study validated the IMPOLIS model as a monitoring tool for ICT policies that made it possible to design and redirect measures for reducing the digital divide.

However, the elderly population should not be seen only as the recipients of educational actions. In a society where life expectancy is increasing, the contribution of the elderly is a valuable resource that needs to be leveraged. In this avenue of research, Ref. [125] proposed the digital inclusion of elderly groups through a participatory process of digital tool co-creation. This work illustrated the appropriation of digital skills by including older adults as content co-creators in a MOOC (Massive Open Online Course) about how to promote active life for older adults through a collaborative economy. This type of collaboration proved to be effective not only in improving the quality of MOOC content, but also in adapting tools for different groups and improving the autonomy of the groups involved.

Reference [126] reinforced this idea by signaling education as a key strategy for addressing demographic challenges, and lifelong learning as a valuable tool with the social potential to support and empower older adults. This study provided some examples from Bulgaria, where people over 60 constitute one of the fastest growing internet communities.

The European Computer Driving Licence (ECDL) program, also known as the International Computer Driving Licence (ICDL) in non-European countries, is a computer literacy certification. Training is provided in Information and Communications Technology and digital literacy. Qualification enables students to understand and integrate new technologies in the e-society. One particular project, the ECDL PD project, is focused specifically on the needs of elderly people and people with disabilities [127].

Recent studies have proposed recovering other educational approaches, such as intergenerational learning, that can also benefit from new technologies. Reference [128] discussed the physical and psychological benefits of History Alive, a program that promotes the interchange of experiences between senior citizens and college students in a mutual learning process. These initiatives improve learning outcomes, enhance senior citizens' sense of accomplishment and self-worth and allow their stories to live on thanks to the support given by college students via social networks.

3.7. The Process of Technology Adoption in The Elderly

Much research has focused on innovative approaches to achieving sustainable, cost-effective technologies to support aging in place. In this regard, disruptive technological approaches include smart cities, the Internet of Things and healthcare technology, among others. The cycle of adoption and use of technologies by the elderly has its own particular characteristics. Several in-depth studies have been carried out into different aspects of this process. They are outlined below: technology adoption; training in the use of technology; and Long-term use and limitations to the use of technologies.

3.7.1. Technology Adoption

One of the main limitations when implementing programs for independent living for older adults is their reluctance to use technology. Fields et al. [129] reported that one-third of older adults do not use the internet. This rejection contrasts with the undoubted benefits of the internet for this group: connectivity versus loneliness and a more sustainable health care system. Concern in this regard is aggravated by the shortage of care workers. Basically, the sustainability of health care systems needs technology capable of overcoming these difficulties.

The rejection of technology has been discussed in papers such as [117]. It is an attitude perfectly illustrated in the work carried out by [130] in the field of Information Science. The aforementioned researchers used semi-structured interviews and focus groups to study the impact of information and communication technologies (ICT) in public access venues (PAV) in Botswanan libraries with Internet connections. Their results revealed differences in the acquisition and use of computer skills between users who attend school and users who do not attend school. Older users who do not attend school tend to rely on site staff for information and services, avoiding computing terminals. Another paper worth mentioning is that of [131]. This work, related to the COVID-19 pandemic, studied how centers for the elderly have tried to maintain their services by replacing them with online activities. The study tried to determine whether such online activities are an appropriate substitute for in-person activities. A survey was conducted among 105 older adults. Participants in the activities tended to be very satisfied. Non-participants justified their non-involvement with reasons such as: ignorance of the web-based program, lack of interest in the content and problems. The study concluded that there was a need for web-based activities to counteract issues of boredom and feelings of isolation and for current programs for older adults to be made more accessible.

3.7.2. Training in the Use of Technology

The lack of computer skills is a major challenge for elderly people. To tackle this problem, many projects have been implemented aimed at increasing senior citizens' computer skills. One such project was OASIS [132]. Fields et al. [129] observed a positive effect of providing in-home digital training for older adults in terms of social support and the more confident use of technology. One particularly innovative study was carried out by Ha et al. [133]. Its aim was to detect barriers to the delivery of distance geriatric training between two countries, Singapore and Uganda. Cross-cultural education via videoconferencing was proven to be feasible, although recommendations will need to be designed.

3.7.3. Long-Term Use and Limitations to the Use of Technologies

Another intriguing area of study affecting the development of sustainable technologies for the elderly is the analysis of factors that cause older adults to discontinue their use of these technologies. Here, it is particularly important to study variations in the use of technologies in the medium and long term. Long-term use and older adults' attitudes towards computers were analyzed in the DITUS project [134]. The same results were obtained by Fields et al. [129] and Pasalich et al. [39]. In the same vein, Ref. [135] studied how ICTs can help family members to continue the healthy living practices they engaged in when they lived together. The authors proved that in families which engage in healthy living practices together, all the family members (regardless of age) have a better and higher quality of life. The use of technology to communicate and support members living apart and to cultivate health habits help them to effectively collaborate in healthy living.

4. Discussion

As in the study by [136], it was thought convenient to perform the content analysis in domains and divide them into technologies. This avoided the mixing up of domains with the techniques used. This section discusses the results and their interpretation from the perspective of previous studies, based on the proposed research questions.

4.1. What Are the Main Patterns Observed in the Publication of Research in This Area? (RQ1)

Growth in this area can be seen in both databases. In both cases this growth became more pronounced from 2016 onwards, although this is more evident in Scopus. In the analysis by country, the USA and China stood out, although European—especially the UK, Spain, Italy and Germany—accounted for a large number of papers. The differences in geographical coverage between the two databases were evident in some countries, especially China, illustrating how the two databases can complement each other.

Regarding the publication medium, the journals Sustainability and, to a lesser extent, BMC Geriatrics were prominent in both databases, while Lecture Notes in Computer Science was relevant in WoS. With respect to authors' affiliations, some Italian institutions, such as the CNR or the University of Pisa, and institutions from the countries mentioned, such as the University of California (San Francisco), also stood out. European interest in the subject was funded mainly by the H2020 program and the European Commission. In the US, the most prominent sources of funding were the National Institutes of Health (NIH) and the US Department of Health Human Services.

4.2. What Topics and Areas of Research Are Addressing Older Adults? (RQ2)

According to the studies about sustainable technologies for older adults appearing in WoS and Scopus, interest in this area grew between 2000 and 2020. In this twenty-year period, the increase was first gradual, but intensified significantly in the last five years. It should be noted that as the elderly population grows and more emphasis is placed on sustainability objectives, interest in this field and the areas it covers is expanding. There is therefore a growing interest in a more nature-oriented, independent living at home and in smart cities, with a more preventive approach to health.

On the one hand, it should be taken into account that most of the projects and research analyzed were related to areas defined in the sustainable development goals, more specifically:

- Goal 3. Good Health and Well-Being
- Goal 8. Decent work and economic growth
- Goal 11. Sustainable cities and communities

As an unprotected group, however, older adults are also affected by other objectives such as: 5. Gender Equality and 10. Reduced inequalities.

On the other hand, the older research papers had a higher degree of medical content. In the more recent papers, there was evidently an evolution towards the domestic domain and independent living. In general, the keywords and themes reflected growing concern about the situation of elderly people living independently in their homes and communities, the attendant energy consumption, older adults' connectivity with health professionals, relatives, care workers, etc. They also reflected growing interest in the creation of programs to promote occupational therapies and social networks, as a means of increasing older adults' independence and well-being as much as possible.

4.3. How Have Sustainable Technologies for Older Adults Evolved?(RQ3)

Table 11 shows mentions of the main technologies in the period 2000–2021 and the percentage of works published from 2016 to the first term of 2021. In the technological keywords indicated by the authors, IoT was the most mentioned technology (1.6% of occurrences). All mentions of this term correspond to the period 2016–2021. Next came robotics (0.7%), sensors (0.6%), artificial intelligence and wearables (0.5%), health monitoring, big data, medical IT and HCI, each accounting for 0.3%, and a group comprising intelligent buildings, assistive technology, wearables, independent living systems, ambient intelligence, smart city, telemedicine, assistive technology or AAL, with 0.2% each. This count can be chronologically misleading, because all mentions of smart cities, smart homes, big data, telehealth, smart communities or wearables belong to the period 2016-2021 in both databases. It should be noted that these keywords were taken from the articles in the database, not compiled by the authors of the present study. From a 2021 perspective, some papers may therefore be associated with other keywords, but the only processing carried out in this study was to formally normalize the keywords to represent how the terminology used in the two databases had evolved. No subsequent thematic attribution was made.

Table 11. The most common technological keywords in the two databases, with the total number of mentions in the period 2000–2021 and the percentage of them published in the period 2016–2021.

Keyword	WoS Total	% WoS 2016–2021	Scopus Total	% Scopus 2016–2021
Internet of Things (IoT)	25	100	73	98
Robotics	19	74	44	45
Sensors	16	88	38	71
Wearables	7	100	26	100
Artificial Intelligence (AI)	3	100	17	64
Big data	5	100	8	100
Automation	1	100	17	82
Human Computer Interaction	0	0	12	83
Assisted living	1	100	11	82
Medical informatics	3	0	5	0
Smart city	4	100	9	100
Telemedicine	5	60	8	62
Ambient Assisted Living	7	43	10	30

As can be seen, robotics, sensors and computational medicine have been a constant over the last 20 years, although in recent years the presence of wearables, smart living and Internet connectivity has increased.

Standardization of keywords is often scarce. For example, between 2018 and 2020, there was an increase in the study of energy efficiency, but different keywords were used associated with this area of research. Terms used included “energy efficient”, “low energy consumption”, “high energy efficiency”, “sustainable energy sources”, “energy optimization” and references to associated topics such as “energy conservation” and “energy management”. Something similar occurred with terms such as “smart communities” and “smart cities”, and the relationship between “eHealth”, “Telehealth” or “Telemedicine”.

4.4. What Research Topics Require Further Attention? (RQ4)

Older adults are often affected by one or several age-related disabilities, either moderate or severe. System features such as usability, accessibility or readability have a more pronounced effect on this type of user, influencing their acceptance or rejection of systems. It is therefore necessary right from the initial planning stage to implement a user-centered design that will result in sustainable, inclusive technology [27,111]. It is also necessary to encourage developers to adopt this type of methodology [137] to create inclusive resources.

One often overlooked aspect is how older adults can improve technology. Even though older adults play an active role in evaluating applications, user-centered design is seldom applied. This problem is worse when research does not take advantage of one of the greatest strengths of the aging population, their knowledge and experience. Some projects have attempted to incorporate and codify this experience to mitigate disasters such as food shortages. Lunga’s thesis [138] is that this knowledge can be incorporated into more sustainable techniques related to the environment.

Another aspect rarely taken into account is the affordability of technology. On the one hand, future society faces a lack of funding for the health care and public pension systems. Older adults tend to have more ailments and physical and cognitive limitations. On the other hand, the impact of lower incomes and purchasing power, especially among women

(Table 2), forebodes difficulties in acquiring, installing and maintaining technologies. The proposals discussed in this paper rarely address the costs of their application or who is to assume those costs, and therefore run the risk of not being generically applicable.

Neither do any studies exist showing the extent to which these technologies have been implemented—for example, detailing the number of older adults using them, the degree of implementation, the results obtained, their benefits in terms of efficiency and sustainability (i.e., savings for the public health care system or energy savings) or their scalability to benefit a larger proportion of older adults. However, the proposal for an EU regulation on Artificial Intelligence [139] does warn of the issues that will have to be considered in the future implementation of these technologies, with experts drawing attention to the privacy of older adults' personal data, the risk that their behavior may be manipulated by artificial intelligence programs and the need to detect risks and ensure the traceability of results.

Finally, most of the research projects presented in this paper are short term projects or programs to train older adults in the use of new technology, so it would be advisable to promote the real use of these technologies in the medium and long term.

5. Conclusions

Technology offers smart, sustainable solutions to enable older adults to live in better conditions. These solutions must cover not only healthcare, but also social and emotional needs in people's daily lives. Smart homes and cities, the IoT, ICT, robotic systems, artificial intelligence and other technologies can offer efficient, scalable, cost-effective and sustainable solutions. These solutions are not only accurate once cognitive or physical decline has become apparent but are also of great interest for the prevention and early detection of age-related decline.

Throughout this paper it can be seen how technology has facilitated aging in place for the elderly population, either by studying the development of older adults' daily lives or by improving their connectivity with community and health professionals. Technology thus improves social inclusion and promotes a life with greater wellbeing, treating health preventively and enabling the early detection of risks and diseases.

It is important to note that the search strategy on which this article is based prescribed that terms associated with sustainability must be expressly included in the abstracts of the articles by the authors. That is to say, the ultimate object of study was the researchers' own perception of these technologies for older adults as vehicles though which to meet sustainability goals. The large number of authors with just one or two papers over a 20-year period suggests a low degree of specialization. This contrasts with the growth in interest in this area in the last five years. The underlying reason is that the technologies were previously in an immature state, and it is only in recent years, due to growing interest in sustainability and awareness of the challenge posed by the aging population, that their degree of applicability to this field has been raised. Given such recent interest and the technologies involved, a low degree of specialization is to be expected.

There is a clear need to study the feasibility of applying these measures from two different perspectives: on the one hand, the extent to which the target population engages with and adopts technology, and how this increases with the implementation of user-centered, inclusive designs and specific training; and on the other, the cost of installing, maintaining and using these technologies for older adults and whether the elderly population will be able to afford them.

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sustainability

Article

Digital Health and Care Study on Elderly Monitoring

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Abstract: Sustainable technologies are being increasingly used in various areas of human life. While they have a multitude of benefits, they are especially useful in health monitoring, especially for certain groups of people, such as the elderly. However, there are still several issues that need to be addressed before its use becomes widespread. This work aims to clarify the aspects that are of great importance for increasing the acceptance of the use of this type of technology in the elderly. In addition, we aim to clarify whether the technologies that are already available are able to ensure acceptable accuracy and whether they could replace some of the manual approaches that are currently being used. A two-week study with people 65 years of age and over was conducted to address the questions posed here, and the results were evaluated. It was demonstrated that simplicity of use and automatic functioning play a crucial role. It was also concluded that technology cannot yet completely replace traditional methods such as questionnaires in some areas. Although the technologies that were tested were classified as being "easy to use", the elderly population in the current study indicated that they were not sure that they would use these technologies regularly in the long term because the added value is not always clear, among other issues. Therefore, awareness-raising must take place in parallel with the development of technologies and services.

Keywords: home health systems; sleep monitoring; sustainable technologies; technology acceptance

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1. Introduction

According to the United Nations, technologies are one of the enablers of achieving sustainability objectives around the world [1]. Concerning the health monitoring of the elderly, new technologies can provide new ways to improve the quality of life for these people without worsening conditions for future generations, which is the goal of sustainable development. In recent years, there has been a steady evolution of home health systems, with a concurrent increase in understanding that sustainability is essential for the development of new systems [2]. Among the reasons for this is that they are able to provide several benefits to different user groups. For example, home health technologies could be used in rural areas where traditional healthcare providers are more challenging to reach. This could lead to decreasing the necessity of travelling to hospitals/family doctors, resulting in resources being saved. These types of technology could be especially beneficial for the older generation. As a result, they could serve to increase the quality of life of this population [3] and could also simultaneously reduce inequality, which is one of the goals stated by the United Nations [1].

Furthermore, home health technologies could be used, for example, to continuously monitor the health conditions of older people in their home environment [4]. This could result in people staying in their own homes longer rather than moving to an assisted environment, as described in reference [5]. According to the United Nations, this would help to overcome economic and social challenges, which is also one of the sustainable development goals set by the United Nations [1].

The topic of sustainable technologies for the elderly has seen significant developments in recent years, as described in reference [6]. In that study, scientific publications in this domain were analysed, and the conclusion that was drawn indicated that technologies for the elderly can, among other things, improve connections with society and health professionals but could also enable the early detection of health problems and could enhance wellbeing.

Another paper [7] describes digital services in relation to the sustainability of elder care. It also concludes that technologies can provide many benefits if used appropriately. However, it is not always necessary to develop and use new technologies because older technologies can be used in new and innovative ways in certain cases.

There are already numerous devices on the market that can be used to measure various biomedical or health-related signals and values in patients, including, for example, heart signals, blood oxygen saturation, respiration, muscle movement, temperature, falls, and sleep patterns [8,9]. To date, these devices and their associated applications have only been used to a limited extent for various reasons. In practice, it is apparent that assistive technologies face a multitude of barriers [10]. They usually only offer isolated solutions: each device often has its own app and data collection method. There is great potential for these technologies if they choose to use integrated data (fusion of data), which is hardly the case at present.

However, the barriers to these types of applications are not only technological or business-related. Two other aspects play a significant role: first, the user has to consider about data protection: how are the data transmitted and stored? Specifically, how are they stored and used in the data centre (in the "cloud" of the service providers)? How can privacy be protected through anonymization or pseudonymization, if necessary, but how can they also serve the advancement of science? Particularly, these questions represent a major cross-border challenge, as they are heavily dependent on national legislation.

On the other hand, current devices and systems do not always consider the aspects of user-friendliness sufficiently (both in terms of usability and user experience) [11–16]. These systems need an intuitive concept of use, often not only for the patient but also for his or her social environment or (informal) caregivers, patient groups, or other social groups. This is organized and perceived differently in different countries and therefore represents a further challenge. The accessibility of technologies is another significant point to consider [17].

Numerous scientific publications have dealt with the topic of the technology acceptance model to answer the question of which aspects of implementation and use lead to an increase in acceptance [18,19]. The results of this research should provide a scientific basis for planning how certain technologies are used.

The presented work focuses on a conceptual home health system that emphasizes certain health domains that can be implemented with AAL approaches. Stress and sleep are the baseline health phenomena for the analysis of technologies. The choice of areas is not arbitrary and is justified by their relevance. Stress is perceived as an extreme burden by up to 30% of the population; it leads to serious chronic diseases or is prevalent in many cases [20]. It is known that a large proportion of sleep disorders is related to stress, some of which are already chronic, and only 35% of US citizens describe their sleep quality as being "good", while 22% describe it as "moderate", and 12% describe it as "poor" [21]. Furthermore, obstructive sleep apnoea is believed to affect approximately 936 million people between the ages 30–69 years old worldwide, according to an AHI criterion of five or more apnoea events per hour and the AASM criteria [22]. Many sleep disorders, such as sleep apnoea, could be detected with a home sleep monitoring system, allowing early therapy and ultimately enhancing health and quality of life [23,24]. Other sleep disorders, particularly in the elderly, are increasingly recognized as essential challenges, and methods for overcoming these problems are being investigated [25]. To improve personal well-being, various rehabilitation techniques could be used preventively or therapeutically. The effect of rehabilitation could, in turn, provide indirect or, in some cases, direct feedback through the measurement of stress and sleep parameters [26].

The importance of the selected topics is also confirmed by the presence of other publications such as [27], where systems that are not only able to monitor stress and sleep but that are also able help users in the struggle against stress and poor sleep quality are described. In this work, the system design is described in detail, and an evaluation is performed with eight subjects, the results of which demonstrated positive feedback from the users as far as the system's usability is concerned.

To be successful and user friendly, sustainable health services should be universal and should accompany the patient or user through the entire cycle: counselling, planning, implementation, operation, and support. People are in charge of providing such services, and AAL technologies support and offer those services. Fairness, non-discrimination, and user acceptance strongly influence the sustainability of solutions, but cost-effective implementation and pricing models and transparency also play an important role [28].

The main objective of the present work is to find out which aspects play an important role in the development of health monitoring systems for the elderly to enable their sustainable use as well as the simultaneous increase of user acceptance. To facilitate 24 h monitoring, two types of devices were selected for assessment: one that can be placed in the bed to monitor vital signs during the night, and another that is worn on the arm to measure heartbeats during the day. General and as well as device-specific recommendations should also be drawn up as best they can. Another important research question to be clarified is whether existing home health technologies (objective measurement) can ensure a sufficient level of accuracy in the recording and analysis of health parameters compared to the sleep medicine questionnaires (subjective measurement) that are commonly used in multiple areas in measuring, for example, sleep quality. Another objective is to investigate whether older people are in favour of the use of sustainable technologies if the relevant aspects are taken into account during their implementation.

2. Materials and Methods

Because the objectives of this work can best be achieved through an evaluation of practical implementation, conducting a field study with a subsequent analysis of the results was chosen as the primary approach. In the following subsections, the general study design is first presented in detail, followed by an explicit description of the methods used to address study queries. It is important to mention that the presented domain "Sleep" was analysed both quantitatively and qualitatively, whereas the domain "Stress" was included exclusively in the qualitative measurement. For this purpose, a device was used that represents, by example, the group of devices for cardiac activity measurement that can also be used for stress measurement after the appropriate analysis, which is explained in more detail in the last subsection of the "Materials and Methods" section. However, direct stress measurement was not carried out in the context of the described study. This has led to differences in the level of detail in the description of these two areas.

2.1. Study Design

Since a specific target group was identified for the study, the following inclusion criteria were elaborated for application in the selection of study participants:

- Age over 65 years old.
- Most of the household work is completed independently.
- In addition, the following exclusion criteria were considered:
- Unable to perform leg training seated with an exercise trainer for about 20 min for a maximum of 10 days over a two-week period.
- Unable to stand up, walk 3 m, walk back 3 m, and sit down again without the active assistance of another person.
- Unable to understand and complete paper format questionnaires.

- Advanced dementia.

A group of 10 individuals (five men and five women) participated in the study. One of them lived in a residential community for older adults, and nine others lived in their own homes. The mean age of the participants was 72.5 years age, with a standard deviation (SD) of 6.2. The mean weight of the study participants was 80.8 kg (SD = 12.6), while the mean height was 167.6 cm (SD = 7.9).

To the best of our knowledge, the study participants did not have severe acute illnesses. They received all of the study information in advance (for example, a detailed description of the procedure, study objectives), and participation was voluntary and could be terminated at any time without giving a reason. All of the study participants received a written consent form, and the participants read and signed a data protection form after the study organizers had answered any remaining questions. The study procedure, including study information and consent forms, was reviewed by ethics officers from the HTWG Konstanz and the University of Applied Sciences Kempten, Germany.

The expected duration of the study was 14 days. On the first day, the study organizers installed and explained all of the necessary technical solutions in the participants' homes:

- The sleep monitoring device was placed under the mattress across the bed. According to the device's instruction manual, its position should be approximately below the chest area, as described in reference [29].
- The device for monitoring the heartbeat was put on the arm of the test person, and the organizers explained how to use and charge it.
- A third hardware element was installed at the subjects' homes to ensure that the used devices had proper Internet connectivity through an access point with an Internet-capable sim card. Therefore, the system was able to function autonomously and was not dependent on the Wi-Fi network of the test subjects.

