USING TECHNOLOGY TO COMBAT DISEASES AND HELP PEOPLE WITH DISABILITIES

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Table of Contents

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EDITORIAL
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Editorial: Using Technology to Combat Diseases and Help People With Disabilities

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Keywords: technological ecosystem, digital transformation, people with disabilities, virtual environment, eHealth, user experience, Elderly People, Dementia Care

Editorial on the Research Topic

Using Technology to Combat Diseases and Help People With Disabilities

Nowadays, we live in a technological society that is involved in an unstoppable digital transformation affecting all the business domains, such as education (Castro Benavides et al., 2020; García-Peñalvo, 2021a), industry (Ghobakhloo and Iranmanesh, 2021), tourism (Infante-Moro et al., 2020; Cuomo et al., 2021) or health (Kraus et al., 2021; Kwon et al., 2021; Massaro, in press).

COVID-19 pandemic has accelerated the digital transformation in all the sectors (Cabero-Almenara and Llorente-Cejudo, 2020; Agostino et al., 2021; Argüelles et al., 2021; García-Peñalvo, 2021b; García-Peñalvo et al., 2021a; Hai et al., 2021), but also this disease, beyond its terrible effects, has caused many psychological sequelae both to the patients themselves and to the people who have been confined, but which have been greatly emphasized in people with some type of disability (Akintunde et al., 2021; Wilson et al., 2021; Panchal et al., in press) or mental disorders (Chirico et al., 2021; Ottoboni et al., 2021).

eHealth ecosystems have a significant presence and importance in the current medical practice to create novelty treatments for people who suffer some disabilities or diseases (Marcos-Pablos and García-Peñalvo, 2019; García-Peñalvo et al., 2021b). Telemedicine, powerful surgery assistants, artificial intelligence agents for diagnosis are real examples that we can find in our hospitals for improving the cognitive capabilities of individuals with Down Syndrome, combating nutrition disorders, assisting people with dementia, improving our older people's well-aging, or connecting persons with a physical impediment among other applications.

This Research Topic comprises 11 papers with studies and experiences of using technology for improving the quality of life of people with disabilities or who suffer from diseases, with more interest in the effect of technology than in the technology itself.

Aesthetically Designing Video-Call Technology with Care Home Residents: A Focus Group Study (Zamir et al.). This study conducts focus groups with an embedded activity with older people to allow for a person-centered design of a video-call intervention.

Digital Fabrication and Theater: Developing Social Skills in Young Adults with Autism Spectrum Disorder (Poveda and Montoya). This article focuses on the digital fabrication workshops, where a group of 10 young individuals with autism spectrum disorder worked on the fundamentals of electronics and programming, as well as 3D design and printing, to make props that were later used on stage in the theatrical performances in which they participated.

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Vocational Training in Virtual Environments for People with Neurodevelopmental Disorders: A Systematic Review (Michalski et al.). The findings from eight selected studies demonstrate that people with neurodevelopmental disorders can transfer vocational skills from virtual environments to real-world settings.

Technological Ecosystems that Support People with Disabilities: Multiple Case Studies (Ramirez-Montoy et al.). This study empirically analyzes the usefulness of treatments that have been supported by technology to answer the question "How do technological ecosystems being used help people with special educational needs?".

Knowledge Gaps in Mobile Health Research for Promoting Physical Activity in Adults with Autism Spectrum Disorder (Lee). This paper provides information on physical activity research and the prospective role of mobile health applications for promoting it in adults with autism spectrum disorder.

Using Technology to Identify Children with Autism through Motor Abnormalities (Simeoli et al.). The authors propose using a smart tablet device with a touch screen sensor to capture detailed information about the motor patterns of children with autism spectrum disorder.

Usability and User Experience of Cognitive Intervention Technologies for Elderly People with MCI or Dementia: A Systematic Review (Contreras-Somoza et al.). This review finds evidence about usability and user experience measurements and features of stimulation, training, and cognitive rehabilitation technologies for older adults with mild cognitive impairment or dementia.