Furthermore, interviews with general questions (age, sex, height, weight, and health status) were also conducted on the first day of the study. Any possible questions about the study procedure or the use of the equipment were also answered. To conduct the study as realistically as possible, the subjects were asked to continue with their regular daily routine and to contact the organizers only if they had any questions or problems. The questionnaires to be completed every day were explained and given to the subjects:

- Sleep diary.
- Graphical questionnaire on sleep quality.

The participants used the devices for 14 days. During this time, they were visited every 3–4 days by one of the study organizers (public welfare AWO staff) to check if everything was going well or if there were any problems or questions.

On the last (15th) day of the study, the study organizers collected the technical solutions, and the final questionnaires were filled out together with the participants in the form of an interview:

- Pittsburgh Sleep Quality Index.
- Questionnaire to assess the acceptance of the technologies used, including free-form comments.

All the devices and questionnaires mentioned above are presented in detail in the following sections.

2.2. Subjective and Objective Measurement Using Home-Health Technologies

As mentioned above, one of the study's objectives was to determine whether existing technologies can guarantee results that are sufficiently accurate compared to health-related questionnaires. For this purpose, sleep analysis was selected as an essential health field that can also be monitored in a home environment [30]. There are two significant types of measurement for sleep-related data: objective and subjective [31]. In the case of subjective measurement, the person's perception is measured. Typically, different questionnaires or sleep diaries are used for this purpose [32]. In objective measurement, health-related values are measured with the appropriate sensors [33].

In sleep medicine, subjective measurement is often used to measure some parameters, such as sleep quality in the detection and treatment of insomnia [34]. Therefore, it was essential to determine whether an objective measurement was able to provide results that were comparable to subjective measurement. For this purpose, we compared the two types of measurement over two weeks [31]. We asked the test subjects to fill out a daily questionnaire determining their sleep quality for subjective measurement. For this, we prepared a graphical representation of sleep quality, as shown in Figure 1 [31]. Subjects were asked to mark the spot on the graph that best corresponded to their perceived sleep quality each morning. After collecting the completed questionnaires, the graph was divided into ten sections, and a number between 1 and 10 corresponding to sleep quality was derived.

Figure 1. Graphical questionnaire to determine sleep quality. Reprinted with permission from Gaiduk et al. (2021). © Springer 2021 [31].

The technology that was used to measure objective sleep quality was the EmFit QS+ system [35]. This device has been described and evaluated in several scientific publications [36,37]. It uses a ballistocardiography approach and can measure several sleep-related parameters (such as heart rate, respiratory rate, sleep quality, and identification of sleep stages). One of the important points that was considered when selecting the technology was the possibility of automatic functioning without the need for user action. The following formula, Formula (1), which proposed by the EmFit company and evaluated in several scientific publications, was used to calculate sleep quality [31,35–37]:

$$\begin{aligned} Sleep\ Quality = {} & [(total\ sleep\ duration + (duration\ of\ REM * 0.5) + (duration\ of\ DeepSleep * 1.5) \\ & -8.5 * (0.5 * awake\ duration\ /\ 3600 + number\ of\ awakenings\ /\ 15)]/10 \end{aligned} \quad (1)$$

The result is a value between 0.1 and 10, which can be directly compared to the subjective measurement of sleep quality described above. We conducted and finally evaluated the recordings with the selected device for the two weeks of the study, which is described in detail in the "Results" section. Any other system that provides a measurement of sleep duration [38] and sleep stages [39] could be used instead of the device used to calculate objective sleep quality.

The use of technologies for the subjective measurement of health-related parameters is also possible. For this purpose, technologies (for example, smartphones, smart watches, or tablets) can be used to fill in the questionnaires [40,41]. This can bring advantages in achieving direct and automatic data transmission and evaluation because of the electronic form of the data collected from the first moment. However, this approach was out of the scope of the study performed and could be considered in future work.

We selected sleep analysis as an example field of home health technologies for the study. To address whether this field is relevant for determining health status, we decided to use a recognized method for determining sleep quality. This would allow us to determine if there is an underdiagnosis of sleep-related disorders that could be overcome with the broad approach of sustainable technologies. Our method of choice was the Pittsburgh Sleep Quality Index (PSQI) [42]. It is commonly used for the assessment of sleep quality in sleep disorders, especially insomnia. This is a recognized questionnaire in professional circles and has undergone multiple evaluations [43,44]. We used a German version of the questionnaire proposed by reference [45].

Standardization in the true sense does not exist for the PSQI. PSQI classification results from the cut-off value of 5; it was calculated in the original work [42] based on the classification of people with sleep disorders and healthy individuals. A total of 18 items are used for quantitative evaluation. They were assigned to seven components, each assuming a value range from 0 to 3. The total score results from the summation of the component scores and can range from 0 to 21. A higher score corresponds to a lower quality of sleep. There is an empirically determined cut-off value (of 5) that allows a division into "good" and "bad" sleepers. A representative study for the German-speaking area [46] surveyed 1049 participants. Here, a proportion of 32.1% of the participants had a PSQI total score > 5. This survey might be used to compare the findings within our study.

2.3. Acceptance of Technologies by the Elderly

Since the acceptance of technologies plays an essential role in their widespread use, this aspect was addressed in the study. Based on the literature review, several points were selected to be considered during the implementation period in order to enable an evaluation afterward:

- The technologies should be self-explanatory and should not require extensive training.
- The devices should function automatically as much as possible;
- The devices should be comfortable and safe to use.

To allow a comprehensive analysis, the following methods were selected:

- Surveying with a questionnaire.
- Free conversations with test participants to receive unstructured feedback.
- Systematic analysis of occurrences and irregularities during the study.

In preparing the questionnaire, an emphasis was placed on ease of use, safety during use, and readiness and suitability of the technologies for regular use. It was also planned to analyse whether there were any difficulties with the use of the devices and the reasons for those difficulties. For this purpose, in addition to answering the standardised questions, the test subjects were asked to provide a free comment (related to the respective device) in case of irregularities/problems with one of the devices being used. Questions were asked during the visits that took place over the 14 days and on the last day, together with the final questionnaire.

To evaluate the acceptance of technologies for different health-related concerns, the system was used that not only included the EmFit QS+ sleep analysis device described above but also included the Polar OH1 heart rate monitor. This kind of device (photoplethysmography based on PPG) can be applied to measure stress levels, which was not performed as part of the presented study. Currently, heart rate variability is often used to detect stress [47,48]. However, existing studies have shown that heart rate variability may be often substituted by pulse rate variability (which can be obtained by PPG measurement), especially at rest [49]. Moreover, some studies have presented the possibility of stress detection by analysing pulse rate variability [50]. However, it is important to note that the Polar OH1 device in this study was used exclusively for qualitative and not quantitative measurement and should only represent a wearable that should be placed on the upper or lower arm and that could be used for stress measurement after appropriate analysis. During the study, the OH1 was to be placed on the right upper or lower arm daily for a fortnight. When the sensor was close to the provided smartphone with the app installed and when new data were available, it paired with the application, and the data were collected for future analysis. The test subjects only had to place the sensor on the upper arm and turn it on by pressing a button. It was also necessary to charge the sensors at night. No other actions were required from the test subjects.

3. Results

After the quantitative analysis of the sleep measurement as well as the qualitative analysis of the devices for both the sleep and heart rate measurements were conducted, a set of results was obtained, which are presented below.

The difference between subjective and objective sleep quality measurement was analysed. Figure 2 shows a corresponding box plot diagram for the ten participants. The vertical axis represents the average differences between subjective and objective measurement for all of the subjects who participated in the study. We can see a clear tendency to underestimate subjective sleep quality compared to the value measured with the electronic device. This underestimation remains relatively stable, with a median value of approximately 13% and a mean value of approximately 10%. However, there are also individuals for whom the difference between objectively and subjectively measured sleep quality is notably more significant. This fact should be taken into account when planning the use of technologies to measure sleep quality. For two subjects, there are significant differences in the number of objective and subjective measurements available. For these subjects in particular, there can be discrepancies in the evaluation of the differences between the subjective and objective measurement, which can also lead to some variation in the results. With the total number of available recordings (115–objective and 90–subjective), it is nevertheless to be assumed that the results are also transferable to the overall population, which is also confirmed below with the calculation of margin of error.

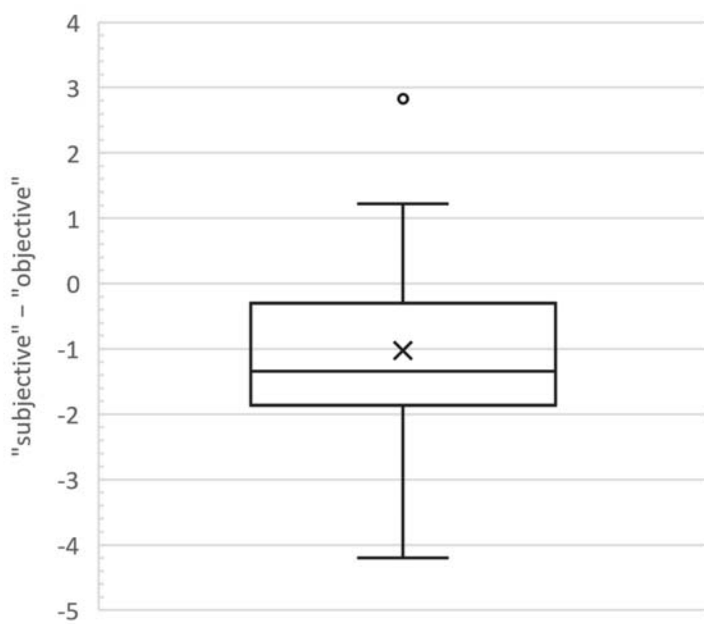

Figure 2. Analysis of the differences between objective and subjective measures of sleep quality for ten subjects. Negative values—subjective sleep quality is underestimated.

To give an idea of the possible differences between objective and subjective measures of sleep quality, the comparison of the measured values (possible values are in the interval from 1 to 10) for a subject with the most significant differences participating in the study is shown in Figure 3.

It can be seen that the median value of sleep quality for the total two-week study period is more than twice as high for the objective measurements taken with the help of an electronic device (approximately 9.2 points of sleep quality) than it is for the subjective measurements taken with the questionnaire (approximately four points of sleep quality). When analysing these results, one can identify two main reasons for this difference: firstly, if there is a large difference between the number of recordings available for both (objective and subjective) measurement methods, then there is more a likelihood that the difference that is measured is greater; secondly, since different parameters are measured in the objective and subjective measurements, the perceived sleep quality may differ significantly from the measured one because measurement with a device cannot take into account all aspects that have an impact on human perception. People typically do not divide sleep quality into the sum of parameters but perceive an overall impression.

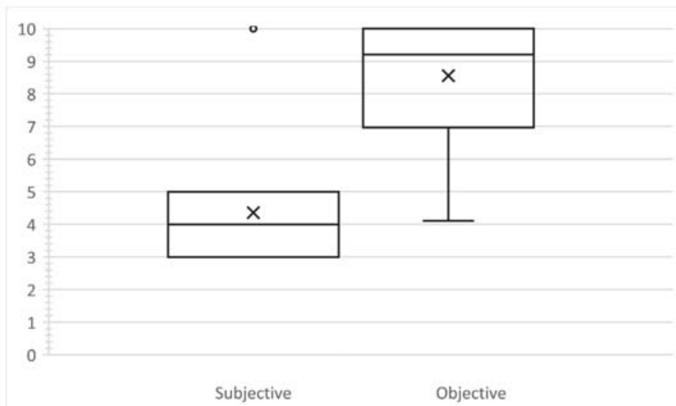

Figure 3. Comparison of subjective and objective measurements for a subject with the most significant differences between two measurement methods.

The results of the PSQI survey are shown in Table 1. From this, it can be seen that there were significantly more people identified themselves as "bad" sleepers than in the previous study reported in reference [46]. There may be several reasons for this, such as:

- The study by reference [46] analysed a broad demographic. In our study, only subjects over 65 years of age were included. Therefore, the results may differ significantly due to the different age groups.
- About 20 years has passed between the study conducted by reference [46] and our study. During this period, the prevalence of sleep-related disorders may have been changed.

Table 1. PSQI screening results.

PSQI Value	Percentage
≤5	40%
>5	60%

The results of the interviews that were conducted at the end of the study are presented in box plots in Figures 4 and 5. Furthermore, the results are analysed and discussed in the following text.

As a result of the analysis of the box plots in Figure 4, the following conclusions can be drawn:

- There was no agreement among test participants on whether they would use the devices regularly. It should be noted that the devices were used over a two-week period, which, among other things, means that the subjects did not have long-term experience with the devices and therefore could not assess whether they would use the devices regularly in the long term well.

- The questions regarding the complexity of the devices, ease of use, and the need for support to use the devices, there is a clear trend in the answers, which is more in favour of the devices being relatively easy to use independently without external support. Moreover, despite the novelty of these types of devices for the subjects, no unnecessary complexity was perceived. According to the technology acceptance model, these points indicate that the proposed concept can increase acceptance [51].

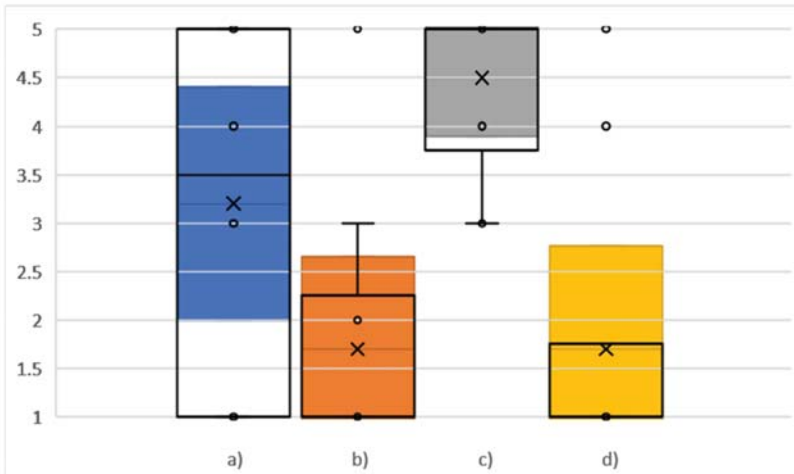

Figure 4. Box plot of the interview results. 1—totally disagree, 5—strongly agree: (**a**) I can imagine using the devices regularly. (**b**) I find the devices to be unnecessarily complicated. (**c**) I find the devices easy to use. (**d**) I think I would need technical support to use the devices.

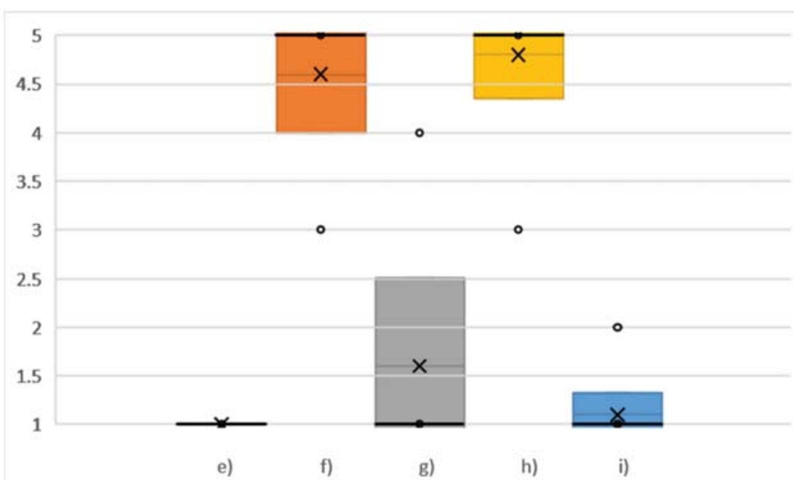

Figure 5. Box plot of the interview results. 1—totally disagree, 5—strongly agree: (**e**) I find that there are too many inconsistencies in the devices. (**f**) I can imagine that most people learn to handle the devices quickly. (**g**) I find the operating of the devices very complicated. (**h**) I felt very safe using the devices. (**i**) I had to learn many things before I could handle the devices.

Analysing Figure 5, one can see that at several points, an obvious conclusion can be drawn that:

- The subjects do not believe that there are too many inconsistencies (confusing or unclear functions or components) with the devices utilized.
- According to the subjects' opinions, the majority of people can quickly learn how to handle the devices.
- The operation of the devices is not very complicated according to the subjective perception of the test participants. However, it should be noted that several people noticed some irregularities in the functioning of the proposed devices, which are described in detail below.
- There was no concern about safety while using the equipment. This means that the perceived risk of using the technologies was relatively low, which according to references [52,53], is essential for the acceptance of technologies.
- It was possible to use the devices without having to learn much new information beforehand. In summary, from the answers to question (e), question (b), and question (c), it can be concluded that the presented concept, where the subjects had to interact with the devices as little as possible, gives a sense of simplicity to users, which can also lead to an increase in the acceptance of such systems [54–56].

When interpreting the results obtained from the surveys, it can be said that the two-week study periods provided the test subjects with sufficient information to be able to assess the ease and safety of using the devices, which can be seen from the fairly clear answers. On the other hand, the strong variance and tendency towards "not sure" in the answers to the question of whether the test participants could imagine using the devices regularly shows us that a significantly longer period of use or familiarization is necessary in order to obtain a clear answer to this question.

Another point that can be observed is the fact that there is at least one outlier in the majority of answers to the questions. There may be different reasons for this. One of them is that it is possible that some questions were misunderstood, resulting in a reverse answer being given. For example, instead of "strongly agree", the answer becomes "strong disagree". This could be caused by the fact that some questions deliberately include two variants in questionnaires to make sure that people answer the questions consciously, the so-called control mechanism. In individual cases, it can lead to misunderstandings or show us that people answer some questions without understanding them precisely. In general, however, it helps to exclude the questions that are not carefully considered by the participants before answering to be excluded from the analysis. Another explanation for the presence of the outliers could be the fact that the individual rare occurrences with the devices, which only happened to a single person, led to this being very distinct from the majority opinion. This could be, for example, a technical malfunction that only occurs once to one person.

A total of 10 participants participated in the study due to the targeting of a specific group of users and the use of not only questionnaires but also the use and installation of the hardware for several devices to be used over a fortnight. Considering this fact, the question arises as to whether the difference to the expected results by the entire population would differ greatly. This point needs to be subject to deep scientific discussion in order to make a well-founded statement. In the following, this question is analysed and supported by statistical evaluation.

To forecast a maximum possible deviation between the results of a study carried out with a sample (ten people in our case) and the entire population, the parameter called "margin of error" is typically used. We have also followed this scientifically recognized approach. According to references [57,58], we calculated the value of the margin of error for each question. For that, (2) was used:

$$d = t\sqrt{\frac{N-n}{N-1}}\sqrt{\frac{S^2}{n}} \tag{2}$$

where t is the Student's t-critical value for normal distribution, N is the size of the population, n is the sample size, and S is the population standard deviation.

Considering the fact that the population size is substantially larger than the used sample size, $\sqrt{\frac{N-n}{N-1}}$ tends towards «1». Due to the impossibility of calculating the standard deviation of the entire population, S can be replaced by s (standard deviation of the sample). Taking into account the mentioned factors, Equation (1) can be transformed as follows:

$$d = t\frac{s}{\sqrt{n}} \quad (3)$$

The t value for the sample size of 10 with 9 degrees of freedom and for the significance level $\alpha = 0.05$ (for the confidence level of 95%) can be found in the corresponding table and is equal to ± 2.262156 (two-tailed). Knowing this, the margin of error for every question was calculated with Equation (2).

The results with a confidence level of 95% are presented in Table 2. The possible range of a mean value for the entire population according to the calculation of the margin of error is represented in Figures 4 and 5, with a coloured rectangle representing each question. Analysing that, even in the case of the maximum possible deviation of the mean value for the entire population from the sample mean according to margin of error calculation, for all of the interview questions except for "I can imagine using the devices regularly", the values still indicate clear agreement or disagreement with the corresponding question, which was also the case for the sample from the current study. This is due to the fact that the responses are very homogeneous and provide us with a clear picture, even with the available number of test persons. Out of that, taking into account the performed margin of error calculation, the results of the study conducted with 10 subjects may be extrapolated to an entire elderly population and can provide a significant scientific added value due to the clear and explicit distribution of the responses. Therefore, it can be stated that no meaningful difference in the results is expected in cases where the study is performed with a large sample size, even for the entire population.

Table 2. Margin of error calculation.

Measure	Question								
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
SD	1.6865	1.3375	0.8498	1.4944	0.0000	0.8433	1.2649	0.6325	0.3162
Mean	3.2000	1.7000	4.5000	1.7000	1.0000	4.6000	1.6000	4.8000	1.1000
Sample standard error	0.5333	0.4230	0.2687	0.4726	0.0000	0.2667	0.4000	0.2000	0.1000
Margin of error	1.2065	0.9568	0.6079	1.0691	0.0000	0.6032	0.9049	0.4524	0.2262

Similarly, the margin of error value can be calculated for the obtained difference between objective and subjective measurement. Performing the calculations according to (3), the margin of error for this measurement with 10 subjects is equal to 1.35, which means that for a 95% confidence level, the mean value of difference for the entire elderly population would be within the interval −2.37–0.33 (−1.02 for the sample of 10 subjects). This means that even in the case of the maximal possible deviation of the mean value of the difference between the objective and subjective measurement, there will still be a clear correlation between these two methods of measurement for the entire population, and the difference will be between 3.3% and 23.7% (0.7–21.1% for a 90% confidence level). This allows one to extrapolate the results of the study conducted with 10 subjects to the entire elderly population with the confidence level mentioned and by considering possible deviations. Based on a statistical evaluation performed using the margin of error calculation, the study results with 10 subjects provide high qualitative and scientifically significant results. It is also important to mention that although only 10 subjects participated in the study, the total number of test nights for the calculation of the difference between subjective and objective measurements was equal to 140, which is a significant number and also increases the reliability of the results that were obtained, as the exact number of evaluation nights (and not only the number of subjects) is relevant for the calculation of the differences between the two types of measurement.

Although the survey results have shown that test persons see the proposed technologies as easy to use, some irregularities can be observed when analysing the available recordings. As shown in Table 3, neither for the objective measurement nor for the subjective measurement of sleep quality are all recordings for all 14 days of the study available.

Table 3. Availability of measurements per person (study duration—14 days).

Measurement	Subject									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Subjective	8	10	14	9	11	13	7	7	5	6
Objective	7	6	14	14	14	14	9	10	13	14

If we visualize the number of available recordings as in Figure 6 and analyse them, we can see significantly more recordings with the objective method. This is because the test participants did not have to make any extra effort. After all, the device automatically took recordings. In the case of subjective measurement, the subjects had to tag a perceived sleep quality on their own. However, even in terms of the objective measurements, there were some days where there were no recordings. According to the interviews that were conducted, there were two main reasons for this: the subject did not sleep in the bed that night, or the device was turned off from the power socket, which was not necessary but allowed. Sometimes, as the subjects self-reported, they forgot to plug the device back into the socket before going to bed.