Framework for the Classification of Emotions in People with Visual Disabilities through Brain Signals (López-Hernández et al.). The authors present a 2-fold framework focused on people with visual disabilities that can classify positive and negative emotions.

Assistive Technologies in Dementia Care: An Updated Analysis of the Literature (Pappadà et al.). The evidence shows that technology is well-accepted and can support people with dementia and caregivers to bypass physical and environmental problems both during regular times and during future pandemic waves.

Psychometric Properties of the Spanish Version of Psychosocial Impact of Assistive Devices Scale in a Large Sample of People with Neuromuscular, Neurological, or Hearing Disabilities (Díez et al.). This study to evaluate measurement properties of the Spanish version of PIADS scale by means of a dataset obtained from its application to a large sample ($n = 417$) of people with neuromuscular, neurological, or hearing disabilities that used different assistive devices.

Nurturing Grandchildren with Down Syndrome: A Qualitative Study on Grandparents' Needs Using Digital Tools (Sánchez Gómez et al.). This study analyzes, from a personal perspective, the situations and needs of grandparents who have grandchildren with Down syndrome.

The contributions of all the selected papers and, by extension, of the Research Topic addressed highlight, in the first place, a problem faced by society when its members, due to age or illness, have limited capacities and require greater attention and care. Secondly, technological advances make it possible to intervene in these problems, although they are not magic solutions but tools in the hands of medical professionals, caregivers, and family members that will help both dependent persons and those who care for them. Artificial intelligence is a field that has just begun to be exploited, and that will indeed allow incredible advances in the care and monitoring of people with needs and support for more accurate diagnoses. For all these reasons, we believe that this Research Topic is only a tiny sample of what is being done and what will be done in the coming years, with the aggravating and stimulus while has meant suffering a worldwide pandemic such as that of COVID-19.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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ORIGINAL RESEARCH
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Aesthetically Designing Video-Call Technology With Care Home Residents: A Focus Group Study

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Background: Video-calls have proven to be useful for older care home residents in improving socialization and reducing loneliness. Nonetheless, to facilitate the acceptability and usability of a new technological intervention, especially among people with dementia, there is a need for user-led design improvements. The current study conducted focus groups with an embedded activity with older people to allow for a person-centered design of a video-call intervention.

Methods: Twenty-eight residents across four care homes in the South West of England participated in focus groups to aesthetically personalize and 'dress-up' the equipment used in a video-call intervention. Each care home was provided with a 'Skype on Wheels' (SoW) device, a wheelable 'chassis' comprising an iPad or tablet for access to Skype, and a telephone handset. During the focus group, residents were encouraged to participate in an activity using colorful materials to 'dress-up' SoW. Comments before, during and after the 'dress up' activity were audio recorded. Framework analysis was used to analyze the focus group data.

Results: Older people, including seven with dementia were able to interact with and implement design changes to SoW through aesthetic personalization. Themes arising from the data included estrangement, anthropomorphism, reminiscence, personalization, need for socialization versus fear of socialization and attitudes toward technology. After this brief exposure to SoW, residents expressed the likelihood of using video-calls for socialization in the future.

Conclusion: Care home residents enjoy engaging with new technologies when given the opportunity to interact with it, to personalize it and to understand its purpose. Low cost aesthetic personalization of technologies can improve their acceptability, usability, and implementation within complex care environments.

Keywords: video-calls, focus group, design, older people, care-setting, personalization, dementia, Skype

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INTRODUCTION

Those engaged in e-health development and implementation have reported key reasons why we should include older users in research pertinent to interventions reliant on technology (Seale et al., 2002). First, they maintain that involvement can avoid the application of technology that may create more problems than it actually solves (Graafmans, 1998b). Second, their contribution in the earliest stages of research and development 'anchors' the technology in end-users' views and experiences (Stern, 1994). Third, the 'design for all' notion claims that what works for older people will work for everyone (Sandhu, 1998). Examples of the effectiveness of older user involvement exclusive to product development are increasing within the United Kingdom (UK). The Royal Society (UK) has actively promoted the idea of older users being involved in research at the early stages of design development through the 'New Design for Old' project (Hewer and Kingsland, 1998). Similarly, the Centre for Applied Gerontology in Birmingham (UK) is recognized as pioneering the involvement of older people in the design and evaluation of products, forming a consumer panel of '1,000 elders' (Graafmans, 1998a).