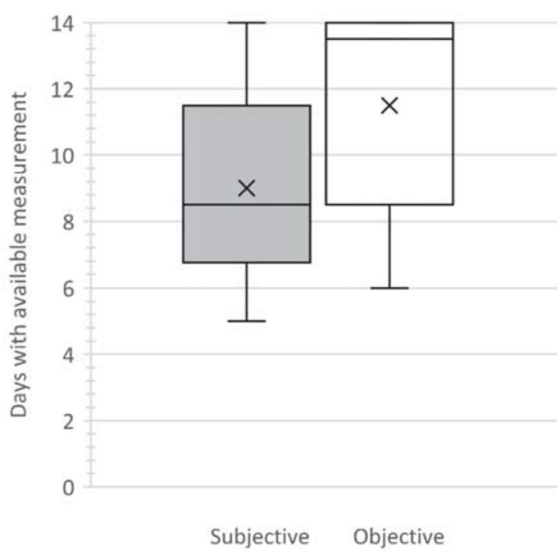

Figure 6. Box plot representing the number of days with available measurements for all subjects for both approaches.

There was only one person who filled out the questionnaire on all 14 days. All of the device recordings were also available for this person. Furthermore, although the questionnaire was created, there was an attempt to make it as simple and as motivating as possible. That is why the graphic form was chosen. It follows that the more effort a method requires from the user (even if it is minimal), the more incompleteness there will be in the data collected.

It is important to address the fact that there is a certain imbalance between the number of objective and subjective measurements in order to assess whether this led to a distortion of the results when evaluating the differences between the objective and subjective measurements presented above. We have a total of 115 nights for the objective measurement and 90 nights for the subjective measurement, which corresponds to a difference of only about 20%. For the majority of people, there are more objective measurements than subjective ones. However, it is important to note that there are also people who have more subjective measurements than objective ones, which means that the differences in evaluation can exist in both directions, but this affects the overall evaluation less than a one-sided shift in the number of measurements. Since the total number of nights is significant (as there is an imbalance exactly in the number of night measurements and not in the number of subjects) in our study and since the evaluation is already statistically significant both at 90 and 115 nights independently, it can be assumed that this imbalance only plays a minor role in the overall evaluation. Another important point is that the difference in the number of subjective/objective measurements is relatively small for most subjects. Only in two subjects (9 and 10) are significant differences present in the number of objective and subjective measurements. These two subjects are mainly responsible for the imbalance (18 out of 25 nights of total difference). With these subjects in particular, there are indeed discrepancies in the evaluation. However, the overall evaluation should remain statistically significant.

Another important finding is that 50% of the test subjects noticed anomalies in the functioning of the home health devices. After a detailed analysis of these reports, it turned out that the main reason for this was the Polar OH1 heart rate measurement device. There were two main problems with it:

- Firstly, the switching button was tiny and partially placed in the device's body. This made it difficult for the subjects to press the button, especially when their fine motor skills were not perfect.
- The second problem was the lack of direct feedback from the device. Therefore, the test subjects did not immediately recognize whether the device was already switched on or not. After evaluating the test results, we found that several recordings were only a few seconds long. This means that the subjects switched on the device, but because they were unsure whether it worked, they tried to switch on the device again, which eventually led to the device being turned off.

It is important to note that the evaluation mainly tried to cover the general points that would also be transferable to other technologies, e.g., the automatic functioning of the system without the need of user actions or the need for feedback from the device will be equally relevant for other technologies. Nevertheless, it is not excluded that, in case of using another system, there may be some differences, which are also listed further in limitations.

4. Conclusions

The study allowed us to collect and analyse relevant data on the use of technologies for older adults. Several conclusions that provide new information to the scientific community can be drawn from the evaluation and are presented below.

One of the questions to be addressed in the study framework was whether an objective measurement with an electronic device could replace a subjective measurement of sleep quality, which is typically conducted through the use of a questionnaire. The analysis that was carried out confirms the possibility of this substitution when it comes to evaluating the sleep quality of a group of people and when the overall average result is of interest. For example, it could be used to conduct a comprehensive study of sleep quality in a region or among a specific subset of people. Considering the accuracy obtained for each person, a substitution is not recommended because it has been shown that the differences between the two measurement methods may be extreme in some infrequent exceptional cases. It is important to note that the results of the study do not mean that a subjective measurement will produce more accurate results. It only means that in some people, the results will differ significantly, and in the practice of sleep medicine, a subjective measurement of several sleep parameters has been the most commonly used method (e.g., for the detection of insomnia [59]). Therefore, this method is a standard procedure, and because it has been used for such a long time, health care professionals have a great deal of experience in evaluating and interpreting these kinds of measurements. For some other measurements, objective measurement methods are used in sleep medicine, for example, for the detection of sleep phases [60]. Therefore, a combination of subjective and objective measurements can currently be recommended to obtain a comprehensive analysis of sleep that includes its different characteristics.

Another critical point examined in the study is whether the elderly are comfortable with the existing technologies for measuring health-related parameters and which aspects should be considered when implementing home health systems.

The concept of implementing the technologies created for the study had a few key points:

- The use of devices that required minimal action on the part of the users. For example, no actions are required except (voluntary) for the unplugging and subsequent re-plugging of the sleep analysis device into the power socket. In the case of the device measuring heart rate during the day, only pressing a button was necessary, and the evaluation of the study showed that even this minimal necessary action led to problems. A possible solution would be to use a device with a more prominent and easier-to-use button to turn it on.
- The technologies should be self-explanatory, and no complex training or support from a third person should be necessary. This goal was achieved according to the results of the interview, as explained in detail below.
- When using electronic devices, there should be a sense of safety. This means that the devices should not contain any parts that could be considered dangerous. Additionally, users should be assured that when using the technologies, they cannot be easily broken. For this, the devices should be robust enough and have as few as possible easily breakable parts.

Another point that was not considered when planning the concept, but which became apparent during the evaluation, is that direct feedback from the devices to the user would increase the feeling that the device was working correctly. This would also help to avoid certain operating errors. The experiences during the study are in line with the usability heuristics known from reference [61].

A significant result was obtained when subjectively measuring sleep quality with PSQI—60 % of the test subjects were identified as "bad" sleepers. This clearly shows that the broad use of sleep monitoring technologies would enhance early diagnosis because many test subjects were not even aware that they might have sleep problems that could be treated. Additionally, currently, when the constant development of technologies and algorithms allows new and less invasive methods to detect sleep stages [62], it is possible to make this early detection easier and more convenient for users.

By directly comparing objective and subjective measurement methods, it can be seen that in the case of automatic measurement using technologies, it is possible to expect better data completeness and consistency than the manual filling out of questionnaires. This may ultimately lead to more relevant data being collected and analysed early, improving the quality of life and possibly the users' health.

The test subjects used the provided devices for a fortnight and finally gave their assessment during an interview. The results allowed us to conclude that the proposed concept is a successful model in terms of the simplicity of independent device operation o and a sense of security when using them. However, the test subjects were not sure as to whether they would use the devices regularly. One explanation for this is that the benefits of using these devices are not always clear to the subjects—there was feedback that they did not think that using these devices would improve their quality of life. To overcome this barrier, a sustained educational effort is needed to communicate clearly and understandably the potential benefits the elderly population using such types of technology. Without this development of motivation to use the technologies, widespread use is complicated, even though handling is not necessarily a big problem, as the conducted study has shown.

There are some limitations in the work presented:

- Only a few technologies could be used and evaluated within the study framework. Therefore, it cannot be excluded that the results could deviate with a different selection of devices. However, it is always necessary to select a specific subset of technologies because it is impossible to test all available devices at once.
- The number of test subjects was limited to 10. In order to obtain statistically relevant data, the period of 14 days was chosen for the study, resulting in a total of 140 person-days of study. In addition, the same proportion of male and female test subjects was ensured. Furthermore, the proposed study contained a certain type of usability testing, which included questionnaires and a free-form interview to understand if there were any problems with the usability of devices. According to reference [63], only 10 $\pm$ 2 subjects are necessary to discover 80% of usability problems. Moreover, the analysis of the transferability of the results to the entire population of persons aged 65 and older with the approach of the statistical parameter "margin of error" was carried out and presented in the section "Results". The margin of error scientifically confirmed the significance of the results that were obtained.
- Since the study target group was people aged 65 years of age and older, the results cannot be directly transferred to other age groups.
- The technologies were not connected to a common platform that could be accessed by the participants directly. Therefore, it was impossible to assess whether the possibility of directly viewing the results of the recordings by the test subjects could have a positive impact on acceptance.

To overcome the limitations mentioned above and to gather additional valuable information, the next step could be planning and organizing a new extended study. This could involve more subjects and could allow a wider range of technologies connected to a common platform to be tested. Furthermore, further work could be conducted on the selection and design of questionnaires for the collection of relevant data for analysis.

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Empirical Study of Virtual Reality to Promote Intergenerational Communication: Taiwan Traditional Glove Puppetry as Example

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Abstract: Based on glove puppetry, a traditional cultural pursuit of Taiwan, this study designed a virtual reality (VR) intergenerational game to bring together the elderly and young participants. In the game, a system of cooperation and sharing was constructed which would lead to an exchange between experience and knowledge of traditional culture and digital technology and result in intergenerational interaction and communication learning. Through interviews with eight subjects after the empirical study, this study explored the operation and experience of this game, the perception of interaction and dialogue, and the cultural heritage and learning. According to the research findings, VR game cultural elements and technology learning positively influence intergenerational relations and communication. Key factors of VR intergenerational games include the following: (1) the game content must be attractive for the elderly; (2) the operating procedure of the game and affordance of the interface for the elderly must be simplified; and (3) the game must establish a sense of achievement for players.

Keywords: intergenerational game; intergenerational communication; VR game; cultural heritage; older adult digital gap

1. Introduction

Through a digital-technology-based virtual reality (VR) game, this study creates the design elements upon "Glove Puppetry" with the characteristics of the traditional art of Taiwan in order to improve the elderly's digital gap and enhance the elderly's interest in digital games. Elderly people play the role of passing on their experience and knowledge and guiding the younger generation to approach the traditional culture of Taiwan. The learning and instruction of the intergenerational interaction enhance the connection between the elderly and digital technology and lead to cultural heritage and intergenerational interaction.

With the progress of medical technology and social care in Taiwan, the average age of the elderly population has continued to increase. According to the Department of Statistics under the Ministry of the Interior, Republic of China (Taiwan), in 2021 the elderly population above 65 years old in Taiwan reached 3,804,000 people and the percentage was 16.2% of the total population. It has passed the threshold of an "aging society" as defined by the United Nations [1]. Thus, the challenge of Taiwan in an aging society refers to the life quality and care of the elderly. Change in family structure, in particular, has lowered the connection between the elderly and other generations, and life after retirement influences one's social connections and mental health. During the COVID-19 pandemic, digital technology has not only provided more precise and convenient medical support but also enhanced people's dependence on and demand for digital technology in their lives. Aging is a globally important issue, and the elderly's positive psychological development via digital technology will result in positive returns for the economy and their health [2].

According to research, a person's social environment influences their use of the Internet. Thus, with the encouragement of family and friends, the elderly can effectively increase the use of digital products such as the Internet, and their personal learning motivation will be more significant than learning in other courses [3,4]. In addition, digital games will improve the elderly's psychological and physical health. From the perspective of business, the elderly are an enormous potential market, but up to now most of the present digital games in the market cannot satisfy the increasing demand of this demographic. Thus, there is an enormous potential market for game designers [5]. The elderly are anxious and unfamiliar with new technology, and the operation and use of it are challenging. However, more than 30% of elderly people suggested that they were interested in the upgrading of their use and abilities with new technology [6], and they expected more learning opportunities to obtain new knowledge of technological applications [7,8]; different measures should thus be more actively developed to cope with the intergenerational gap.

The convenience of digital technology serves as a connection between the elderly and families and friends, establishing new relationships and allowing the elderly to search for information related to community activities [9]. Technological training for the elderly reinforces the cohesion of teams and connection among families who have not lived together as well as among friends [10]. For healthy seniors, learning and using social networks enhance their participation in social activities, maintain and improve cognitive functions, and reveal the advantages of online social networks [11]. In the future, the use and progress of the elderly of social technology (such as e-mail and Skype) can strengthen their social connection in old age. Other kinds of technology such as smartphones and virtual assistants change elderly people's management and communication of personal daily activities. VR experience, artificial intelligence, and robots are the directions of technological application to enhance social connection and avoid social isolation [12]. Digital games are recognized as serving to effectively improve and cope with various symptoms of elderly adaptation. Encouraging the elderly to develop physical and mental health and delay illness reinforces their quality of life [13]. According to the overall trend, VR effectively improves the quality of life of the elderly and positively influences their health, social life, and emotion. It is a potential field for further development [14].

According to the "cross-strait elderly life survey" of the Industrial Technology Research Institute (IEK Consulting) in 2010, as to the ideal model of "domestic life" for the elderly above 50 years old in the ranking of the first 40% of monthly income, percentages of "living alone" and "living with spouses" increased significantly; in addition, percentages of "living with other seniors in institutions" and "living with children" successively decreased. This thus shows that if the elderly can live independently, then local aging and living alone will be the future trend. In addition, the domestic life of the elderly has changed, and the percentage of living with children is down. Digital technology such as smartphones has accelerated the elderly's use of technological products, such as laptops, tablets, and others, which have become important tools to contact families and have replaced traditional telephones.

Intergenerational learning is an important measure to preserve culture and historical tradition. It passes on knowledge from the elderly to the younger generations. Continuity of intellectual property rights is extremely important in intergenerational education [15,16]. Interaction between different individuals is mostly based on communication among the same ages. Intergenerational communication can be associated with internal and external interactions of families (such as the interaction between young people and children, and the interaction between middle-aged people and grandparents and grandchildren). At different stages of life, there are different kinds of communication, goals, demands, and behaviors, and so there can be a communication gap [17]. Thus, technological experience not only triggers the topics and interests of different generations but also reinforces interaction between the generations and sustainability of the intergenerational relationship. In the concept map of the intergenerational game developed by Agate et al. (Figure 1), the priority of the game's process is to promote participants' motivation. By constraints of the content, participants can obtain points and achievements in the process; by different functions of the game content and learning of technological use and rules, the participants acquire benefits through different processes of games [18].

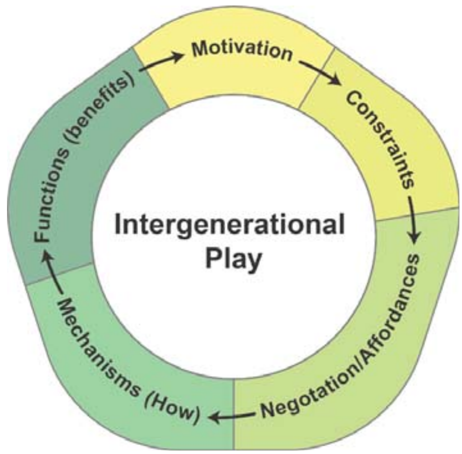

Figure 1. Concept map of the intergenerational game. (Re-drawn for this study.)

Previous related research has established that digital technology has a positive impact on the elderly in many respects, including but not limited to health, medical care, communication, etc., and bringing more convenience [19–22]. Digital technology has not only effectively improved the quality of life for the elderly, but also allowed them to maintain social connections and introduce new learnings and topics into their life. However, in the application of intergenerational communication, there is an issue in the understanding and usage of digital technology by different generations, and it has a certain influence on the digital divide of the elderly. With the advance in digital technology, most elderly maintained the habit to approach and comprehend new technology with the support of family and friends; they learn actively and use new technology in their lives. Therefore, when the elderly, who are not familiar with digital technology, interact and communicate through digital technology with the digital generations, i.e., those born into or raised in the digital era, it may bring about the opposite effect [23–25].

The purpose of this study is to explore whether we can leverage the elderly's deeper understanding of traditional culture to reduce the imbalance and digital gap in the application of digital technology to intergenerational communication. Thus, for this research, we designed a VR game in the theme of Taiwanese puppetry, connecting with local culture, dialect, and history to interest and entertain the elderly, and reduce the sense of rejection to using and learning digital technology. Meanwhile, storytelling and interactivity is also explored in gaming, to determine whether it can create a more relaxed experience, and achieve knowledge sharing and learning regarding cultural inheritance and digital technology between the elderly and younger generations. According to the research purpose, the following research aims are formulated: (1) to discover how an intergenerational program can be properly applied to a game design for the elderly and younger generations; (2) to explore the model of a VR interactive game, which shows Taiwanese culture for the elderly and intergenerational interaction; and (3) to assess the possibility of applying VR in an intergenerational program and providing research development for the interaction and design of future intergenerational programs.

2. Design of VR Intergenerational Game

According to the literature, a proper intergenerational program can successfully enhance intergenerational communication. The game developed by this study focuses on the communication and interaction of different generations. Thus, the game's interaction becomes an extremely important design core. From the scenes of the game, the elderly can recall their childhood, and the younger generation can approach the culture and history of Taiwan through its content. The research design (Figure 2) and game characteristics are shown below.

(1) The setting is the temple square from 1951 to 1961, and thus the elderly can return to the time of their childhood through the game.
(2) It selects the waning traditional open-air theatrical performance culture. When the younger generation operates the game, they approach the development and charm of traditional glove puppetry culture at that time and the initial heritage of traditional culture.
(3) The interaction of VR integrates teamwork, instruction, and communication to learn about different generations and constructs intergenerational interaction and communication.

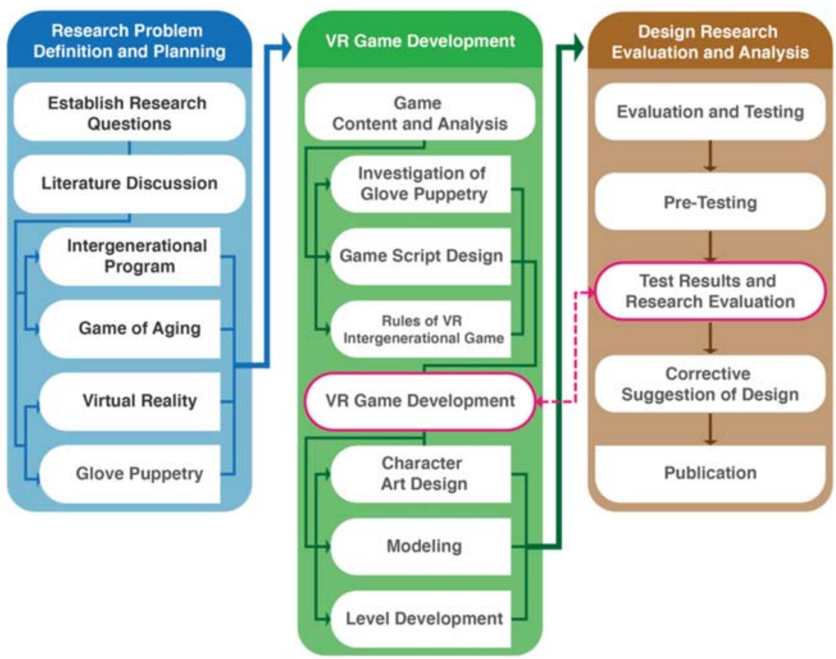

Figure 2. Research design.

The setting of the game is based on an open-air theatrical performance in Taiwan in 1951. According to the traditional stage and environment of an open-air theatrical performance (Figure 3), this study designed the classical plot of the Legend of the White Snake as the theme of the performance. The art design was based on the Song Dynasty. According to the wooden puppet model of traditional glove puppetry, this research designed the appearance and costumes of three important puppets (Figure 4). Virtual puppets are operated by the VR hand gesture function. Thus, the subjects could be immersed in the performance of glove puppetry.

(**a**) (**b**)

Figure 3. Inside and outside views of open-air theatrical stage (the reality of a VR game). (**a**) Game login interface, (**b**) Game teaching screen.

Figure 4. 3D character design of virtual puppets (from left to right, Fa Hai, White Snake, and Hsu Hsien).

3. Empirical Study

In order to recognize the intervention effect of intergenerational game programs, this study recruited four groups of intergenerational subjects, including eight people. In each group, there was one young adult below 35 years old with VR and digital game experience and one senior above 60 years old with experience and interest in the glove puppetry of Taiwan. The subjects' education and gender were random (Figure 5). The subjects were selected by purposeful sampling. In addition to meeting the age requirement, the subjects must live and move independently with good physical and mental health. The logic and validity of sampling aimed to select cases with rich information. According to the goal setting on subjects, this study selected proper cases for the research while considering whether they could provide much important information.

Figure 5. Experience of the game during the empirical study.

The whole empirical study and interview lasted for 80 min, and the game experience was 40 min. Since VR mainly serves as a short-time display experience, each VR game lasted for 15 min. There were eight subjects; A to D refer to different groups, and the coding was anonymous. This study included six female and two male subjects. In each group that participated in this empirical study, there were young adults aged 20~35 and elderly aged 60~75. The subjects were relatively familiar with digital products and could operate them. However, they were not required to possess profound experience or knowledge of VR technology or gaming. Basic information of the subjects is shown in Table 1.

Table 1. Basic information of subjects.

Codename	Gender	Age
A01	Female	66
A02	Female	25
B01	Female	67
B02	Female	30
C01	Male	70
C02	Female	27
D01	Female	60
D02	Male	23

Data collection of this study aims to focus on the interaction of the group in which the elderly and young people experienced the game of VR glove puppetry. The study adopted a semi-structured questionnaire design and collected data from the experience of individual subjects by intensive interviews.

(1) Depth interview: Through a data collection strategy and method of qualitative research and semi-open-ended questions, the study conducted in-depth interviews with the subjects. During the interaction with the subjects, the researcher maintained sensitivity to explore the topics in order to profoundly recognize the subjects' various kinds of perceptions regarding the use of the device as well as the operation and experience of the game during the empirical study process to further describe the facts. Thus, in the phase of data analysis, this study was able to more properly interpret the perception and significance from the subjects' perspectives. During the process of the interviews, the researcher defined themselves as an observer. By open and flexible data collection, this study fully used the subjects' immediate problems and the characteristics of different cases.

(2) Semi-structured questionnaire: In the interview with the subjects from different groups, the researcher adopted an open-ended interview and the subjects recalled

and described their various kinds of perceptions, problems, or difficulties from the beginning to the end of the empirical study. When the subjects could not properly describe the problems, the researcher tried to help simplify the description or guide the cases and confirm the origin of the descriptions. The questionnaire of semi-structured interviews aims to result in clearer and smoother questions in the previous interview process, and it validated that subjects' views and perceptions were collected by the questions (Table 2).