Contemporary socialization interventions for older adults incorporate internet use including applications such as Facebook (Jung and Sundar, 2016), and email (Osman et al., 2005; Cotten et al., 2013). More recently, advanced telepresence technologies that integrate video-calls have been developed, and tested among older people with and without dementia to reduce loneliness (Moyle et al., 2017). These current socialization interventions have been demonstrated to be enjoyable and beneficial for older adults who live alone or in care environments (Morris et al., 2014; Zamir et al., 2018). For example, low-cost videophones have been tested for feasibility among older, frail care home residents to enhance communication with distant relatives proving to be an effective socialization tool (Mickus and Luz, 2002). The concept of videophones has also been trialed for usability among older people with dementia and their social contacts. Similarly, the results revealed positive attitudes toward them, demonstrating users' perceptions of videophones as worthwhile (Boman et al., 2014). Nonetheless, such studies have identified technical and design problems with an older cohort, which need to be addressed before being readily implemented as a long-term technology solution (Zamir et al., 2018).

Successful technology implementation is now more often being characterized as 'bricolage' (pragmatic customization of technologies), by the participant or by 'bricolers', someone close to them (Greenhalgh et al., 2013). The concept was first put forward by Greenhalgh et al. (2013) in relation to assistive technologies. As the world now accesses technology on a daily basis, we habitually engage in bricolage every day. We tend to put together available objects and technology devices that are at our disposal in different ways to their intended purpose to create solutions for either our social, health or mental well-being needs. For example, carriers or those with dementia engage in bricolage as they adapt assistive technologies in dynamic and innovative ways such as sticking tapes over buttons or even building their own telecare systems to meet their needs (Gibson et al., 2018).

Such ideas are being implemented in practice where residents in care homes have been able to 'dress up' and 'pimp' their Zimmer frames and other assistive objects (Health Foundation, 2017). Aesthetic personalization of technologies has been explored with consumer electronics, where design companies have realized consumers' perceptions can sway the process of choosing and using such products (Tzou and Lu, 2009). Tzou and Lu explored the emotional (brand attachment and uniqueness), aesthetica (pleasure and beauty) and ergonomic (perceived usefulness and ease of use) conceptions that can impact public acceptance of products. Their study suggested that aesthetic facets are a vital determinant to acceptance intention.

For a successful and efficacious design development process with older adults using the idea of bricolage (Gibson et al., 2018) and personalization through shared group activities can promote a better understanding of perceptions of design features. In turn this produces outcomes that are useful for the investigators at the early stages of the research cycle (Seale et al., 2002). Therefore, focus groups or group market research activities have been advocated in health and technology advancement to allow for exploratory research where little is known in the earliest phases, or to add further depth to and understanding of the topic (Kitzinger, 1995; Seale et al., 2002).

The European project ACTION (Assisting Carers using Telematic Interventions to Meet Older people's Needs) is one illustration of how focus groups have been applied to the topic of technology solutions. Discussions with participants revealed older people's concerns with technology, but also the belief that modern technology could have a positive impact on their lives and well-being (Magnusson et al., 1998).

Avis et al. (2015) reported challenges and opportunities that focus groups aimed at refining digital technologies might present. These challenges, especially when including older people, can produce a long list of concerns. Aging participants may be inexperienced in using modern technologies (Vaportzis et al., 2017). Participants with dementia are not always included in such discussions meaning their views can go underrepresented (Fukuda et al., 2015; Zamir et al., 2018). Participants may be reliant on a caregiver to be present and so their responses may not always be representative. Also, older individuals may feel inadequate to contribute toward the refinement of advanced technologies, feeling it is not relevant to them (Stern, 1994; Vaportzis et al., 2017). It can be nearly impossible to control for all of the potential challenges listed above, however, focus groups with older participants are rewarding in facilitating intervention implementation and evaluation for a number of research studies (Seale et al., 2002; Demiris et al., 2004; Mitzner et al., 2010; Vaportzis et al., 2017).