Table 2. Questionnaire of semi-structured interview.

Items	Dimensions	Interview Questions	
1.	Operation and experience of the game	a.	Is there a difference between the operation of VR glove puppetry and realistic puppets?
		b.	In the game using the VR device, what were your physical perceptions and experiences?
		c.	Which parts of the game should be improved? What are the problems?
2.	Perception of interaction and dialogue	d.	What was the interactive content in the game? What impressed you the most?
		e.	In the interaction and communication elements of the game, what were the experiences and perceptions that do not exist in real life?
		f.	Did you enjoy the interactions in the game? Why?
3.	Cultural heritage and learning	g.	Through the game's model and content, did you approach the traditional culture of glove puppetry?
		h.	In the VR game, were there new cultural experiences or knowledge learning?
		i.	Did you enjoy cultural or related knowledge learning by the VR game? Why?

The design of the interview items focused on the following research purposes: (a) whether the intergenerational program was properly applied to the game design for the elderly and younger generation; (b) exploring the problems and advantages of applying VR games to the elderly; (c) exploring the model of VR interactive games of Taiwanese culture for the elderly and intergenerational interaction; and (d) assessing the possibility of applying VR to intergenerational programs and to serve as a reference for research development for the design of future intergenerational programs. Thus, the topics of the interviews were based on VR devices, the design of the user interface, pair game cooperation, and reflections and experiences after using the game.

4. Analysis

As to the result of coding, this study adopted the Cohen Kappa coefficient. Analysis of two researchers' coding results showed that 0.6 was a stable and reliable standard. According to the selective coding result from the grounded theory, through triangulation, this study cross-checked with other researchers to validate the consistency and objectivity of the analytical results. The analytical process of the three phases is shown below (Table 3).

Table 3. Three phases of categorization in oral analysis.

Phase	Process	Number of Encoding
1	Open Coding	305 Concept Tags
2	Axial Coding	11 Category Items
3	Selective Coding	5 core categories

(1) Open Coding: At the phase of open coding, the main purpose was to obtain concept tagging and search for concept titles by transcription. The process to categorize data reduced a great number of words and screened the related data content. According to the transcription of the eight subjects, in the first phase of open coding, this study was organized into 305 concept tag groups.

(2) Axial Coding: The analytical process mainly generalized the correlation among the previous categories. By the structural method, it re-connected and integrated data that facilitated the searching of related clues. In categorification, it searched for keywords and similar questions allocated as axial coding. Axial coding of the second phase in the first categorification included 27 categories. However, after triangulation, this study realized that it could further generalize the keywords and questions. Thus, part of the open coding was reduced and combined into 11 categories. For instance, the same questions with different descriptions were combined. The coding content that was not related to this study and could not be allocated in the 11 categories was deleted (Table 4).

Table 4. 11 Category Items.

Items	Subcategory
1	VR puppetry games can effectively enhance intergenerational communication and improve parent–child interaction
2	The game theme affect the topicality and resonance during intergenerational communication
3	Younger respondents express interest in playing games with the elderly
4	Young respondents take the initiative to help the elderly to solve problems without getting bored
5	Deepening younger generations' understanding of the value of cultural heritage from puppetry culture and traditional society while playing
6	The elderly need clear instructions and game guidance functions
7	The elderly enjoy playing with younger generations, but are also prone to stress and lack of self-confidence
8	Elderly people enjoy puppetry-themed VR games
9	Insufficient feedback during gaming affects the immersive experience
10	Interruptions during gaming cause frustration and an unpleasant gaming experience
11	Most respondents are more sensitive to the sense of space in VR games and are easily stressed

(3) Selective Coding: Selective coding is the process of generalizing and refining grounded theory. By the systematic method, different categories are clustered into larger ones as core categories. Thus, in the original 11 categories, the study reviewed the context of the categorification and proposed five core categories: (a) the elderly needed more specific instructions of the operational process; (b) the elderly were not confident in the process of the intergenerational game; (c) related themes of the game effectively enhanced intergenerational communication and parent–children relationships; (d) the spatial visual gap was an important factor in the VR game design and influenced the

sense of equilibrium of space; and (e) the sound and action feedback of the VR game were important factors of game experience.

During the analysis of oral data, an interesting phenomenon was found. Before playing games, most of the elderly had common views: they felt more pressure playing with younger generations, because they may not be patient with them (C01Q3-3, A01Q8-4, D01Q3-2); they lacked of confidence and initiative when new to a game (B01Q8-1); they were resistant and worried about not being able to keep up with other players and causing trouble; and generally, they felt that they were not suitable to play with younger generations (A01Q8-2, D01Q3-3). However, experiencing the game brought unexpected surprises to the elderly: they were very willing to play games with younger generations, especially when given assistance (B01Q8-2, C01Q7-2), and once familiar with the controls they found it to be more enjoyable (A01Q9-2).

Although most younger generations had no experience playing games with the elderly, they enjoyed the experience and felt a great sense of accomplishment (B02Q8-3); they were willing to take the initiative to assist the elderly to quickly familiarize themselves with the game and interact like friends (A02Q7-7, C02Q8-1, D01Q3-5). With guidance, the elderly could become familiar with most of the game functions in a short period and feel that the operation of puppets was very realistic, allowing them to quickly understand how to operate the game (B01Q2-3, A02Q6-1). After becoming familiar with the game, several elderly people not only gradually showed improvement in their self-confidence, but even took the initiative to teach the young people how to walk and perform with the Taiwanese puppet and share stories about puppetry culture (A01Q7-5, C01Q4-5).

In addition, most respondents expressed that in wearing VR glasses for the first time, they felt more sensitive and uneasy in visual space, afraid of colliding or falling, and unable to easily grasp the sense of space (A01Q4-13, A02Q4-9, B01Q5-2, C01Q5-1~7, C02Q2-2, D01Q5-1). However, after an adaptation period, they could focus on the immersive game environment, and felt the operation of the game getting easier and simpler (A01Q9-2, C01Q3-5, B01Q2-3, A02Q6-1). Even elderly respondents suggested in the interview that virtual puppets could have more complex or realistic dynamic effects or a sense of feedback, and rich sound effects would make it more immersive (B01Q1-13, C01Q4-5, A01Q7-4). Another suggestion was to increase the degree of freedom in the game content, allowing for more collaboration and gaming time (D01Q9-3, C01Q6-8). The elderly helped themselves cross the threshold of learning and unconsciously improved their digital ability through establishing self-confidence and interest in the game.

5. Discussion

This study reveals several important findings. According to the interview result, the elderly, in comparison to young people, paid more attention to their performance in the games. They worried that they could not catch up with the young people and that they might cause failure or errors in the game. Therefore, with a lack of game experience, they resisted playing with young people due to the feeling of pressure. This was why the elderly were not confident before participating in the empirical study. Furthermore, the design of the game model and operation for the elderly should not be based on the perspective of the younger generation. It must understand the factors of an age gap. Therefore, the game design of VR glove puppetry not only simplified the complicated interface but also showed a more intuitive operation of puppets instead of relying on joysticks.

The theme of the game was not competitive, and participants should discuss with and help each other regarding the content of the story or the performance of puppets. This could positively influence intergenerational relations and communication. In addition, most of the subjects suggested that the cooperative model to accomplish common tasks in the interactive game and the accumulation of points could effectively enhance the parent–children relationship. Because of game content and themes, they could develop topics besides their own lives. This significantly enhanced the social interaction of players of different generations and promoted common activities. Based on the previous discussion and the analytical result, this study elaborates on the following.

5.1. In the Closed and Independent Visual Operation Environment of VR Games, the Older Adult Needed More Specific Guidance on the Operational Process and Interface

According to the result of the interviews, most of the elderly people had not experienced VR and needed more time to adapt to and learn the operation of the game. In addition, the speed of the elderly in the game was different from that of young people. The elderly expected a slower process of the game in order to properly receive different kinds of information. Although the young people did not have the same problem, they slowed down to allow the elderly to successfully play the game.

As to the interface design such as the instruction, it was simplified and clearer during the phase of design. However, the elderly still could not intuitively find the menu from the free perspective of VR. With the users' vision of the glasses and since others could not see the operational interface, they were not able to help them. Therefore, it was important to avoid the frustration of the elderly in the process of the game by using a float menu to meet the movement of the users' vision and guidance of different phases of the game.

5.2. Spatial Visual Gap in VR Game Design Influenced the Sense of Security of the Older Adult Players

The VR game developed in this study lasted around 30 min. Since the characters did not move in the game, the players only needed to change their angle of view at the fixed places and to operate glove puppetry and a simple menu by hand. Thus, after playing the game for a while, most players felt fatigued in their hands, or they suggested a function to change the players. According to some female players, the VR glasses were heavy and after a while they were not easy to move. The players who wore glasses were not used to VR glasses, and their glasses tended to become dirty and blurred when they played the game. Furthermore, most of the subjects suggested that when they wore VR glasses at the beginning, they needed some time to adapt to the virtual environment. After taking off the glasses, they needed time to adjust, too. During the process, they did not feel dizzy or uncomfortable.

In the progress of the game, although most of the subjects did not show physical discomfort, in the virtual space most of the subjects noticeably encountered an optical illusion of a cliff at the edge of the scene. It resulted in visual imbalance and the feeling of falling. When they changed the angle of view, they saw themselves floating. In addition, it was not easy for the subjects to control the distance in the virtual environment. When they took the puppets in front of them, it was difficult. The height of the places of puppets indirectly influenced the users' poses. When they had to bend, they were afraid of falling, and so they became nervous.

5.3. The Elderly People Were Not Confident in the Process of the VR Game

Before playing the game, most of the elderly people suggested that they were not good at games and worried that they might affect the other young player in the process. After playing the game, they paid more attention to the instruction and description of steps, and in comparison, they were more careful to avoid errors than their younger counterparts. They even became stressed. After a while, they tended to be less nervous. In the empirical study, the young people would actively help, guide, and wait for the elderly. Thus, they both felt relaxed in the game.

In the interviews, the elderly people suggested their anxiety and concern about the common game and thought that young people would be impatient with them. In comparison to the younger generation, they tended to resist playing the game with those younger than themselves and even preferred playing the game with those of the same age. Nevertheless, in the interview, the young people were open-minded and looked forward to playing the game with the elderly. They understood that the elderly were unfamiliar with the game. They not only actively assisted with their difficulties but also enjoyed playing the game with them. Thus, the young people enjoyed the game, and by communication and guidance, they helped the elderly and accomplished the tasks. The elderly were delighted when they were helped by the young people, and it resulted in their heightened sense of achievement in the game.

5.4. Sound and Action Feedback of the VR Game Were the Important Factors of Game Experience

The operation design of virtual glove puppetry in this study was based on right-handed gestures to simulate the realistic manipulation of traditional glove puppetry. According to most of the subjects, the operation was intuitive and was similar to the operation and imagination of realistic puppets. However, due to the limitation of programming design, the operation of virtual puppets could not totally simulate realistic puppets. The players could manipulate the legs and steps, but the movement of heads was more sensitive in the program. Therefore, in comparison to the operation of real puppets, it required a concentration of gestures in order to more precisely control the movement of puppets.

In the game, the subjects expected a simulation of a realistic performance of VR glove puppetry. Therefore, they mentioned the issues of sound and action feedback. As to action feedback, besides the manipulation of the movement of puppets, most of the subjects expected the feedback of bumping instead of penetration. The bumping effect included that between puppets and between puppets and the background. According to some subjects, the most interesting part of glove puppetry was the emotion of different characters interpreted by the puppets' actions. The fighting was less effective due to the lack of bumping. In addition, as to sound, although there was background music, the proper sound effects showed that the simulation of the performance of realistic puppets and the experience of the game could adhere to reality.

5.5. Related Themes of the Game Effectively Enhanced Intergenerational Communication and the Parent-Children Relationship

Most of the elderly people had never played with young people in a game. Thus, in participating in the interactive game, the interaction between the elderly and young people was positive. They all were relatives or friends. Young people made efforts to help the elderly be familiar with the environment and operation of the game, and the elderly thus successfully played with them. In addition, most of the subjects restarted after the end of the game and discussed with each other regarding the combination of different characters and scripts. Most of the groups were familiar with the rule of the game by the second or third round, and in the process, they further discussed with each other and showed in-depth experience.

These discussions were mostly derived from the elderly who shared their childhood experiences and memory of glove puppetry. They discussed the content and stories with the young people as well. The interesting interaction mostly did not originate in the process of the game, but rather it was accumulated in the interactive game, and their topics were developed in the interview after the end of the game. Some young subjects suggested that in the past, they did not know that the family members liked glove puppetry. Through the game, they realized the families' different interests. Thus, the elderly people's resistance or lack of confidence in the VR game did not influence their interaction in the game, but it in fact enhanced their relationship. Therefore, most of the subjects suggested that cooperation in the interactive game, the accomplishment of common tasks, and the accumulation of points could strengthen the parent–children relationship, and they developed different topics by the themes of the games.

6. Conclusions

Although the VR game emphasized the reality constructed by the virtual environment, the operation of the game still relied on the menu instructions, and thus the players could successfully play the game. However, this was challenging for the elderly who showed inferior reading competency. For the elderly with a demand for different dialects, the lack of a voice function increased the obstacle of operation. Nevertheless, most of the respondents gave positive affirmation to the intergenerational relationship between the elderly and the younger generation in the game, especially after the game was over, there are more parent–child topics. Most of the subjects nevertheless recognized the intergenerational relationship between the elderly and younger generation in the game. After the end of the game, topics of discussion increased between parents and children.

Noticeably, the interaction in the game was successively developed a while after the end of the game, which might reflect the reality that people rely on different mediums that lead to different topics and relations. It shows in the environment of the virtual game that people can construct dialogues by new identities and relations instead of their roles in reality. Although not all subjects could successfully play the game, unexpectedly they developed interesting topics and interactions and thus learned from and comprehended each other. Therefore, combining the traditional culture familiar to the elderly into the game theme can indeed effectively help the elderly adapt to the game content and operation more quickly. The key factor lies in the design, which not only strengthens the self-confidence of the elderly, but also allows the two generations to achieve a balance in knowledge sharing. In addition, through the virtual puppets and game design, a new way of communication was established between generations, allowing the elderly to gradually improve their digital technology ability while enjoying the interactive process of the game.

Finally, some subjects proposed different views and argued that a virtual interactive game is similar to the present social networks. Although there are interactive functions such as voice communication, video communication, and games, they cannot replace realistic interpersonal connections. This shows the gap in the interaction. However, the purpose of the development of digital technology is not to weaken the relationship between humans and society. In the current global pandemic, person-to-person human relations have been negatively affected. However, for many people, digital technology maintains such relationships and reduces distance, thus becoming indispensable for life and work. Virtual interaction might not totally satisfy human beings' needs for affection, but it is certainly the present option to maintain relations and exchange affections. It can pass on knowledge such as culture to different generations.

Therefore, this study has some potential limitations. First, due to the pandemic, considerable difficulties were encountered in the selection and willingness of participants. The main subjects were not to be situated in the same institution or community, but from different regions; they also had to match the age combination. Therefore, in addition to the willingness to participate in the empirical study, the same group of subjects had to be able to provide a good health certificate to participate in the two stages of the empirical study and interview. In addition, the research adopted intensive interviews and conducted individual interviews with eight subjects. The amount of data in the subsequent oral analysis was relatively large. For the quality of interviews and data analysis, only eight ideal and suitable respondents were selected in the end.

Secondly, as to the gesture function of VR, although it simulated the operation of glove puppetry, it led to new problems. The subjects' experience could not last long due to the fatigue in their hands. In addition, in VR network games the quality and stability of the network significantly influence the gaming experience. Thus, this study encountered problems and challenges in terms of the server's stability.

The study did not discuss the acceptance or attitude of different genders. In the future, further research can be conducted regarding the number of subjects and gender to explore even more diverse issues of intergenerational communication, and also add new perspectives for more development possibilities. Taiwanese puppetry had a significant effect in the study of cultural inheritance and intergenerational communication. Therefore, in the future, intergenerational interventions can be combined with reminiscence therapy to leverage the elderly's memories and experiences to achieve treatment goals, which can be beneficial for connecting within society and improving quality of life.

This study has been reviewed by the Institutional Review Board (IRB) of Nation Changhua University of Education Research Ethics Committee with consent No. NCUEREC109-046.

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The Role of Socially Assistive Robots in the Care of Older People: To Assist in Cognitive Training, to Remind or to Accompany?

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Abstract: The rapid development of new technologies has caused interest in the use of socially assistive robots in the care of older people. These devices can be used not only to monitor states of health and assist in everyday activities but also to counteract the deterioration of cognitive functioning. The aim of the study was to investigate the attitudes and preferences of Polish respondents towards interventions aimed at the preservation/improvement of cognitive functions delivered by a socially assistive robot. A total of 166 individuals entered the study. Respondents completed the User's Needs, Requirements and Attitudes Questionnaire; items connected to cognitive and physical activity and social interventions were analyzed. Perceptions and attitudes were compared by gender and age groups (older adults $\geq$ 60 years old and younger adults 20–59). Women showed a more positive attitude towards robots than men and had a significantly higher perception of the role of the robots in reminding about medications (p = 0.033) as well as meal times and drinks (p = 0.018). There were no significant differences between age groups. Respondents highly valued both the traditional role of the robot—a reminding function—as well as the cognitive interventions and guided physical exercises provided by it. Our findings point to the acceptance of the use of socially assistive robots in the prevention of cognitive deterioration in older people.

Keywords: elderly; cognitive impairment; psychosocial interventions; sustainable technology; socially assistive robots

1. Introduction

The world's population is ageing: older persons are increasing in number and make up a growing share of the population in virtually every country [1]. The proportion of people aged 65 or more will increase from 9% in 2019 to 16% by 2050 [2]. As the population grows older, the prevalence of age-related diseases such as dementia will surge [3]. Dementia is an umbrella term for diseases characterized by a decline in multiple domains of cognitive function that affects a person's ability to perform daily activities. Its most common type, Alzheimer's disease (AD), contributes to 60–70% of all dementia cases [4,5]. Another distinct kind of cognitive decline is mild cognitive impairment (MCI), defined as a heterogeneous clinical syndrome reflecting a worsening in cognitive performance and neuropsychological assessment results. MCI does not significantly influence the activities of daily living. However, it is considered to be a risk state for further cognitive and functional decline, with 5–15% of people developing dementia per year. Approximately 50% of people suffering from MCI remain stable for up to 5 years; in some cases, cognitive symptoms improve over time [6,7].

Age is the most important risk factor for cognitive decline, but ageing is not inevitably associated with dementia [8]. A link between cognitive decline and dementia and lifestyle-related risk factors (sedentary lifestyle, smoking, unhealthy diet, harmful use of alcohol) is also indicated. In addition, some diseases, such as hypertension, diabetes, hypercholesterolemia, obesity and depression, are known to be associated with an increased risk of developing dementia. Modifiable risk factors also include social isolation and cognitive inactivity [8,9].

In recent years, many studies have been conducted on the use of psychosocial interventions in people living with dementia and those at risk of dementia based on evidence of modifiable lifestyle risk factors [10,11]. Such interventions can be effective in the management of the clinical symptoms of dementia and can play an important role in the prevention of this disorder in people with MCI and cognitively intact older people at risk of dementia [11]. Psychosocial interventions include a diverse and broad range of treatments [12]. Among them, cognitive rehabilitation (CR), which supports people with dementia and their caregivers using a goal-oriented approach, is particularly important. The aims include, among others, activities of daily living, self-care, social activities and communication, to optimize the ability to function in everyday life [13]. Psychosocial interventions include cognitive training, physical exercise, dietary treatments, art-oriented therapy, reminiscence therapy [12], cognitive stimulation and social activity [8]. Cognitive training involves repeated, planned, structured practice of tasks targeting specific cognitive domains, such as executive functions or memory [14]. Cognitive stimulation is engagement in various types of activities and discussions aimed at the general enhancement of cognitive and social functions [15,16]. Psychosocial interventions, such as cognitive training as well as physical and social activity, are recommended by the WHO guidelines on risk reduction for cognitive decline and/or dementia [8].

The availability of caregivers is not sufficient to keep up with the increasing demand for specialized care. Therefore, it is necessary to explore the applicability of intelligent systems that could enable older people to live independently and make more efficient use of human care services [17]. Sustainable technologies can improve older adults' health and wellbeing, promote their social inclusion, and facilitate independent living and contribution to the community [18]. Robots are one of the options that could accommodate the widening gap between the need for and supply of healthcare services [19].

So far, several robots have been developed to assist the elderly in various aspects of daily life, including monitoring the environment of the elderly by detecting gas or fire [20], assisting in food preparation [21] and the consumption of meals [22,23], supporting bathing [24] and doing housework [25]. These devices are designed to ensure the safety of the elderly [26,27], inter alia through fall detection [28,29] or by monitoring health [30,31]. They can also compensate for memory impairment through the use of cognitive prostheses—technological solutions compensating for memory impairment and improving the performance of everyday tasks requiring memory [32], for example providing reminders for meetings or of the need to take medicines [33].

Socially assistive robots are designed to develop an interaction with people in an interpersonal manner [34]. Prominent among these are companion robots, which create a close interaction with humans and accompany them to reduce loneliness and mental stress [35]. Another group includes socially assistive robots (SARs), which also develop close, effective interaction with users; however, their purpose is to assist with and achieve measurable progress in rehabilitation or learning [18]. It is stressed that SARs are robots that assist users (e.g., older people, children with autism spectrum disorder) through social rather than physical interactions [36]. They are also defined as robots capable of providing assistance to the user by means of social interaction. SARs can also be a valuable tool in providing interventions that target cognitive and functional abilities [37–39]. When tailored to the needs and expectations of older people with cognitive impairment, SARs may allow seniors to maintain independence and stay at home for longer [40].

However, even with extensive research and development (e.g., GiraffPlus EU FP7 [31], Mobiserv EU FP7 [41] and Hobbit EU FP7 projects [42]), robots have yet to become prevalent in the homes of older people, and much of the research is driven by technological developments rather than careful consideration of user needs [43]. In the implementation of robots in the care for older people, successful human–robot interaction (HRI) is a key issue [44]. A study by Peca et al. [45] on human–robot interaction showed that a semi-autonomous robot is a better solution than a fully autonomous one for vulnerable populations such as people with cognitive deficits. According to Orejana et al., in order to improve a user's cognitive function, the robot should take into consideration the user's situation and develop good collaboration to engage the user in long-term training [38,46].