The current study employed focus groups to address a principal barrier toward implementation of a video-call intervention, 'Skype on Wheels' (SoW) (**Figure 1**) in care homes for residents with and without dementia. The 'Skype on Wheels' idea in the form of telepresence robot (e.g., Giraff) had been trialed before (Tsui et al., 2011; Do et al., 2012) but was expensive. Our SoW device was intended as a 'budget version' with no robotics, moved around the care home by staff. The long-term aim of SoW was to improve socialization and reduce loneliness

FIGURE 1 | Skype on wheels (SoW) intervention.

by helping residents to connect to distant loved ones and create new social contacts. Feedback from care home staff and residents in the previous research (Zamir et al., 2018) revealed key barriers to and benefits of video-calls for socialization suggesting the need for residents to aesthetically personalize or 'dress-up' SoW which, at that time, appeared 'scary' and 'clinical looking.'

The aims of the focus groups were twofold. First, it was to elicit and qualitatively explore the views and expressions of residents toward SoW and its overall design. Second, it was to serve as an activity to allow residents to aesthetically personalize SoW, thus taking from the concept of bricolage. This focus group activity could help normalize a new technology within a complex care environment and help inform better ways to implement video-calls for socialization purposes.

MATERIALS AND METHODS

Design

The study followed Avis et al. (2015) seven-step approach to using focus groups for refining digital technologies: (i) a 'checklist to plan, track and report' all aspects of the focus group; (ii) the inclusion of a 'helper' to act as facilitator to help manage the group dynamics and flow of the discussion; (iii) factoring in time for 'constructive feedback' such as unexpected remarks and negative expressions; (iv) tailoring questions to participants by moderating questions and making use of probes or prompts; (v) seeking participants' views on elements such as aesthetics, ease and logic of navigation; (vi) managing feedback to the task at hand; (vii) leveraging the digital expert, the person with experience of the intervention, design or technology.

Ethics

This study was approved by the University of Plymouth ethics committee in August 2016. All residents and staff gave written consent and an information sheet was provided. For those who had dementia and/or were unable to give written consent, verbal consent was gained before the focus group and a care staff member confirmed this in writing with the first author.

Care Homes

The recruitment and participation of older people was via a convenience sample of four care homes. The criteria for inclusion of the care homes was that the managers agreed to participate and trial the use of the SoW device, they said the home had a good internet connection, and the homes were within traveling distance for the lead researcher. Characteristics of each care home including average number of residents, type of care provided, video-call equipment available and WiFi connections were noted in the study and are described below (**Table 1**).

Participants

The participants comprised a convenience sample of 28/107 older people from the four care homes. Initially care staff identified potential participants who had ability to consent to the study (the only inclusion criterion). For those who were able to consent the

TABLE 1 | Characteristics of care homes participating.

	C1	C2	C3	C4
Number of care staff at site	45	60	15	45
Care staff participating	2	3	3	2
Average no. elderly persons in care*	30	30	17	30
Minimum age of elderly persons	65+	65+	70+	65+
Type of care given	Dementia	Dementia	Dementia	Dementia
Weekly visits**	40%	30%	95%	40%
No visits***	15%	15%	1%	10%
Video-call equipment available	• iPad • Samsung Galaxy tablet • SoW device • Telephone handset	• iPad • SoW device • Telephone handset	• iPad • SoW device • Telephone handset	• iPad • SoW device • Telephone handset
WiFi connection	Throughout the site	Throughout the site	Throughout the site	Throughout the site
Speed of WiFi* (as reported by care staff)	Good enough	Fast	Good enough	Good enough