According to the Technology Acceptance Model (TAM), an individual's perceptions of technology can impact their decisions regarding its use [47]. It should be stressed that, in order to be successful in introducing such robots to care for the elderly, they must meet the expectations of older people and their caregivers so that they want to use these devices [48]. There is little research concerning robots aimed at counteracting the deterioration of cognitive functioning. In recent years the number of such studies has increased significantly [49]. Research conducted to date in this area has largely focused on the use of robots for cognitive training.

Cognitive training consists of cognition-based interventions designed to provide structured practice in performing tasks connected with aspects of cognitive functioning, such as memory, attention, language or executive functions [50]. It also improves social communication skills [46]. According to Kim et al. [51], conducting cognitive training using robots has greater effects than training carried out in the traditional way, using paper and pencil. This is because exposure to new technology is more difficult and challenging for seniors than using familiar devices, and the novelty effect may not only contribute to increased brain activity but may also enhance seniors' motivation to participate [51]. Li [52], on the other hand, demonstrated that physically embodied robots are more persuasive, are perceived more positively, and provide better effectiveness compared to virtual agents (chatbots). The role of robots in providing cognitive training is to improve impaired cognitive functions, e.g., memory function [53] and attention [54,55]. Robots can facilitate social interaction, communication and positive mood, thus further improving the efficiency and effectiveness of cognitive training [56]. In a study by Pino et al. [57], better therapeutic behavior was observed in elderly people with MCI, some of whom had reduced depressive symptoms, who participated in memory training using a humanoid social robot (NAO).

To date, several different robots with functions connected with cognitive training have been developed, including Hector (Europe, [58]), Cafero (New Zealand, [59]), IRobiQ (Korea, [60]), Ifbot (Japan, [61]), Silbot (Korea, [51]), Mero (Korea, [51]) and Wam arm [62]. Kim et al. [51] found that multi-domain robotic cognitive training in the elderly has an inhibitory effect on age-related structural changes in the grey matter of the brain. According to Andriella et al. [62,63], cognitive interventions, especially the use of games in the treatment of mild dementia, are very promising, not only in terms of maintaining cognitive performance at the same level but also contributing to its improvement. Older people taking part in such training have been reported to have a lesser decline in the ability to perform daily activities, allowing them to remain largely independent in their own homes [64,65]. Physically embodied robots represent a promising technology that could be used in the future as accessible, effective tools for conducting cognitive training [46].

The development of a socially assistive robot that can provide cognitive training for older people is a challenge. According to Breazeal et al. [34], such a task requires an understanding of human intelligence and behavior across multiple dimensions (i.e., cognitive, affective, physical, social, etc.) as well as a multidisciplinary approach including robotics and artificial intelligence specialists, psychologists, neuroscientists, design engineers and anthropologists. This article describes research into one of the first steps—a study of preferences regarding robot functions. This study was conducted by a multidisciplinary team that included psychiatrists, community therapy specialists, psychologists, an anthropologist and an occupational therapist.

The aim of the study was to investigate the attitudes and preferences of Polish respondents towards psychosocial interventions aimed at the preservation/improvement of cognitive functions, delivered by a socially assistive robot. We examined the perception of individual functions of a SAR as well as age and gender differences in the acceptance of this technology. The results of our study are expected to contribute to a better understanding of users' needs and requirements for the design and development of socially assistive robots that provide psychosocial interventions for older adults with dementia and mild cognitive impairment and that support their caregivers.

2. Materials and Methods

The data collection was carried out as part of the ENRICHME (ENabling Robot and Assisted Living Environment for Independent Care and Health Monitoring for the Elderly) project, financed within the European Union Horizon 2020 Programme (ID 643691). The aim of the ENRICHME project was to evaluate the use of the robot in the home environment to support patients with mild cognitive impairment [66]. The research was conducted with the consent of the Bioethics Committee of the Poznan University of Medical Sciences (consent number 389/17). The Bioethics Committee did not consider our study a medical experiment; thus, written consent was not required. The subjects received detailed information about the research and that their participation would be voluntary. Questionnaires were distributed and returned anonymously; returning a completed questionnaire was considered implied consent to participate.

2.1. Recruitment

The subjects were recruited in the general population. The group of participants was a convenience sample; the recruitment process took place through advertisements on local radio and in local press, and leaflets and the snowball method were also used. The criteria for inclusion were an age above 18 and a command of the Polish language sufficient to complete the questionnaire. The participants did not receive remuneration for their participation in the survey.

2.2. The Studied Group

The study involved 166 people aged between 20 and 84 years, consisting of 131 women and 35 men. The average age of the studied group was 41.5 $\pm$ 18.2 years (men 48.2 $\pm$ 19.6, women 39.7 $\pm$ 17.4 years). The surveyed persons were divided into two age groups: younger adults, 20–59, consisting of 129 persons, and older adults, 60+, consisting of 37 persons.

2.3. Users' Needs, Requirements and Abilities Questionnaire

The research was conducted using the UNRAQ (User's Needs, Requirements and Abilities Questionnaire) survey, developed within the ENRICHME project. UNRAQ contains a series of statements on the function and role of the robot in elderly care and is described in detail elsewhere [67,68]. Participants specify their level of agreement or disagreement on a symmetric agree–disagree Likert scale [69]. In order to obtain a point-based score, the following values are assigned to the answers: I strongly disagree—1 point; I partially disagree—2 points; I neither agree nor disagree—3 points; I partially agree—4 points; I strongly agree—5 points. The questionnaire was completed in paper form. Participants in the survey did not have any experience with socially assistive robots. Before completing the UNRAQ, they were shown a picture of the Kompai robot (Robosoft, France) for a realistic image of the socially assistive robot concept. The researcher was present at all times during the survey to address questions when needed.

Only the items concerning the psychosocial interventions delivered by SARs are included in this study. The results obtained are presented as mean values and standard deviation (SD).

2.4. Statistical Analysis

All calculations were made using the Statistica 13 package (Statsoft, Poland). Statistical significance of differences between individual groups was assessed using the Mann-Whitey U test. Differences of $p < 0.05$ were assumed to be statistically significant.

3. Results

In the study group, a positive attitude towards robots assisting elderly people was observed. Most of the statements were strongly agreed to by more than half of the participants. The respondents most often strongly agreed with the statements concerning the role of the robot in terms of reminding (about medication, appointments, meals) and helping to find lost objects (over 70% of the respondents strongly agreed). An important finding was that over 75% of the respondents were positive toward memory training, and over 65% toward cognitive stimulation, encouragement and guidance on physical exercises. Less than half of the respondents strongly agreed with statements concerning actions aimed at mood (about 40%), social contacts (about 45%) or the role of the robot as a companion (34%). The results are presented in Tables 1 and 2.

Table 1. Opinions on cognitive interventions of socially assistive robots (SARs) (N = 166) [a].

Cognitive Intervention	Statement	Strongly Agree (%)	Strongly Disagree (%)	Other (%)	Mean ± SD
Training	The robot should help the elderly to preserve their memory function, e.g., by playing memory games with them	127 (76.5)	0 (0.0)	39 (23.5)	4.7 ± 0.6
Stimulation	The robot should have entertainment functions (e.g., gaming partner, reading aloud or playing music function)	110 (66.3)	3 (1.8)	53 (31.9)	4.5 ± 0.9
Prosthesis	The robot should remind the elderly about medication	149 (89.8)	0 (0.0)	17 (10.2)	4.9 ± 0.5
	The robot should remind the elderly about appointments	124 (74.7)	0 (0.0)	42 (25.3)	4.7 ± 0.6
	The robot should remind about meals and drinks	121 (72.9)	4 (2.4)	41 (24.7)	4.6 ± 0.9
	The robot should help the owner to find lost objects (e.g., glasses, keys)	129 (78.7) [a]	1 (0.6) [a]	34 (20.7) [a]	4.7 ± 0.6

[a] Data computed for 164 respondents due to missing data in two questionnaires.

Table 2. Opinions on guided physical exercise, mood and social interventions of SARs (N = 166) [a].

Intervention	Statement	Strongly Agree (%)	Strongly Disagree (%)	Other (%)	Mean ± SD
Physical exercise	The robot should encourage and guide the elderly to perform physical exercises	113 (68.1)	1 (0.6)	52 (31.3)	4.6 ± 0.7
Mood	The robot should detect the owner's mood (facial expression)	68 (41.2) [a]	8 (4.8) [a]	89 (53.9) [a]	4.0 ± 1.1
	The robot could decrease the sense of loneliness and improve the mood of the elderly person	60 (36.4) [a]	9 (5.5) [a]	96 (58.2) [a]	4.0 ± 1.1
Social activity	The robot could encourage the elderly to enhance their contacts with friends	72 (43.4)	8 (4.8)	86 (51.8)	4.1 ± 1.1
	The robot should initiate contacts with others (calling friends, initiating skype conversations)	76 (45.8)	5 (3.0)	85 (51.2)	4.2 ± 1.0
Companionship	The robot should accompany the owner in everyday activities (watching TV, preparing meals)	56 (33.9) [a]	11 (6.7) [a]	98 (59.4) [a]	3.9 ± 1.1

[a] Data computed for 165 respondents due to missing data in one questionnaire.

3.1. Opinions of Women and Men on Cognitive Training

Women and men showed roughly the same high acceptance of statements on cognitive training and cognitive stimulation. Both groups had a relatively low appreciation of the usefulness of mood evaluation and intervention functions and the function of the robot as a companion in everyday activities. Women were more likely to accept individual robot functions. A higher percentage of women than men strongly agreed with reminder and physical activity statements; however, these differences did not achieve statistical significance. In terms of mean values, women had significantly higher scores in terms of reminding about medication and reminding about meals and drinks. The results are presented in Tables 3 and 4.

Table 3. Subjects' opinions on cognitive interventions of SARs, broken down by gender; Male (M)—N = 35, Female (F)—N = 131 [a].

Cognitive Intervention	Role of the Robot	Sex	Strongly Agree (%)	Strongly Disagree (%)	Other (%)	Mean ± SD	p Value
Training	Help in preserving cognitive functions (memory games)	M F	26 (74.3) 101 (77.1)	0 (0.0) 0 (0.0)	9 (25.7) 30 (22.9)	4.7 ± 0.5 4.7 ± 0.6	0.766
Stimulation	Entertainment functions (gaming, reading aloud, playing music)	M F	23 (65.7) 87 (66.4)	0 (0.0) 3 (2.3)	12 (34.3) 41 (31.3)	4.6 ± 0.7 4.5 ± 0.9	0.977
Prosthesis	Reminding about medication	M F	28 (80.0) 121 (92.4)	0 (0.0) 0 (0.0)	7 (20.0) 10 (7.6)	4.7 ± 0.6 4.9 ± 0.4	0.033
	Reminding about appointments	M F	24 (68.6) 100 (76.3)	0 (0.0) 0 (0.0)	11 (31.4) 31 (23.7)	4.6 ± 0.7 4.7 ± 0.6	0.367
	Reminding about meals and drinks	M F	20 (57.1) 101 (77.1)	2 (5.7) 2 (1.5)	13 (37.1) 28 (21.4)	4.3 ± 1.1 4.6 ± 0.8	0.018
	Help to find lost objects (e.g., glasses, keys)	M F	25 (71.4) 104 (80.6) [a]	0 (0.0) 1 (0.8) [a]	10 (28.6) 24 (18.6) [a]	4.6 ± 0.8 4.8 ± 0.6	0.187

[a] Data computed for 129 respondents owing to missing data in two questionnaires.

Table 4. Subjects' opinions on other functionalities of a socially assistive robot broken down to gender; Male (M)—N = 35, Female (F)—N = 131 [a].

Intervention	Role of the Robot	Sex	Strongly Agree (%)	Strongly Disagree (%)	Other (%)	Mean ± SD	*p* Value
Physical exercise	Encouraging and guiding physical exercises	M F	20 (57.1) 93 (71.0)	0 (0.0) 1 (0.8)	15 (42.9) 37 (28.2)	4.5 ± 0.6 4.6 ± 07	0.160
Mood	Detection of mood (facial recognition)	M F	12 (34.3) 56 (43.1)	1 (2.9) 7 (5.4)	22 (62.9) 67 (51.5)	4.1 ± 0.9 4.0 ± 1.1	0.864
	Reducing loneliness and mood improvement	M F	11 (31.4) 49 (37.7) [a]	0 (0.0) 9 (6.9) [a]	24 (68.6) 72 (55.4) [a]	4.1 ± 0.8 3.9 ± 1.2	0.839
Social activity	Encouragement of social contacts	M F	12 (34.3) 60 (45.8)	1 (2.9) 7 (5.3)	22 (62.9) 64 (48.9)	4.2 ± 0.8 4.1 ± 1.1	0.887
	Initiation of contacts (calls, video conversations)	M F	18 (51.4) 58 (44.3)	0 (0.0) 5 (3.8)	17 (48.6) 68 (51.9)	4.4 ± 0.8 4.1 ± 1.1	0.263
Companionship	Accompanying in everyday activities	M F	12 (34.3) 44 (33.8) [a]	2 (5.7) 9 (6.9) [a]	21 (60.0) 77 (59.2) [a]	3.9 ± 1.1 3.9 ± 1.2	0.795

[a] Data computed for 130 respondents owing to missing data in one questionnaire.

3.2. Comparison of Acceptance of Robot Functions between Younger and Older Respondents

A larger percentage of people in the older age group (over 60 years of age) positively assessed the usefulness of robot functions connected with cognitive training and cognitive stimulation. However, the difference did not reach statistical significance. Mean values for most of the analyzed statements were slightly higher in the older group. The situation was different with regard to the statement concerning meal and drink reminders; there was a tendency towards a difference between older and younger respondents, with mean values lower in older respondents. The results are presented in Figures 1 and 2.

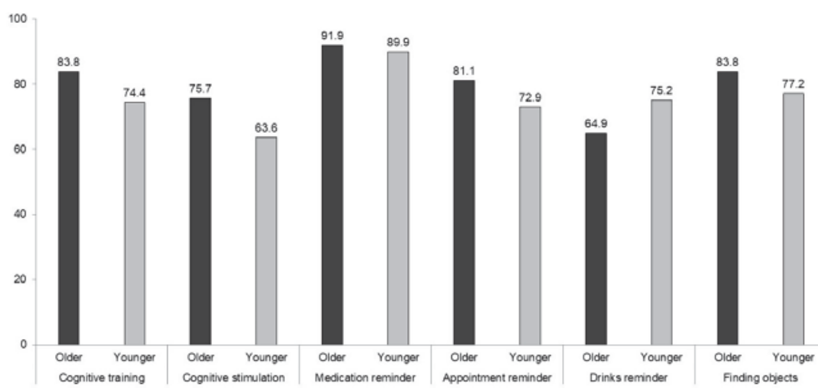

Figure 1. Opinions of older and younger participants on cognitive interventions using a socially assistive robot (data expressed as % of 'strongly agree' answers).

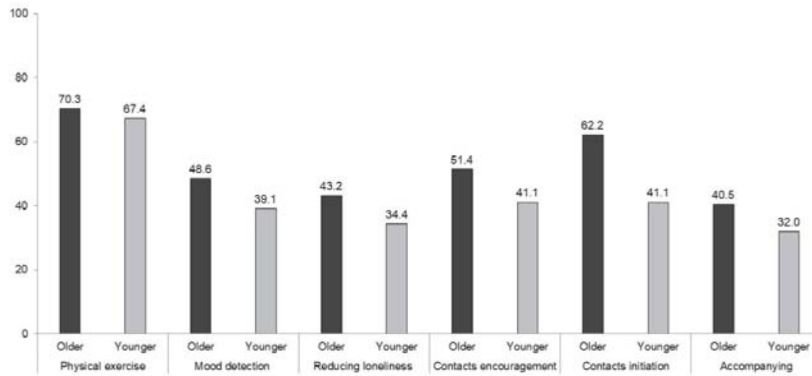

Figure 2. Opinions of older and younger participants on guided physical exercise, mood and social interventions using a socially assistive robot (data expressed as % of 'strongly agree' answers).

4. Discussion

4.1. Opinions on Psychosocial Interventions Provided by Socially Assistive Robots

Each year, technology is increasingly permeating various aspects of our lives. It is also increasingly applicable to the care of the elderly [70]. Assistive robots not only can help seniors to remain independent for longer but can also support the work of doctors and caregivers of the elderly [71]; thus, research in this area is extremely important. Our research was focused on the perception of assistive robots as a potential tool for psychosocial interventions aimed at the preservation/improvement of cognitive functions in seniors. The results revealed a positive attitude towards cognitive intervention delivered by robots, which is consistent with previous reports on the acceptance of assistive robots for older people in the home environment [72].

The most important finding in our work is that older respondents rated highly not only the reminding functions of robots, but also cognitive training and cognitive stimulation, which shows that the elderly are aware of the need to take action to prevent the deterioration of cognitive functions and see the potential of assistive technology in this area. It is crucial to understand older people's approach to assistive technologies. In addition, the level of acceptance of the individual functionalities of assistive robots is crucial when designing them. This will ensure appropriate interaction between robots and older people and thus make them more effective [73]; even the best-planned cognitive intervention will not produce the desired result if the older person does not wish to participate. Our findings complement the results of previous studies on the perception of robots. Previous studies mainly focused on the general acceptance of the robot or the acceptance of its individual functions [67,72,74–76]. Research to date has focused primarily on the acceptance of robots already produced [77] rather than the expectations of seniors or their caregivers regarding such devices, as in case of this study. It should be noted that the expectations of users of socially assistive robots are not always consistent with the beliefs of those responsible for their design or production [78]. Therefore, knowing the exact needs and expectations of potential users of these devices is crucial and necessary for older people not only to want to use them but also to feel comfortable in their presence [79].

4.2. Opinions on Psychosocial Interventions of SARs—Gender Differences

Our research indicates a similarly high acceptance of cognitive interventions (cognitive stimulation and training) in both gender groups. Women gave a higher rating to the usefulness of reminder functions of robots; there was statistically significant difference regarding drug reminders and meal and drink reminders. We, therefore, did not confirm the results of the Heerink et al. [80] study, in which women "would not want any technology that would help them too much in doing and remembering things" and "would prefer to try to remember and do as much as possible without any help until there would really be no way out but to use technology".

Other studies have also indicated lower acceptance of robots by women. In the study by Cortellessa et al. [81], women were more likely to indicate that a robot can cause problems at home and to keep a greater distance in personal interaction with the robot. Men more often accepted the fact that a robot makes decisions autonomously. It should be noted that the functions that were more accepted by women than by men in our study were simple reminder functions that could be considered beneficial to health and may accepted by women for pragmatic reasons.

4.3. Opinions on Psychosocial Interventions of SARs—The Influence of Age of the Subjects

Our research demonstrated that older people show acceptance of the psychosocial interventions provided by robots. This confirmed the results of the study by Backonja et al. [82], in which most reactions to the psychosocial impact of socially assistive robots did not differ between age groups. Many studies to date on the general acceptance of technology, rather than a specific narrow application as in the case of this study, point to concerns and problems of older people regarding technology, including robots. It is stressed that the current young generation is more technology savvy and may, therefore, be more inclined to using social robots than the current older generation [83]. Younger people who have grown up with the development of technology are often seen as experts and are more positive about new technologies than older people. On the other hand, young people may be more aware of the limitations of technology (e.g., just having functionality does not determine its effectiveness if the training is not properly designed and selected). It is emphasized that when older adults were asked about their perceptions, they were open to new robotic technologies [73,84,85]. Older people may be more accepting of integrating certain robotic technologies into daily life than younger ones [86]; it is thus necessary to adjust strategies and approaches for their needs [82].

4.4. Perception of the Individual Functions of the Robot

Our research showed that older people, potential users of the socially assistive robot (people over 60 years of age) demonstrate a similar acceptance of psychosocial interventions by the robot as that of younger people (aged 20–59). The exception was the meal or drink reminder function of the device. This observation is consistent with previous reports in this respect [67,75]. This may be connected with the desire to maintain the autonomy of the user, a state in which the robot should behave as the user wants and not the other way around [87]. At the same time, for older people, acknowledging that their condition requires a reminder of such basic needs may be associated with a sense of failure [67,75].

The seniors surveyed rated equally high the empowering (related to active cognitive training) and supporting (e.g., reminding about the location of a given object) functions of robots [88]. This is an interesting observation, because the effect of cognitive training will not be immediately noticeable to the user. According to Talaei-Khoei, older people are more likely to accept devices that support them immediately (e.g., hearing aids) than those that are intended to empower them [89]. The positive approach to cognitive training provided by robots observed in our study may be due to the fact that older people are aware of their own limitations and know what they will not be able to live independently in their own homes without and the fact that they see greater chances for independence in training. As a result, they consider long-term activities to be as important as short-term help in the case that they forget where they put something. Similarly, about 70% of the respondents (both younger and older) definitely accepted the role of a robot in encouraging and guiding physical exercise, which can also be seen as an empowering activity. It has been suggested that a key motivation in technology adoption by older adults is the presence of a significant perceived benefit [90]; therefore the beneficial aspects of a socially assistive robot may include the fact that it helps people to help themselves rather than doing it for the user [87].

It is important to note that the functions of a robot such as social activity and interventions concerning mood were rated lower than those aimed at cognitive or physical activity. Average values were about 4 (or 'partially agree'), which still means acceptance. It should be noted that the percentage of people strongly opposed to equipping the robot with these functions ('strongly disagree') was small: up to 5.5% in the younger group and up to 11% in the older group. Low acceptance of the role of a robot as a companion in daily activities is worth noting: as much as 18.9% of older people did not accept this function of robots. Only 40% of older people and 32% of younger people definitely agreed with this task of the robot. It should be noted that many older people in western cultures live independently in their own homes and want to stay there. Socially assistive robots are therefore intended to serve as tools to enable older people to live independently for longer [19]. Subjects in our study group treated robots as a tool for cognitive training and guided physical activity. In addition, only half of the older respondents expected encouragement of social contact, a little more (62%) expected initiation of social contact. Less than half of the older people expected the robot to recognize the mood of the user or help reduce the feeling of loneliness. Such an attitude of older people may result from their fear of the negative influence of robots on their lives, as introducing a robot into an older person's home may be associated with reducing opportunities for human social contact and the neglect of older people by society and their families. The misconception that a robot meets the emotional and social needs of older people can be a justification for this. Concerns about loneliness and social isolation indicate that robots should not be used to replace human companionship [91]. The robot's accompaniment in everyday activities may be also associated with a sense of loss of privacy and autonomy [92]. It is noteworthy that older people in our study considered SARs as multidomain technology. Limiting the cognitive assistance function to making the user remember their plans and taking medication [17] is insufficient. Bedaf et al. [93] highlighted that the introduction of robots is not justified when tasks can be solved equally effectively by a simpler and cheaper technology; for example, robots may not be needed to improve communication between older adults and their relatives. On the other hand, in the wake of the global pandemic, socially assistive robots could be used to maintain social networks, connect with relatives and peers and help with treatment compliance, without the risk of spreading a COVID-19 infection [48,94,95]. Furthermore, it should be noted that seniors' attitudes towards SARs may change during their use (interaction with the SAR). A study by Portugal et al. [96] showed that seniors are more likely to interact with assistive robots if they have had a previous opportunity to familiarize themselves with SARs; hence, it is conceivable that seniors' attitudes towards a function that provides them with companionship in everyday life could change over time. For this reason, it is important to design robots in a modular way, i.e., so that it is possible to change or extend their functionality over time if necessary [96].