**Between March–December 2016 **Estimated proportion of older people who were usually visited each week by loved one. ***Estimated proportion of older people who usually received no visits over a 4 weeks period.*

first author then visited and invited them to participate to the study, regardless of physical or mental limitations or previous use of video-calls. The four focus groups ranged from five to nine participants per group. There were six males and 22 females. Ages ranged from 65 to 97 years (mean = 80 years). All participants spoke English as their first language. Race and ethnicity were not diverse within the sample; all participants were white Caucasian. Three participants had previously used video-calls but 25 had not. Eight participants were thought by the care home staff to have dementia of varying degree, two with advanced dementia (but still able to give consent), three with moderate dementia, and three with early stage dementia. Other impairments of participants were also noted. These included hearing impaired (n = 14), visually impaired but able to see with glasses or moving objects close enough (n = 9) and frailty (n = 10). Two participants were non-verbal but were able to lip read and communicate through sign language or gestures and from support of the care staff facilitator.

Eight care home staff took part in the study. Five care home staff participated as ‘active facilitators’ who supported the researcher in presenting SoW to residents, and supported non-verbal residents or those with dementia to partake. Three care home staff and one student from the University of Plymouth were involved as ‘inactive facilitators’ who observed interactions and made notes throughout the focus groups to improve the accuracy of data.

Materials

The SoW intervention comprised an iPad and a colorful telephone handset (**Figure 1**). Care home staff suggested materials to ‘dress-up’ and personalize SoW to improve its acceptability among residents. Specifically, three care home staff suggested the need for colorful and soft materials that residents were able to touch, feel and add on to SoW to reduce its ‘clinical’ appearance. This was similar to the art therapy sessions in two of the care homes that residents were accustomed to and enjoyed, particularly as a group activity. Materials were selected by the researcher (first author) and shown to care home staff before the commencement of the study. The same materials were used across all four focus groups, namely: stickers [letters and numbers, a sticking chalk board (A5 size), cocktail heart and star shapes], purple butterfly wings and wand, Hawaii flower necklace, bow tie, squares of different colorful tissue, small paper men and women, A4 sized colorful windmills, fluffy colorful and flexible pipes (**Figure 2**).

Focus Group Script

The script was semi-structured and designed to facilitate discussion between residents regarding domains of purpose, design, and overall aesthetic appeal. In addition, the likelihood of using a telecommunication technology such as SoW for socialization was discussed. Although some residents had experience of using video-calls on a tablet or iPad, SoW was a novel device not seen by many prior to the focus groups. In previous research (Zamir et al., 2018), patients and residents were presented with SoW and reactions were recorded. Older people mostly asked “*what is this?*” and therefore our first question in the focus group was “*Do you know what this is meant to be used for?*”, which was followed by discussion prompts that varied across each group. The researcher or care home staff member who was an ‘active facilitator’ then explained SoW’s purpose and asked if participants felt the device mirrored its function. For the design domain, participants were asked “*What do you think of this device?*”, “*What do you like/dislike about this device? Why?*”, “*What would you change? How?*”, “*What would you keep the same?*”, and “*What color handset would you prefer?*” For the usability domain, participants were asked “*Do you feel comfortable using this?*” and “*Does the handset feel comfortable to you?*”, which acted as a prompt for participants to touch and feel the device.

FIGURE 2 | Focus group materials.

A second discussion after 'dressing up' SoW was to understand whether participants felt the device was now more acceptable and normalized to their environment. This open and unstructured conversation was dependent on how each group had aesthetically personalized the device. The researcher asked each group if they wanted to participate in future video-call activities, and whether they better understood what an iPad and Skype was before the close of the focus group activity.

Procedure

Each focus group was conducted in the care home lounge of the participating site and lasted approximately for 1 h. The researcher summarized the purpose of the focus group as being part of the University of Plymouth's research on improving the design of new technologies for older people, and the need to gather some useful feedback from them to implement these design changes that would increase their usability. Participants were told that the technology in front of them (SoW) was a new device and was for their care home to keep, therefore it could be useful for them to personalize it to their liking. The researcher or care staff further explained the rules of the discussion (one person to speak at a time to contribute their thoughts and ideas).