A thorough analysis of the needs and attitudes of the elderly prior to the design and deployment of social robots is therefore necessary. This stems from the very definition of an SAR: a social assistive robot is a robot, the goal of which is to create close and effective interaction with a human user for the purpose of giving assistance and achieving measurable progress in convalescence, rehabilitation, learning, etc. [97]. If we want SARs to be successful, they need to be accepted by older people [19].

According to the Technology Acceptance Model, it is essential to know when and how people accept technology because acceptance is the determinant of whether people will use a certain technology or not [98]. If people have a positive perception of the usefulness of a technology and perceive this technology as easy to use, the corresponding product will be accepted by the user group [98]. However, it is necessary to bear in mind that this model is mostly applied to technologies that are far into the development stage or are already in use [99], and SARs are still in their development stages and are not yet widely in use. The aim of development of social assistive robots is to provide cost-effective sustainable technology for vulnerable older people. These robots could provide cognitive training and other psychosocial interventions that complete the work of caregivers and therapists [100]. Our results support the idea of user-driven, rather than technology-driven, robot design and development [101], with involvement of end-users (older people) and other stakeholders (formal and informal caregivers, therapists) [46,101]. The results of our research into the acceptance of psychosocial interventions provided by socially assistive robots may be useful in the design process of robots for the care of seniors, who are often considered a population that requires a custom-tailored integration of robots. They may also be important for healthcare professionals in order to adequately prepare older people for the introduction of sustainable technology, helping them overcome fears related to technology.

4.5. Limitations of the Research and Future Directions

Our research is not without its limitations. One is the relatively small number of people involved in the study, which reduces the chance of detecting effects. For this reason, the results obtained should be interpreted with some caution. It should also be noted that only people living in Poland, whose needs and views on cognitive-enhancing robots may not reflect the views and needs of older people living in other European countries, participated in the study. Different countries have different care habits for their older citizens and different family cultures in general [81]. However, it should be underlined that surveys among inhabitants of one country are justified because they provide the homogeneity of a sample. Another weakness of this study is the lack of interaction between respondents and socially assistive robots.

Finally, we point out some strategies that may prove useful in designing further studies on socially assistive robots in support of older people and their caregivers:

- carrying out the research on a larger group of people who would come from different cultural backgrounds and live in different environments;
- increasing the number of longitudinal studies to examine how older people's expectations and requirements regarding social robots change with age;
- investigating whether users' attitudes and expectations towards SARs providing psychosocial interventions change as a result of their interaction with them (e.g., through live demonstration of the device to test subjects), and determining whether they continue to prefer the same functions of the robot;
- forming research teams from different scientific disciplines (medical, technical and social sciences) to conduct more in-depth and comprehensive research on the needs and requirements of older people regarding SARs.

5. Conclusions

Our results revealed a positive attitude of the people surveyed towards the function of a socially assistive robot that enables psychosocial interventions in older people. In the studied group, women assessed the reminder function more positively than men. Seniors, as potential users of socially assistive robots, recognize their potential for providing integrated health and social care in a home environment and see the need to equip such devices with a function for providing the active training of cognitive functions (e.g., through cognitive games). At the same time, they appreciated the usefulness of the reminder function for everyday tasks.

Socially assistive robots can enable older people to live independently and remain at home for longer, which is especially useful for people with mild cognitive impairment and Alzheimer's disease. However, knowing the exact needs and expectations of seniors with regard to assistive devices is not only important for them to want to use them, but also to feel comfortable in their presence. By focusing on cognitive interventions, we tried to achieve and show a deeper insight into the preferences of older people, as they require a tailored introduction to robots.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Bioethics Committee of the Poznan University of Medical Sciences (protocol code 389/17 and date of approval 6 April 2017).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

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A Platform Based on Personalized Exergames and Natural User Interfaces to Promote Remote Physical Activity and Improve Healthy Aging in Elderly People

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Abstract: In recent years, there has been a significant growth in the number of research works focused on improving the lifestyle and health of elderly people by means of technology. Telerehabilitation and the promotion of physical activity at home have been two of the fields that have attracted more attention, especially currently due to the COVID-19 pandemic. However, elderly people are sometimes reluctant to use technology at home, mainly due to fear of technology and lack of familiarity. In this context, this article presents a low-cost platform that relies on exergames and natural user interfaces to promote physical activity at home and improve the quality of life in elderly people. The underlying system is easy to use and accessible, offering a number of interaction mechanisms that guide users through the execution of routines and exercises. A relevant feature of the proposal is the ability to customize the exergames, making it possible for the therapist to adapt them according to the user's needs. Motivation is also addressed within the developed platform to maintain the user's engagement level as time passes by. An empirical experiment is conducted to measure the usability and motivational aspects of the proposal, which was evaluated by 17 users between 62 and 89 years of age. The obtained results showed that the proposal was well received, considering that most of the users were not experienced at all with exergame-based systems.

Keywords: healthy aging; remote physical activity; telerehabilitation; personalized exergames; natural user interfaces

1. Introduction

The population is aging both in absolute and relative terms, that is, considering the number of people over 65 years of age and taking into account the proportion of this group of people with respect to other age groups, according to the World Health Organization [1]. In particular, it is estimated that in 2050, 16% of the world's population will be over 65 years of age, which approximately doubles the current figure and quintuplicates the rate in 1950. Thus, the number of people over 60 will reach 2 billion by 2050, having already surpassed the 1 billion threshold in 2020. While the increase in longevity represents, in itself, a great success in recent history, it is also the root of another major socioeconomic problem that is aggravated, especially if it is related to the decline in the fertility rate. In this sense, population aging presents a number of challenges for health systems and countries' economies because older people tend to need more care than younger people and are less likely to continue working if their health deteriorates [2]. Therefore, it is clear that we are facing a global challenge, without historical precedent, in which a response is needed to meet the needs of the elderly.

In this context, the concept of healthy aging (HA) appears, which is defined as the process of increasing opportunities within a framework of physical, social, and mental health, enabling older people to play an active role in society and to enjoy independence, autonomy, and quality of life [3]. Thus, ensuring HA has to become a priority to successfully meet the previously introduced challenge [4]. To this end, technology, through e-health-based solutions [5], plays a key role in maintaining and improving the health habits and lifestyles of the elderly. Currently, there are already a significant number of e-health applications oriented to health promotion and care, highlighting fields such as telemedicine, virtual interventions, and the use of electronic health records. In the field of HA, these solutions can be extrapolated to motivate and facilitate a lifestyle that mitigates the effect of an aging population [6].

Although it may seem obvious that e-health-based solutions offer a convincing response to the problems raised, the adoption of technology by the elderly currently involves a series of barriers to be overcome [7]. Specifically, the difficulties associated with the interaction and how the technological tool is used, the lack of accurate and guided information when using it, the economic cost, the inherent complexity of the technology, and the lack of social interaction and communication, among other issues, stand out. It is also possible to consider and evaluate both intrinsic factors linked to the attitude of the elderly regarding their independence and sense of security [8] in a context of motivation and use of technology, and extrinsic factors related to usability, the feedback offered by the tool, or the aforementioned economic costs [9].

Physical exercise has been recognized as one of the best habits for maintaining health at any stage of life. In general, the available evidence shows that physically active older adults have lower mortality rates, better cardiorespiratory and muscular functioning, and better body mass and composition. They also have a lower risk of falls and a lower risk of moderate and severe functional limitations [10].

The integration of virtual reality platforms into physical activity programs for the elderly has provided a new incentive for physical exercise [11]. Virtual reality provides an interactive and individualized environment that stimulates and facilitates motor learning through multimodal sensory information [12]. In the last decade, virtual-reality-based exergames have attracted the attention of researchers and clinicians who, in order to prevent functional impairment and the occurrence of falls, have developed physical exercise programs focused on balance control, endurance, and muscular strength [13]. In addition, the use of exergames provides important advantages such as increased motivation and adherence, the option of offering dual-task training (physical and cognitive), or the graduation of exercise intensity through the different levels of gameplay [14–16].

The rapid expansion in the use of exergames as a clinical tool to improve the mobility of the elderly is mainly due to the emergence of low-cost commercial exergames from the entertainment industry. Some devices traditionally associated with the area of video games, such as the Nintendo Wii, Microsoft Kinect, or PlayStation Eye Move, are frequently used in community and residential centers with the aim of promoting physical exercise and improving the health of the elderly [17]. However, despite their popularity, commercial exergames present significant limitations when they are intended to be used to achieve clinical goals such as increasing balance, body segment mobility, or fall prevention. The hardware of commercial consoles does not allow to reliably detect the movements of the body segments involved, to graduate the speed and amplitude of the movements necessary to achieve the challenges proposed in each game, or to measure ranges of movement and save these data for successive treatment sessions. These deficits reveal the need to implement virtual platforms, designed from a clinical perspective, that are capable of giving the therapist access to the grading of each exergame, the collection of kinematic information, and remote monitoring. This facilitates the design of treatment sessions adapted both to the motor and cognitive performance of the elderly.

In this research work, we present a platform aimed at promoting and enhancing physical activity at home by the elderly, especially considering in its design the difficulties and barriers previously introduced. Figure 1 shows, graphically, the context or scenario in which this proposal is framed. From the hardware point of view, the platform is composed of a laptop computer connected to a multisensor kit capable of integrating and analyzing voice and computer vision models. The former is used to run the overall software of the platform, while the latter allows the tracking of the user's skeleton and facilitates interaction with the platform through natural user interfaces.

On the other hand, the platform integrates a set of activities or games that can be customized according to the physical routine to be established. These games incorporate gamification mechanisms to motivate the use of the platform over time. Thus, the main contributions of the proposal are the following: (i) integration of a scalable mechanism for defining customized games, based on a language that enables their automatic generation, (ii) use of accessible mechanisms, based on minimalist interfaces and voice commands, to facilitate and simplify the use of the platform, (iii) adoption of natural user interfaces so that the platform recognizes, in an accurate and agile way, the movements of users without the need to use physical sensors, and (iv) integration of a module based on web technology to facilitate remote monitoring, if necessary, of the activity developed by the users of the platform.

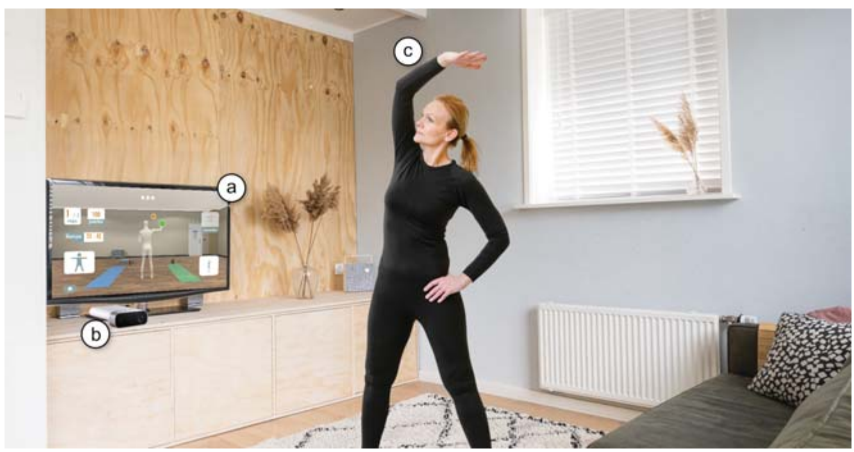

Figure 1. Graphical overview of the proposed system setup. (**a**) TV monitor to provide visual feedback; (**b**) tracking device; (**c**) person doing exercise at home.

2. Materials and Methods

2.1. User Interfaces

In Section 1, the importance of overcoming the barrier that the use of technology can impose on older people who do not use it frequently was introduced. Particularly, the aspect related to the usability and interaction scheme offered by a system that aims to promote active aging through exercises performed at home by the user autonomously was mentioned. In this context, the present subsection focuses on the natural interaction mechanisms designed and integrated in the present proposal. At a general level, these mechanisms can be summarized as (i) the possibility of using the system without using a physical interaction device and (ii) without the user having to install physical sensors on his body. In this sense, the user's own body serves as a communication mechanism, since it is possible to interact with the system through voice commands (e.g., word 'OK') or through physical movements (e.g., moving the right hand to a point in 3D space that activates a menu), which the system itself can recognize.

In this research work, we consider the use of a natural interaction between the user and the system, eliminating the use of wearable devices or color bands that facilitate the acquisition of data related to the tracking of the skeleton, i.e., the positions and orientations in 3D space of its joints (see Figure 2). On the contrary, the system integrates a hardware/software mechanism to, from the color and depth information of the captured videos, extract the information of the patient's skeleton. This natural interaction has been adopted transversely throughout the system, being possible to use it both when performing the physical exercises and when interacting with the system menu. One of the advantages of this decision is the increased consistency when using the system, since the interaction mechanism is unique and global.

Figure 2. Graphical representation of the data collected by the tracking device. Multiple skeletons can be simultaneously tracked.

In terms of voice commands, the system makes use of the Microsoft SpeechSDK tool (https://docs.microsoft.com/en-us/azure/cognitive-services/speech-service/, accessed on 10 June 2021) to detect certain keywords used to navigate the functionality offered by the system and to interact with the system when exercising. The approach is simple and is based on a set of predefined voice commands that the system is able to identify in several languages. In addition, the system itself incorporates a contextual menu, which is visually reflected in the user interface, and which serves to let the user know which voice commands can be issued at any given moment. As an example, Figure 3b shows, in the upper right part, the list of voice commands available in the general menu. At the top center, the system provides a vumeter that changes appearance when the user is speaking, so that the user knows that the system is detecting his/her voice.

2.2. Architecture

The architecture that supports the proposed architecture is shown visually in Figure 4, which is structured in two main layers:

- **Hardware layer**. This layer integrates the physical devices used in the platform which, in turn, are used to run the various software modules of the other major conceptual layer. In particular, this layer includes a laptop with an Nvidia graphics card and a Microsoft Azure Kinect DK device™.
- **Software layer**. This layer integrates the different modules and software libraries that make up the architecture. As can be seen, a modular design has been proposed to facilitate scalability and maintainability when making modifications or increasing the offered functionality.

Figure 3. Different views of the system supported by the proposed architecture: (**a**) main screen, (**b**) screen to select multiple modes (regular exercises to the left and autonomous exergames to the right), (**c**) screen to select the limbs to be exercised, (**d**) screen to select the exercise or exergame to be performed. Although the interface is shown in Spanish, the platform supports localization to handle multiple languages, including English.

With respect to the hardware layer, two relevant issues stand out. On the one hand, the tracking device used, Microsoft Azure Kinect DK™, integrates a high-quality depth camera, a 360º microphone array, a 16 megapixel RGB camera and an orientation sensor for the construction of advanced computer vision and speech recognition models. The top right of the Figure 5 shows, visually, the different components integrated in this device. The depth camera is the one that allows to obtain, in real time, information related to the positions and orientations of the joints of the human body in 3D space, as shown in the left part of the Figure 5. On the other hand, at the hardware layer it is necessary to deploy a laptop computer integrating an Nvidia graphics card, as this is a necessary requirement to employ the body tracking SDK. The currently employed laptop is shown at the bottom of Figure 5.

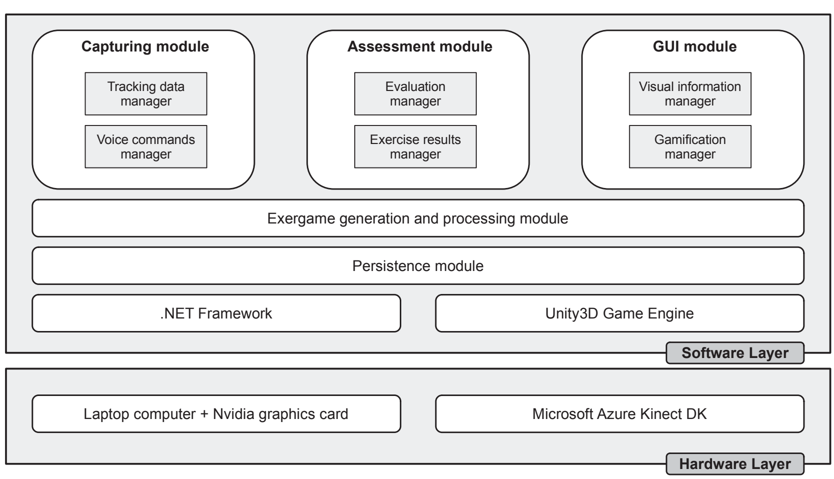

Figure 4. General overview of the underlying architecture that supports the proposed platform.

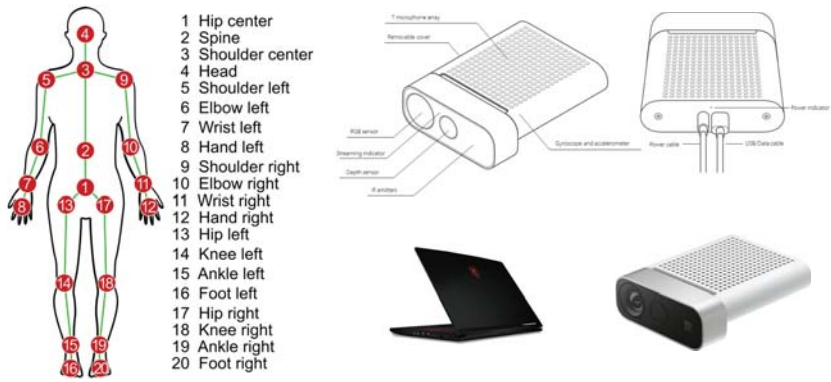

Figure 5. Microsoft Azure Kinect DK™ basic tracking capabilities and internal hardware architecture. A laptop computer that integrates a Nvidia graphics card must be used to fully take advantage of the tracking module.

With respect to the software layer, the proposed design contemplates several modules and components, as described below:

- **Microsoft.NET Framework**. This component provides the runtime environment for the entire platform, offering independence and transparency with respect to the underlying hardware and communications networks.
- **Unity Game Engine**. This component has been integrated into the software layer to facilitate and streamline the development process from a general point of view. In essence, Unity is a cross-platform game engine that can be used to create 2D, 3D, virtual reality, and augmented reality applications.
- **Persistence module**. This module is responsible for managing the database in which all the platform information is stored, highlighting the progress information of the system users.
- **Exergame generation and processing module**. This module has the necessary functionality to generate and validate exergames automatically from a formal specification using a high-level language for their subsequent integration into the platform. The Section 2.3 introduces, at a general level, this language. It is beyond the scope of this paper to discuss the different submodules responsible for the validation and syntactic and semantic interpretation of the specification of the exergames built with this language.
- **Capturing module**. This module is responsible for capturing the data provided by the tracking device integrated in the platform. This data contains the positions and orientations, in 3D space, of the user's joints. It is possible to explicitly indicate which joints to monitor. This module also integrates the software necessary to capture and recognize the voice commands issued by the user when interacting with the system.
- **Assessment module**. This module is one of the most important of the architecture, since it provides the basic functionality to evaluate and classify the movements or physical exercises performed by the user. This module is also responsible for calculating the necessary information to provide feedback to the user, based on her performance.
- **GUI module**. This module has as input the information generated by the assessment module and offers the user a representation of it in the form of multimedia feedback, i.e., by means of visual and sound information. The ultimate goal of this module is to motivate and engage the user so that he/she uses the platform continuously over time. For this purpose, gamification aspects are integrated, such as, for example, scores and information on the user's level of progress.

2.3. Definition of Personalized Exergames

The proposed platform makes use of a high-level language, called Personalized Exergames Language (PEL) [18], which enables the specification of exergames adapted to a user based on his or her physical condition and ability to perform certain physical movements. Thus, from a high-level point of view, two fundamental processes can be distinguished: (i) the definition of the exergame itself, either through direct constructions of the language itself or through a graphic tool that supports the visual editing process of the exergame, and (ii) the automatic generation of the exergame from the previous definition.

The definition of an exergame includes the following steps:

1. Definition of the exergame considering the benefits obtained from its execution. As an example, in this step, one could think of improving specific capacities, such as muscular strength or mobility. In this sense, this step is associated with the therapeutic nature of the exergame.
2. Choice of the interaction mechanism between the user and the platform. At this point, preliminary aspects to the execution of the exergame are considered, such as the position of the user or of the virtual camera, and aspects of real use of the system, such as the natural interaction itself that relates the user's physical movements with the virtual effects of the same in the exergame.
3. Specification of the motivation mechanisms. In this step, the exergame integrates basic visual and sound feedback elements to provide feedback to the user when he/she is executing the exergame and when he/she finishes it. This feature is intended to increase the chances that the user will continue to use the system later on.
4. Definition of metrics to measure the user's progress level. This step, closely related to the previous one, is focused on storing information about the user's performance after the exergame has been completed. A simple example of metric could be the amount of time spent to perform the exergame.

The aspects listed above are materialized through language constructs, i.e., there are sentences that enable their definition by a nontechnical user, who would usually play the role of clinical supervisor of the platform. Section 2.4 describes how an exergame can be defined by using this language. This very same example is shown in Appendix A.

The implementation of this language is based on the GL Transmission Format (glTF) specification [19]. glTF is an open standard, based on the JSON format that is known for its popularity as a means for information exchange, and that was conceived to work with information from 3D models. This standard offers a set of constructs that greatly simplify the specification of exergames with the proposed language, so that the peculiarities linked to the specification of exergames, i.e., domain knowledge, can be realized in the form of extensions to glTF. The glTF syntax facilitates the definition of issues traditionally linked to interactive graphics applications in 3D space, such as collision between virtual objects. In this sense, the basic interaction mechanism provided by the platform is precisely the interaction of virtual objects, considering the virtual representation of the user's joints and the representation of virtual objects in 3D space.

2.4. Experimentation

In order to perform a preliminary evaluation of the proposed platform, an intervention has been carried out with a set of 17 random users, aged between 62 and 89 years, who fit the profile of people who can benefit from the concept of healthy aging.

This group belongs to the Association of People with Physical and Sensory Disabilities (COCEMFE (https://www.cocemfe.es/, accessed on 10 June 2021). It is a public service for care of the elderly people in a Grade I of dependency situation. This association is located in Talavera de la Reina, Spain. The participants were recruited both for the aforementioned association and for the Service for the Promotion of Personal Autonomy (SEPAP-MejoraT (sepap-mejoraT, accessed on 10 June 2021).

They were attended by SEPAP-MejoraT in the rural areas of Velada and Torralba de Oropesa, who met the following inclusion criteria: (i) age: older than 60 years; (ii) Grade I of dependency level in activities of daily living; (iii) upper or lower limb motor impairment; (iv) no serious and disabling conditions; and (v) who lives at home. Regarding the exclusion criteria, four were defined: (1) presence of cognitive deficit; (2) psychiatric conditions; (3) visual or attention deficit; and (4) written nonacceptance of informed consent.

Two intervention groups were configured, according to the place of residence: Velada (n = 10) and Torralba de Oropesa (n = 7). The underlying disease presented by each participant was not considered, but rather their functional consequences and their degree of dependence, defined by the inclusion and exclusion criteria.

Figure 6 shows different photos taken on the day when the system test took place.

Figure 6. Photographs taken the day of the intervention: (**a**) system connected to a projector, (**b**) user being guided for the first time, (**c**) user testing the system.

Prior to the execution of this activity, the participants were explicitly informed that the data collected would be treated confidentially and used exclusively in the present study. The ethic approval and consent form statement, which is available for the reader (https://www.esi.uclm.es/www/dvallejo/SI_Elderly_Life, accessed on 10 June 2021), was filled out by every single patient before conducting the experiment.

A intervention was designed with the proposed system, which was applied to all study participants. For data collection, an ad-hoc questionnaire was designed, in which all the study variables were included, in addition to the data provided by the system. Each session lasted 40 min, and was divided into three parts:

- **Preparation**. An instructor presented the system to each participant for about 10 min. During the explanation, an example was projected on the wall so that the participant could follow the explanation perfectly and understand the activity to be performed.
- **Development**. Each participant performed an exercise routine included in the system and tested one of the available exergames.
- **Evaluation**. Once the participant had completed the previous step, he or she was encouraged to fill in a questionnaire to evaluate the exergames and the software system usingMicrosoft One Drive Forms (https://forms.microsoft.com/, accessed on 10 June 2021), to facilitate their subsequent digital processing.

In the stage of preparation and contact with the platform, the instructor made a preliminary tour of the functionality offered by the platform, so that each participant knew how to use it and had an initial reference of the graphical aspect and the functionality provided by it. In this context, Figure 3 shows the main views of the software prototype supported by the proposed platform. It should be noted that the system supports multiple languages, and that due to the fact that the experiment was carried out in Spain, the interface shown below is in Spanish.

As introduced above, in the development stage, each user had the opportunity to execute both physical exercises and exergames integrated in the platform (see Figure 7). Particularly, the physical exercises performed were two: (1) It consists in, from an upright bipedal posture, raising three times the right or left arm from the hip to the shoulder, passing the hand in red color through the spheres placed in the 3D world that draw a trajectory. Fundamentally, the hand must pass first through the sphere close to the hip and with the largest size, ending the repetition when the colored joint reaches the sphere close to the shoulder and with the smallest size. (2) As in the previous exercise, the user should start from a straight bipedal position and raise the right or left arm from the hip to the shoulder with an elbow flexion movement. The elevation of the arm should be in a straight line.

Figure 7. Selected physical exercises and exergame for the conducted experiment. (**a**) Shoulder abduction, (**b**) elbow flexion, and (**c**) restaurant exergame. In the latter, the patient must move virtual objects from one specific location to the central tray.

The proposed functional exercise (exergame) takes place in a virtual restaurant, in which the participant pretends to be the waiter. As can be seen in Figure 7c, the dynamics of the exergame consists in moving virtual objects, such as a can of soda or a piece of cake, from a certain point to the central tray that is positioned on the bar of the restaurant. In this particular exergame, the user controls the upper limbs of the virtual avatar that can be seen in the foreground. These limbs will move according to the physical movements made by the participant in the real world, which will be captured by the system through its natural user interface.

Figure A1 in Appendix A shows the full PEL definition of the right hand to head exercise. PEL is the language previously introduce to specify exergames, so that the written sentences can be automatically processed to generate exergames which can be added to the proposed platform. In this concrete exercise, the following aspects were considered:

- The joint tracked by the system was the right hand (see line 25).
- The interaction kind is simple and consists in touching the virtual spheres (see lines 26–27).
- If a repetition of the exercise is correctly done, then the number of repetitions is increased and the user gets 100 points; if the repetition is not correctly performed, then the user must make it again (see lines 28–34).
- The user should not move part of the body when making the exercise. Particularly, the joints denoted as constraints should not be moved (see lines 37–41).
- Two metrics were included in the exercise definition (see lines 42–58): (i) the degree of mobility of the joints right elbow and right shoulder, and (ii) the performance when completing a series of the exercise. This part of the definition allows to monitor the user's progress if needed.

Once each participant finished the exercise, they were asked to complete a questionnaire with questions related to the usability of the system, and whether it helps them in promoting their personal autonomy.

The questionnaire comprised 25 closed-answers questions (see Table A1 in Appendix B), scored with a Likert scale (1: totally disagree; 5: totally agree), grouped in five dimensions: AP (activity perception), CL (cognitive load), UT (utility), GE (game elements), and TAM (Technology Acceptance Model) framework. These five dimensions are briefly described below.

- **Activity perception (AP)**. This dimension contains questions related to interest (INT), effort (EFF), and ease of learning to use the system (LEA).
- **Cognitive load (CL)**. This group includes questions inspired by the Cognitive Load Theory (CLT) [20]. It has been used to measure the complexity of the task (TD) and the complexity required by the system (DD). Additionally, two questions were introduced to measure the participant's effort with respect to the activity performed (E).
- **Utility (UT)**. The third group consists of questions related to the participant's opinion regarding the usefulness of the system. That is, if they would use it to complement the tasks performed in a rehab center (COMP), if the system encourages them to be more consistent when performing exercises (CONS), if the system enhances motivation (PAS), and if they like the application to be a game (GAM).
- **Game elements (GE)**. This dimension contains questions regarding the degree of suitability of each of the elements included both in the user interface and in the exergame scene itself, that is, elements such as the avatar representation, the number of repetitions, the score, and the remaining time or music, among others.
- **TAM**. The fifth dimension consists of questions based on the TAM framework [21]. It helps measure the perception of system usability (PEU), the utility perception (PU), and the intention of use (ITU).

2.5. Statistical Analysis

The statistical analysis was performed by RStudio® using the version 1.4. Firstly, a descriptive statistical analysis was carried out to help understand the data. Therefore, the mean ($\overline{x}$), standard deviation (σ), and mode (μ) arithmetic operations were applied to describe the variables. To contrast data normality and the behavior of the variables, the Shapiro–Wilk test was computed. As a result of the test, a nonparametric one was applied to measure the degree of association between variables. Fundamentally, it was used to determine how one item causes changes in another item. Thus, interesting findings may be discovered. For this analysis, the Spearman correlation test was used. The statistical significance level was set to 0.05.

3. Results and Discussion

The aim of this study was to know empirically the elderly people's view with respect to the use of video games combined with virtual reality to perform physical exercises at home so as to promote their autonomy.

The results collected from the questionnaire to evaluate the usability of the system, as descriptive analysis, are presented in Table 1.

Table 1. Descriptive statistics of the dimensions evaluated by the participants.

Dimension	Item	Mean ($\bar{x}$)	Standard Deviation (σ)	Mode (μ)
AP	1. INT1	**4.35**	0.86	5.00
	2. INT2	**4.35**	0.86	5.00
	3. EFF	3.76	0.83	4.00
	4. LEA	**3.59**	0.51	4.00
CL	5. TD	3.29	0.59	3.00
	6. E1	3.71	0.47	4.00
	7. E2	2.88	0.60	3.00
	8. DD	**2.41**	0.62	2.00
UT	9. COMP	**3.29**	0.77	4.00
	10. CONS	3.94	1.14	5.00
	11. PSA	4.06	1.09	5.00
	12. GAM	**4.24**	1.03	5.00
GE	13. GE1	**3.76**	0.90	4.00
	14. GE2	3.59	0.80	4.00
	15. GE3	**3.82**	0.88	4.00
	16. GE4	3.18	0.73	3.00
	17. GE5	2.94	0.43	3.00
	18. GE6	3.41	0.71	4.00
	19. GE7	3.24	0.66	3.00
	20. GE8	**3.47**	0.72	4.00
TAM	21. PEU1	**3.82**	1.01	4.00
	22. PEU2	**3.53**	0.72	4.00
	23. PU	3.76	1.09	4.00
	24. ITU1	**4.06**	0.97	4.00
	25. ITU2	**4.12**	1.05	5.00

Generally, the system has received a positive feedback by achieving a good overall score in all dimensions. It should be pointed out that the participants were not experienced at all with exergaming systems, since they indicated as the first question that they had never used a system of the characteristics presented in this paper.

Regarding the first dimension **AP**, the participants generally appreciated that the activity conducted was fun (INT1) and interesting (INT2). Furthermore, they were involved in the task and tried to do it well (EFF). Alternatively, they rated positively the system was easy to use (LEA). It seems to be logical for people who perform repetitive tasks in sessions to promote autonomy. With the use of technology, sessions are different than usual, and they seem to be more interesting, enjoyable, and helpful for elderly people.

When the subjects were asked about **CL** questions, they considered themselves to be focused on the task as it required certain concentration (TD, E1). The reason for this consideration can be attributed to the first question in which the participants manifested that they had never used a virtual rehabilitation system. Therefore, the users were totally inexperienced using technology to perform physical activity. The item E2 was rated relatively low, whose analysis may be interpreted as the participants did not put a lot effort to complete the exergames because they were intuitive enough. This may be related to the fact that the exergames were previously designed and adapted putting the focus on elderly people whose mobility may be relatively middle-low. On the other hand, the overall response of the question DD was unsurprisingly quite good as this item indicates that they found reasonably easy to perform physical exercises. It may be related to the previous idea which refers to the fact that exergames were previously designed with the aim of being easy to use and intuitive enough for people who are not very familiar with technology and, above all, virtual reality.

There was a significant positive score related to the **UT** dimension in which the participants rated that the exergames were motivating enough because the system is presented as a game. Surprisingly, the majority scored positively the question COMP. It was not expected as the target population are elderly people who are generally not familiar with technology and are normally reluctant to use it. The reason for this great valoration may be because they considered that our system may help them be more consistent in improving their autonomy (CONS). This may be also related to the **TAM** dimension in which they remarked the system is intuitive and easy to use. Moreover, our system appears to have been striking for them because of the score of the items ITU1 and ITU2, which actually indicate their intention of use at home. In view of this, it seems to be logical that they manifested that they would use our system at home as they believed the system can adequately guide them to single-handedly perform exercises and improve their autonomy.

On average, we found relatively good score for **GE** dimension of questions GE1, GE2, GE3, GE4, GE6, GE7, and GE8. It was expected as the elements of the interface was designed and included to make the system as intuitive and user-friendly as possible so that users can single-handedly use the system at home. However, the item GE5, which corresponds to the video tutorial showed during the play mode, was quite low. This result was not expected. However, a possible explanation for this may be that the vision problems some participants manifested during the experiment because of their age.

Correlational analyses were used to examine the relationship between items (see Figure 8). The most interesting findings are discussed below.

There was a significant positive correlation between INT1/INT2 and PSA items (r = 0.97, p <0.05), which suggest that enjoyment and interest are factors closely related to motivation. Likewise, we have found that the first two items (INT1/INT2) maintain a positive correlation with the variable GAM (r = 0.99, p <0.05), showing that exergames contribute to motivate people to perform more exercises. In relation to the perception of the participants regarding the usability of the system, we have found that intuitive and easy of use correlated positively with the INT1 (r = 0.85, p <0.05) and INT2 (r = 0.84, p <0.05) variables. It means that the perception of the activity, i.e., whether it was interesting or fun, had a great impact on the opinion about the usage of the tool, which seems to make sense. Interestingly, the item GE6 totally correlated with INT1 and INT2 variables (r = 1, $p < 0.05$). It seems to indicate that the fact the system includes a timer to perform an exercise suggests that it turns into an activity more enjoyable for them. Furthermore, it may be attributed to the fact that they can make use of the time to compete between them. In turn, the item PSA did correlate positively with the GE1 (r = 0.76, $p < 0.05$), GE2 (r = 0.66, $p < 0.05$), GE3 (r = 0.71, $p < 0.05$), GE4 (r = 0.72, $p < 0.05$), GE6 (r = 0.97, $p < 0.05$), GE7 (r = 0.75, $p < 0.05$) and GE8 (r = 0.87, $p < 0.05$). This indicates that the interface elements contributed to motivate the elderly people to perform physical activity. Remarkably, the correlation between PSA and ITU2 variable (r = 0.9, $p < 0.05$), and GAM with ITU2 variable (r = 0.93, $p < 0.05$), indicate the intention of elderly people to use the system. In other words, the more they find it motivating, the more they would use it at home. However, the apparent lack of correlation of DD and EFF (r = 0.05, $p < 0.05$) can be attributed to the fact that the participants did not put a lot effort to perform the tasks proposed, which indicates that the exergames set out were adequately adapted to their condition. Alternatively, the negative correlations make sense as they are all related to DD and E2 items. It means that the more the users find it difficult to perform exercises with the system, the more they will be reluctant to use this technology. In this sense, it essential to design well assistive technologies in which they do not turn into a barrier but a solution to meet their needs so that they do not abandon their therapy.

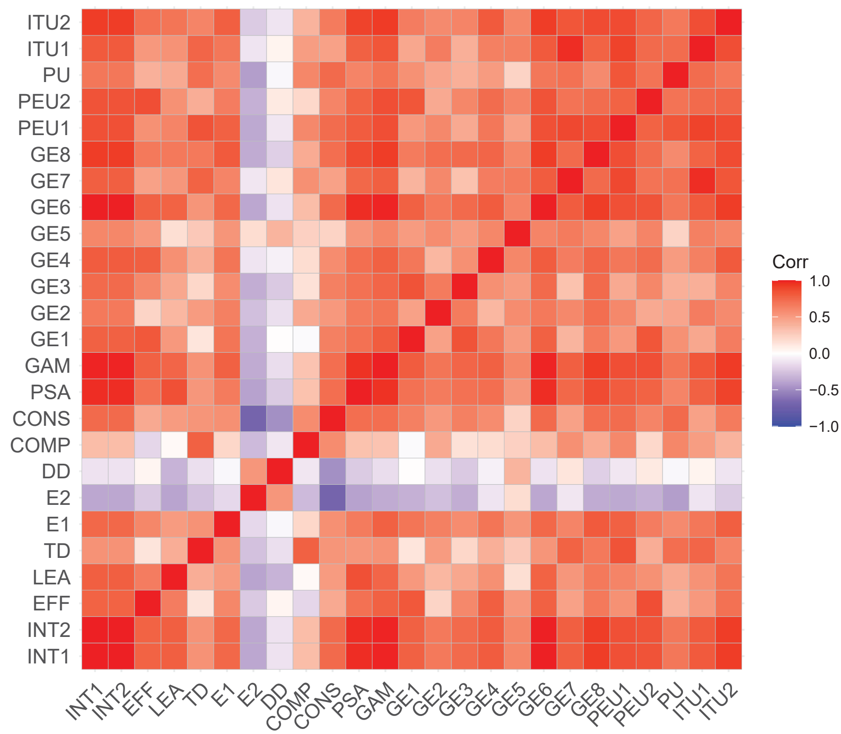

Figure 8. Spearman's rank correlation coefficient. Red squares represent higher correlation, while blue squares represent lower correlation. The level of statistical significance (*p*-value) is 0.05.

However, given that the results are based on a limited number of people, they should therefore be treated with caution. In effect, it represents a limitation of our study, so the findings obtained from this analysis may not be representative enough.

4. Conclusions

One of the major advantages of the presented proposal is the capacity to personalize the exergames integrated into the platform, which offers therapists and physicians the ability to adapt the exercise routine according to the user's needs. The gamification components have been designed to keep the user's engagement level as time goes by. In the end, ease of use and flexibility provided by the interaction mechanisms integrated in the platform make it possible to use it at home, autonomously and independently.

The platform has been evaluated by a set of 17 random users who can benefit from the concept of healthy aging through a quasiexperiment that analyzed characteristics such as the system usability, the utility, and the intention of use. We were particularly interested in measuring these items because they are strongly related to some of the barriers that elderly people face when adopting technology-based solutions, which were introduced in Section 1. The collected results reflected a positive feedback by the users, achieving a good overall score in all the assessed dimensions. It is important to point out that most of the users that took part in this experiment did not have experience in using similarhealth aging platforms.

As future lines of research, and once the proposal has been validated in terms of usability and motivation, we intend to run a clinical trial that considers a significant number of users during a longer period of time. Its aim is to objectively evaluate the quality of life of users along with their improvement of physical condition. In this trial, we are likely to find subgroups of patients who will respond well and others who will not respond as expected.

Therefore, one question that remains to be answered is related to the acceptance of the platform when used on a continuous basis over time by users who may not necessarily be familiar with the daily use of technology. Lastly, another clinical trial will be conducted to analyze the efficacy of the system compared to traditional methods. The study of this data will help us improve the proposal.

Alternatively, we are also interested in integrating the ability of automatically recommending exercises in the platform. This feature will allow the platform to dynamically adapt to the user's progress level, which is also strongly related to keeping the users motivated and engaged.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patient(s) to publish this paper.

Data Availability Statement: Data available in a publicly accessible repository that does not issue DOIs. Publicly available datasets were analyzed in this study. This data can be found here: https://www.esi.uclm.es/www/dvallejo/SI_Elderly_Life/, accessed on 10 June 2021.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Full PEL Definition for the Right Hand to Head Exergame

```
{
    ''description'': { ''text'' : ''Right hand to head'' },
    ''setup'' : {
        ''avatar'' :   { ''id_avatar'' : ''avatar-1'',
                        ''posture''   : ''standing'',
                        ''position''  : [7.27, 0.00, 4.45],
                        ''rotation''  : [0.00, 0.00, 0.00, 0.00] },
        ''camera'':  { ''id_camera'' : ''camera_1'',
                        ''position''  : [10.504, 1.27, 4.378],
                        ''rotation''  : [0.0, -90.0, 0.0] },
        ''clock''        : { ''activated'' : true, ''countdown_time'' : 120 },
        ''repetitions'' : { ''activated'' : true,
                             ''max_number_repetitions'': 3 },
        ''score''        : { ''activated'' : true }
    },
    ''trajectories'': [
        {
            ''id_trajectory'' : ''right-hand-head'',
            ''3d_path''       : [ [7.42, 0.95, 4.85], [7.43, 1.53, 4.75]],
        }
    ],
    ''gameplay'' : [
        {
            ''id_trajectory''   : ''right-hand-head'',
            ''involved_joint'' : ''hand.right'',
            ''interaction''     : { ''type'' : ''touch'',
                                    ''interaction_time'' : 0 },
            ''on_repetition_completed''  : {
                ''repetition_increment'' : 1,
                ''score_increment''      : 100
            },
            ''on_repetition_failed'' : {
                ''action'' : ''retry''
            }
        }
    ],
    ''constraints'': {
        ''joints'': [ ''pelvis'', ''spine-naval'', ''spine-chest'',
        ''hip-left'', ''hip-right'', ''ankle-left'', ''ankle-right'',
        ''knee-right'', ''knee-left'' ]
    },
    ''metrics'' : [
        {
            ''mobility'' : {
                ''joints_extension_degree'' : {
                    ''joints'' : [''elbow-right'', ''shoulder-right'']
                }
            }
        },
        {
            ''performance'' : {
                ''score_performance'' : {
                    ''score''  : [100, 200, 300],
                    ''labels'' : [''not-bad'', ''good'', ''perfect'']
                }
            }
        }
    ]
}
```

Figure A1. PEL definition for right hand to head exergame.

Appendix B. Textual Description of the Items Evaluated by Elderly People

Table A1. Textual description of the items evaluated by the participants.

Dimension	Item	Description
AP	1. INT1	This activity has been fun for me
	2. INT2	I found this activity interesting
	3. EFF	I have worked to do it well
	4. LEA	It has been easy for me to learn how to use this system
CL	5. TD	The activity required a lot of concentration
	6. E1	I have been very concentrated during the activity
	7. E2	I have had to work pretty hard to get the activity done
	8. DD	I have found difficult to perform the exergames using this system
UT	9. COMP	I would use this system at home as a supplement to the tasks I perform in a rehab center
	10. CONS	This system would make me more consistent in performing the exercises at home
	11. PSA	I believe that using this system to do physical exercise may be motivating
	12. GAM	I like the system to be like a game
GE	13. GE1	Avatar representation
	14. GE2	Number of repetitions
	15. GE3	Score obtained by making a good performance
	16. GE4	Trajectory to be followed by the avatar
	17. GE5	Icon representing the limbs being exerted
	18. GE6	Remaining exercise time
	19. GE7	Video anchored on the right hand side showing the movement a user has to replicate
	20. GE8	Background music based on the exercise to be played
TAM	21. PEU1	This system is intuitive
	22. PEU2	This system is easy to use
	23. PU	Using this system may help me in performing exercises
	24. ITU1	If I coud borrow this system, I would use it at home
	25. ITU2	I would recommend my friends to use this system to perform the exercises at home

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Exergames to Prevent the Secondary Functional Deterioration of Older Adults during Hospitalization and Isolation Periods during the COVID-19 Pandemic

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Abstract: The COVID-19 pandemic is having an intense impact on the functional capacity of older adults, making them more vulnerable to frailty and dependency. The development of preventive and rehabilitative measures which counteract the consequences of confinement or hospitalization is an urgent need. Exergaming can promote physical activity, prevent falls, and maintain functional and cognitive capacity. However, although the use of exergames in health programs for the elderly is promising, their widespread use should not be considered without the supervision of a social health professional. Therefore, the objective of this work was to evaluate and analyze three video game consoles (Nintendo Wii®, Xbox-Kinect® and Play Station 4®) and 26 commercial exergames with the aim of identifying their usefulness for the prevention of functional deterioration. Three occupational therapists analyzed the data independently, and subsequently agreed on the results. The examination of the commercial consoles met three criteria: components, interaction channels and the type of the exergame. Each exergame was analyzed taking into account its ability to train postural control, balance, upper limb functionality and cognitive function. The results of the evaluation showed that exergames contain game activities that can be part of the rehabilitative treatment aimed at the prevention of the functional impairment of older people affected by COVID.

Keywords: virtual reality exposure therapy (VRET); exergames; rehabilitation; improve functional capacity; SARS-CoV-2; post-COVID syndrome; older adults

1. Introduction

Severe acute respiratory syndrome 2 (SARS-CoV-2) has spread worldwide, affecting more than 163 million people [1]. An estimated 80% of the mortality corresponds to people over 65 years of age. In survivors, the clinical manifestations of this new disease vary widely, from mild manifestations compatible with a common cold, to death itself. In this wide spectrum of symptoms, respiratory, cardiovascular, hepatic, olfactory–gustatory, digestive and neurological affectations stand out [2].

Surviving the acute phase means that older adults face two major threats to their functional capacity: the residual symptoms of SARS-CoV-2, also called post-COVID syndrome [3], and the consequences of a prolonged period of immobility. The former is characterized by persistent fatigue, dyspnea and neuropsychological symptoms, and it affects 35% of COVID patients treated on an outpatient basis and 87% of hospitalized patients [4]. The effects of immobility in older people are widely known, characterized by sarcopenia, cardiovascular disease, osteoporosis, intestinal problems, impaired balance and an increased risk of falls, sensory deprivation, and cognitive impairment [5].

Similarly, older people who experience periods of isolation or confinement in order to avoid infection also see their functional capacity reduced by having to exacerbate a sedentary lifestyle and considerably reduce their level of mobility and daily performance [6–8].

It is evident that the pandemic is having an intense impact on the functional capacity of older adults, making them more vulnerable to frailty and dependency. In order to preserve the autonomy and quality of life in this sector of the population, the development of preventive measures that counteract the consequences of isolation, and rehabilitation programs that combat the physical and cognitive deterioration generated by SARS-CoV-2 infection is a priority.

Technological advances can offer accessible and economical alternatives to prevent dependency and initiate rehabilitation processes in situations of home, hospital or residential isolation. Telerehabilitation services, supervised by an occupational or physical therapist [9], are a viable and safe alternative for the promotion of the performance of rehabilitation exercises at home, in a hospital room or in a residence.

An emerging technique that has proven effective in improving the functional capacity and well-being of older adults is virtual-reality–based therapy [10,11]. This type of technology has made it possible to develop virtual rehabilitation activities that add dynamism and fun to treatment sessions. The key to this type of therapy is the interaction between the person and the virtual activities, as the virtual reality system emits different types of feedback depending on the movements made: sounds that inform the participant of success or failure, images or photos of the participant and messages of achievement or encouragement.

Virtual exergames represent a low-cost and commercially accessible type of virtual reality, and they have given rise to the technique of exergaming. This term, composed of "exercise" and "gaming", has been defined as any type of video game that requires the movement of the player's entire body [12,13]. Exergaming, although it comes from the entertainment industry, is being applied to enable older people to exercise in a pleasant and enjoyable way [14,15].

Exergaming breaks with the concept of the sedentary "armchair" video game and requires movement and action from the player to interact with the different game scenarios. Due to their direct relationship with physical activity and, therefore, the promotion of health, exergames have captured clinical and scientific interest since their launch on the market as a technological tool of increasing use in day centers and nursing homes.

Active video game consoles use technology that tracks movement and projects the player's motor reaction onto the game screen. They contain attractive and multisensory game environments with a high immersive capacity (for example, driving on a circuit, going down a river in a canoe or practicing a multitude of sports with the ovation of the public), in which the interaction takes place through global body movements. In this way, the practice of physical exercise becomes a dynamic and fun activity, which breaks down the barriers of repetitive and monotonous physical exercise. The gamified approach and immersive scenarios motivate older people to acquire a greater commitment to the practice of physical and rehabilitative exercises.

The potential of exergaming to promote autonomy, prevent falls, and reverse anxiety/depressive states in aging has been widely studied in the last decade [16–18]. The therapeutic application of exergames in older people has been effective in improving balance [19–21], gait speed [22,23], lower limb strength [24] and cognitive function [25,26], all of which are predictive indicators of functional disability. The incorporation of exergames in treatment sessions generates a new rehabilitative context in which the person identifies themselves and gets involved. It allows older adults to achieve actions that are not always possible in real life, due to fragility, disability or social isolation caused by aging [27]. These characteristics make exergaming an appropriate intervention to contribute to the recovery of the baseline functional state prior to SARS-CoV-2 infection. They can also be used to combat the consequences of reduced mobility due to periods of preventive confinement [28].

However, it is necessary to consider that, although the results are promising, its generalized use in the elderly should not be promoted. Commercial exergames need to be evaluated and graduated by a therapist, who should adapt the characteristics of the game to the preventive or rehabilitative intervention according to the functional level of the user. The wide variety of exergames (walking, cycling, tennis, bowling, climbing, soccer, resistance exercises, one-legged balance, adventure, zumba, aerobics, etc.) requires an exhaustive analysis of their motor and cognitive requirements, with the objective of selecting the one best suited to the needs and capacities of the person. If the level of cognitive and motor skills of the exergame exceeds the capabilities of the person, it can be demoralizing and frustrating to fail to keep up with the video game or reach the desired scores. In addition, the limits of balance and muscle strength can be altered, causing falls or musculoskeletal injuries. Jalink [29], for example, found 38 papers in which musculoskeletal injuries of the upper limbs and neck were identified in older adults who practiced physical exercise with exergames.

This study has two objectives: (1) to describe current commercial video game systems with physical motion sensors, and (2) to select commercial exergames based on four rehabilitation criteria, i.e., maintaining and changing the position of the body, maintaining or improving balance, strengthening the functionality of the upper limbs and stimulating cognitive function. With this information, rehabilitation professionals—such as occupational therapists and physiotherapists—are able to use those exergames with gaming activities that are easily adaptable to the characteristics and needs of older adults who are at risk of becoming frailer as a result of confinement and periods of hospitalization caused by SARS-CoV-2 infection.

2. Materials and Methods

Three occupational therapists independently analyzed three video game consoles and 26 commercial exergames: 12 Nintendo exergames, ten Xbox-Kinect exergames and four Play Station exergames. The results of this evaluation were then agreed upon to produce a final result.

The analysis of the consoles was based on three criteria: the components, the interaction method and the type of exergame. The evaluation of the exergames was based on four criteria: (1) the changing and maintaining of the position of the body, (2) balance, (3) the use of the upper limbs for activities of daily living, and (4) the stimulation of cognitive functions.

2.1. Commercial Videogame Consoles

Nintendo Wii®, Xbox-Kinect® and Play Station 4® are seventh-generation consoles that allow exergaming. Their use has expanded rapidly in clinical and rehabilitation units for several reasons: ecological and challenging treatment environments, immediate multimodal feedback (visual, auditory and proprioceptive) on the level of performance, high motivation and adherence to treatment, the possibility of graduating the intervention, and the low cost of the equipment.

2.1.1. Wii Nintendo®

The Wii Nintendo® video game console was the first virtual reality video game console to be launched on the market. In 2012, it was succeeded by the Wii U®, and in 2017 by the hybrid console Nintendo Switch®. The feature that differentiated the Wii from the rest of the existing consoles at that time was its wireless controllers (the Wii Remote® and Nunchuck®). The controls contain accelerometers and infrared detection that allow the determination of their position in three-dimensional space, detecting changes in direction, speed and acceleration. They also include an internal speaker and vibration. The wireless and movement detection system, through the controller, makes it possible to participate in the game, regardless of position: sitting in a wheelchair, sitting in bed or standing with a walker. This property has favored the Wii® being used by older adults with wheelchair mobility or reduced mobility.

The Wii Balance Board (WBB)® accessory is a balance platform that incorporates a Bluetooth connection and four pressure sensors that detect weight and changes in pressure in any direction, reproducing the player's movements on the screen. WBB® has found a place in clinical practice as a portable and accessible tool for the assessment of balance and the risk of falls [30,31].

WBB®-compatible exergames are related to physical exercise, sports and entertainment. Wii Fit Plus® and Wii Ski® are the most widely used exergames in clinical research. Wii Fit® includes programs for balance exercise, fitness, yoga and aerobics.

In 2020, Nintendo renewed these accessories by designing the Ring Fit Adventures® video game for the Nintendo Switch® console, which includes aerobic exercises for strength, balance and muscle stretching. The player's movements are detected through a Pilates ring (Ring-Con®) and a strap with a controller (Joy-Con®) that is fixed on the left leg. A recent study [32] found that the energy consumption of this video game is higher than that required by other exergames such as Wii Fit or Kinect Adventures.

2.1.2. Xbox® and Kinect®

The Xbox360® is the seventh-generation console produced by Microsoft®. It was introduced in 2005 and has now been succeeded by the eighth-generation Xbox One® (2014) and Xbox Series X® console. The Xbox 360® and Xbox One® incorporate the Kinect® real-time tracking sensor. Its launch in 2010 revolutionized the world of video games, making the Xbox the first console that did not need controllers to be used. In 2013, Microsoft® introduced the Kinect 2® sensor, designed for the new Xbox One® console, which included enhancements such as greater horizontal and a 60-degree vertical field of view, increased perceived depth range, and higher resolution to differentiate the orientation of the body, including hands and fingers.

The Kinect does not require the player to hold a controller to participate in the game, but the cameras and sensors are able to recognize, capture and follow their movement, and display it on the screen, without the need for manual controllers or force platforms, unlike the Wii Nintendo®. This allows physical movements and cognitive responses to take place in a more natural and ecological way.

The Azure Kinect DK® is the latest Kinect sensor from Microsoft®. This new sensor appears to hold substantial promise for functional rehabilitation processes. It was designed to be used in life sciences, fashion, robotics and logistics. It consists of: (1) a 1-MP depth sensor with wide and narrow field of view options; (2) a 7-microphone array to capture far-field sounds and voice; (3) a 12-MP RGB video camera for an additional color sequence; (4) an accelerometer and a gyroscope; and (5) external sync connections.

Although a few adverse effects of the use of Kinect have been described, some disadvantages have also been reflected, such as the need for free space in the rehabilitation department or at home (at least 2 m), the low possibility of the graduation of the speed of the games, and the non-real correlation between the score obtained and motor recovery.

2.1.3. Sony PlayStation EyeToy® and PlayStation Move®

The PlayStation3 is the third game console of the PlayStation model from Sony Computer Entertainment®. It was first marketed in Europe in 2007, and its sales were lower than those of other consoles of the same generation, probably due to its higher cost.

The PlayStation EyeToy® and PlayStation Move® accessories are PlayStation devices for motion recognition. PlayStation Move® is the main controller of the console. It consists of inertial sensors and a sphere of motion at its end. It is handheld and glows in a full range of colors using light-emitting diodes. This light serves as an active marker and is tracked by the PlayStation EyeToy® camera, which uses computer vision and features a dual focus zoom lens for gesture recognition. It also contains a built-in microphone array for multi-directional voice tracking, echo cancellation and background noise suppression.

Studies like that of Neil [33] state that playing with the PlayStation EyeToy® generates a significantly higher activity count than the Wii®, both in healthy populations and in stroke survivors. Other works have also confirmed that the use of the PlayStation is feasible in older adults with disabilities, and in people with stroke [34,35].

The PlayStation exergames most used in clinical practice and research have been Eye Toy Games, Kung-Foo, Keep-Ups, Wishy-Washy [33,34], Goal Attack, Mr. Chef, Dig and Home Run [35,36]. Dance video games have also been combined with balance exercises in older adults [37].

3. Results

3.1. Selection, Graduation and Adaptation of Commercial Exergames to the Rehabilitation of Processes Secondary to SARS-CoV-2

Commercial exergames have the great advantage of being economically accessible and highly motivating. The richness of their graphics and visual, auditory and tactile feedback achieve an active, dynamic and engaged motor response from their players. However, the dynamism of the proposed activities and the multi-feedback emitted by the system can be overwhelming for older people who are in the subacute stage of SARS-Cov-2 infection and are experiencing neuromuscular alterations such as decreased muscle mass and the loss of strength [38,39].

Like any other rehabilitation technique, exergames need to be guided with specific therapeutic objectives that respond to structured planning. Concerns have arisen about the lack of standardized clinical guidelines and treatment protocols for the use of exergames in older people [26,40,41]. Decreased visual or auditory acuity, muscle weakness, the loss of motor dexterity, slow gait speed, or difficulty in processing simultaneous stimuli can hinder the optimal participation in exergames and generate feelings of incompetence, thus risking the loss of the benefits derived from the practice of physical exercise with virtual technology.

Considering the presence of these deficits in older people affected by prolonged periods of hospitalization or preventive confinement, we propose a classification system of exergames based on four global rehabilitation objectives: (1) change and maintain the position of the body, (2) balance, (3) the use of the upper limbs for activities of daily living, and (4) stimulation of cognitive functions. This classification system facilitates the selection of exergames based on the therapeutic objectives identified for each user.

3.1.1. Change and Maintain the Position of the Body

First of all, it is necessary to identify the position in which the exercises are performed. Some exergames can be practiced from a wheelchair and others allow the player to participate only while standing. Most exergames on the Wii® or Wii U® console allow for both positions (sitting and standing); however, the Xbox Kinect sensor has difficulty capturing precise body movements when seated.

Second, the mobility functions to be rehabilitated need to be identified. From a functional perspective, we propose to distinguish four basic functions required for the performance of activities of daily living and included in the International Classification of Functioning, Disability and Health (ICF): getting up, sitting down, bending over or changing the center of gravity of the body [42]. In order to train and improve these functions, exergames can be used that include games related to maintaining balance in different body positions, imitating postures, collecting coins or points located in different parts of the screen, or getting up/sitting down. Table 1 shows exergames containing game activities that include this classification of movements, and that can be applied to optimize functional mobility.

Table 1. Exergames to rehabilitate body position.

	Getting up/Sitting Down	Bending Over	Changing Center of Gravity
Perfect 10 (Wii Fit®)			x
Table Tilt (Wii Fit®)		x	x
Rhythm Parade (Wii Fit®)		x	x
Soccer Heading (Wii Fit®)			x
Leaks (Kinect Adventure)	x	x	x
Ski Jump (Wii Fit®)			
Zazen (Wii Fit®)			
Segway Circuit (Wii Fit®)			
Reflex Ridge (Kinect Adventure®)			
River Rush (Kinect Adventure®)	x	x	x
Super Goalkeeper (Kinect Sport®)		x	x
Crash Test Dummy (Kinect Carnival®)		x	x
Bowling (Kinect Sport®)		x	x
20,000 Leaks (Kinect Adventure®)		x	x
Squats (Ring Fit®)	x		
Bank Balance (Ring Fit®)			x

3.1.2. Balance

Changing balance is especially important for older people because it compromises the safe and efficient performance of activities of daily living and increases the risk of falls [43,44]. Equilibrium has been defined as the ability to control the center of gravity on the support base itself and in the event of unforeseen events caused by external environmental factors [45]. Four different balance training modalities have been identified: the bipodal and unipodal static balance (balance in a stable position), dynamic balance (balance when walking), proactive balance (balance to maintain the functional range) and reactive balance (compensation for the unexpected) [46,47].

There is evidence that exergames such as Wii Fit and the Wii Balance Board (WBB) are useful for the assessment of balance ability. Sato [48] found that evaluations carried out with Wii Fit exergames and slalom skiing correlated with the results of the Sensory Integration Clinical Test in the measurement of the center of pressure. Similar results were obtained when comparing the measurement of exergames with high cost posturography systems [49] and force platforms [50,51], concluding that WBB is an economic resource to evaluate the shifting of the center of pressure.

In contrast, evidence has also been found that multicomponent programs that include exergames are effective in improving the balance of older people and lowering the risk of falls [52–54]. Exergaming encourages older people to perform movements that are part of the so-called Systems Framework for Postural Control (SFPC) [55,56], such as: bending over while standing, moving the upper limbs and turning the head simultaneously, coordinating movements of the lower and upper limbs, and moving the body back and forth or perform a double task while standing. Exergames such as Wii Fit, Kinect Adventures, Kinect Sport or Kinect Carnival include game activities that motivate the performance of these types of movements in a dynamic and progressive way. Table 2 details the movements included in each of these exergames. WiiSki® has ski and snowboard variants, and is clinically used to train the shifting of the center of gravity and balance. Other Wii exergames used for the prevention or rehabilitation of functional impairment that do not require the use of WBB are: Wii Sports®, Wii Resort® or Big Brain Academy®.

Table 2. Exergames to rehabilitate balance.

	Bipodal Static Balance	Unipodal Balance	Dynamic Balance	Proactive Balance
Soccer Heading (Wii Fit®)	x			
Ski Slalom (Wii Fit®)	x		x	
Ski Jump (Wii Fit®)	x		x	
Table Tilt (Wii Fit®)	x		x	
Tightrope (Wii Fit®)	x		x	
River Rush (Wii Fit®)	x		x	x
Penguin Slide (Wii Fit®)	x		x	
Obstacle Course (Wii Fit®)	x		x	
Cycling (Wii Fit®)	x		x	
Running Plus (Wii Fit®)	x		x	
Rhythm Kung Fu (Wii Fit®)	x	x	x	
Rhythm Parade (Wii Fit®)	x		x	
Skateboard (Wii Fit®)	x		x	
20,000 Leaks (Kinect Adventure®)	x	x	x	x
Super Striker (Kinect Sport®)		x		
Soccer (Kinect Sport®)		x	x	
Table Tennis (Kinect Sport®)	x		x	x
Bowling (Kinect Sport®)	x		x	
Super Goalkeeper (Kinect Sport®)	x		x	x
Ski (Kinect sport®)	x		x	x
Track and Field (Kinect Sport®)	x		x	
Bank Balance (Ring Fit®)	x		x	x

3.1.3. Promote the Use of the Upper Limbs for the Activities of Daily Living

Upper limb functionality has been identified as an index of frailty in older people [57–59]. Periods of hospitalization and prolonged time in bed trigger the loss of muscle mass and strength in the arms, which reduces the performance of the activities of daily life—such as personal hygiene, dressing or housework—and generates high levels of dependency. Sports exercises such as tennis, table tennis, bowling, golf or basketball could help improve the mobility and muscle strength of joints such as the shoulder and elbow. Table 3 proposes different exergames to plan an exercise program aimed at restoring the functionality of the upper limbs.

Table 3. Exergames to rehabilitate upper limb functionality.

	Upper limbs Below the Shoulders	Upper Limbs Above the Shoulders
Rhythm Parade (Wii Fit®)	x	
Rhythm Kung-Fu (Wii Fit®)	x	
Golf (Wii Fit®)	x	x
Big Top Juggling (Wii Fit®)	x	x
Tilt City (Wii Fit®)	x	
Tennis (Wii Sport®)	x	
Bowling (Wii Sport®)	x	
Golf (Wii Sport®)	x	x
Boxing (Wii Sport®)	x	x
Baseball (Wii Sport®)	x	
Tennis (Kinect Sport2®)	x	
Darts (Kinect Sport2®)	x	
Table Tennis (Kinect Sport®)	x	
Super Goalkeeper (Kinect Sport®)	x	x
Beach Volleyball (Kinect Sport®)	x	x
Boxing (Kinect Sport®)	x	
Tennis (Kinect Sport®)	x	
20,000 Leaks (Kinect Adventures)	x	x
Space Pop (Kinect Adventures®)	x	x
Leaks (Kinect Sport®)	x	x
Crushing Blow (Kinect Sport®)	x	x
Robo-Wrecker (Ring Fit®)	x	
Crate Crasher (Ring Fit®)	x	
Smack Back (Ring Fit®)	x	
Bank Balance (Ring Fit®)	x	
Squattery Wheel (Ring Fit®)	x	

3.1.4. Stimulation of Cognitive Function

Recent trials have detected short-term memory deficits [60], decreased attention and disorientation [61], and the exacerbation of neuropsychiatric symptoms [62] in older patients admitted with SARS-CoV-2 infection without a prior diagnosis of dementia. In the case of people with dementia, coronavirus infection has been found to exponentially accelerate the course of the disease. A study carried out in Spain found that, during confinement, 70% of patients abandoned previous daily activities and 60% had cognitive decline reported by relatives [63].

Exergaming, by combining physical and cognitive exercise in an interactive environment, can act as a stimulating tool for cognitive function. Systematic reviews coincide in pointing out promising results on cognitive function in older people, using exergames to improve the levels of orientation, attention and executive functions [64–66]. Exergames like Brain Training®, Dr. Kawashima®, or Kinect Adventures® can be helpful in stimulating cognitive functions such as attention, concentration, sequencing and processing speed.

4. Discussion

The aim of this work was to study the potential of exergaming in the rehabilitation of older people who are in periods of confinement, or who have had SARS-CoV-2 infection.

The analysis of commercial exergames revealed their versatility in both standing and seated positions. This property is important, because it may allow the progressive planning of rehabilitative treatment. In this regard, previous studies have reported the successful adaptation of Wii exergames for people with reduced mobility and wheelchair users [67]. Moreover, Kinect exergames can improve the muscle strength needed for wheelchair propulsion [68]. It therefore seems reasonable that exergames can contribute to the rehabilitation of older people who have lost mobility after hospital admissions for Covid-19.

Regarding balance rehabilitation, certain exergames such as WiiFit® include specific activities to improve anteroposterior and lateral balance. Previous systematic reviews and meta-analyses confirmed that exergaming increases balance and prevents the risk of falls in older people [40,46,54]. In our analysis, we found that 90% of the exergames contained games with which static bipodal balance and dynamic balance could be trained. However, the functional analysis revealed that only 30% could train proactive balance, and only 18% could train unipodal balance. These results could be of interest for the design of new exergames aimed at balance rehabilitation.

The rehabilitation of upper limb functionality with virtual reality has been explored mainly in people with stroke [69,70] or multiple sclerosis [71,72]. Our analysis showed that exergaming can also be used to train upper limb mobility below and above the shoulder girdle, improving the overall functional range of elderly people. It would be interesting to explore this aspect in future research.

Finally, our analysis is not without limitations. Firstly, we did not analyze all of the exergames available on the market, although we selected the most popular and best-selling ones. Moreover, other body functions, such as specific lower limb functions, were not considered in the analytic variables, as we selected global functions related to the performance of the activities of daily living.

5. Conclusions

Older people are more likely to suffer more serious and persistent consequences from SARS-CoV-2. Low-cost virtual-reality technology, such as exergames or active video games, can be used to prevent functional impairment, or to rehabilitate motor and cognitive functions. However, it is necessary to prescribe virtual exercises based on rehabilitative criteria tailored to the symptoms in each case, which requires an individualized evaluation of the patient, taking into account the variability of symptoms and sequelae associated with SARS-CoV-2 and an exhaustive analysis of each exergame. Our proposal was based on the use of exergames from Wii and Xbox consoles to prevent and/or rehabilitate the appearance of problems associated with postural control, balance maintenance, upper limb functionality and cognitive stimulation. With this analysis, we provided relevant information to rehabilitation staff to make decisions which allow them to select the games efficiently, based on the type of exercise offered by the game, its level of challenge and the possibilities of graduation based on the therapeutic objectives.

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