Each group discussed SoW over three domains of understanding the purpose, design, and usability over two discussion points, which were at the start and end of the session. The focus group sessions were split across three segments. First, participants discussed each domain prior to 'dressing up' SoW. At this point, the researcher or 'active facilitator' wheeled the device to each participant for them to gain a closer look and feel of Sow and to further ask questions about it or make comments on its texture or features. Then, participants were given time to select and aesthetically individualize or 'dress up' SoW according to their personal taste with support from the researcher or 'active facilitator' (i.e., to physically stick on materials and move the device across to each participant). Third, participants re-discussed each domain and were asked if they wanted to participate in future video-call sessions using SoW. Throughout the focus groups, the 'inactive facilitator' made observations and took notes on interactions with SoW, and between participants.

Data Collection and Analysis

The focus groups were audio recorded and for those participants who were non-verbal, the researcher described aloud the hand gestures or movements. Additionally, the 'active facilitator' voiced the participant's answer to ensure the audio recording device captured all comments. Similarly, for those participants who had dementia or were unable to speak loud enough (due to frailty), the researcher repeated back what the participant had said to improve clarity and accuracy when transcribing the data. Focus groups were transcribed verbatim and personal identifying information was omitted. Observations throughout were taken as handwritten notes by the 'inactive facilitator' and became field note data.

Transcripts were analyzed using framework analysis as developed by Ritchie et al. (2003). Gale et al. (2013) provide a clear and comprehensive step-by-step guide in using the framework in health care research. Their outlined procedure for the analysis of the current focus group transcripts was applied. First, transcription of the audio recording was done verbatim. The researcher then became familiarized with the transcript and the observation notes were included to help interpret the data. After familiarization, open coding on the first 2–3 transcripts was done by adding a 'label' or paraphrase. Codes included behaviors, values, and emotions. A second researcher (second author) independently coded three (of four) focus group transcripts, and then the researcher (first author) added codes to these. Researcher one and two then developed an analytical framework by comparing the codes they had applied and agreed on a final set of codes to use. Codes were listed and grouped together into categories (if necessary) into Excel, which would become the final codes. These final codes were applied to the subsequent transcripts (including field notes from observations). Codes or categories were assigned abbreviations for easy identification in the subsequent transcripts. The analyzed data was then charted into a framework matrix, which included reducing and summarizing the data by category or code, and adding a supporting reference to each. Finally, analysis of the matrix generated themes by making connections between the codes and categories. All authors agreed the final set of themes within the manuscript.

RESULTS

All four care homes successfully engaged in the activity producing a noticeably distinct SoW at the end of the session (**Figure 3**). The analysis of the focus group data revealed codes and categories, which informed six final themes (**Table 2**). Residents from C1 had mixed reactions toward SoW during the session with one resident who was disinterested throughout the focus group. Here, residents preferred to interact with SoW by touching and feeling the device to understand it better. Residents from C2 appeared to be the most dismissive group pre dress-up. They portrayed more negative reactions and confusion toward SoW compared to the other care homes. This group engaged in far more talk about the appearance of the device and its aesthetic appeal, rather than the feel of it. Residents from C3 reinforced the notion of 'personalization' that emerged from the data. Here, residents preferred materials such as the letters and numbers to help remind them what SoW was, and to attach their personal names to the device to increase its acceptability. Residents in C3 were not confident in engaging with technology but were open to the idea of using SoW for communication with distant relatives. Residents from C4 appeared more intrigued toward the prospects of having a new technology in their home. Because of this, they focused their attention on, and selected materials that could personalize SoW to their liking.

Estrangement

Residents initially expressed negative feelings toward the SoW design, and overall technology use before dressing up the device. As a result, a theme of 'estrangement' emerged from the data where residents were dismissive of SoW when it was first introduced stating that they "*wouldn't really bother with it,*" and would "*leave it for other people*" as "*it's nothing to do with me.*" For a few, the device was noticeable which sparked interest as some residents stared at the device and pointed to it stating "*I think this would be interesting*" and remarking '*Oh my gosh. . .interesting.*" One resident from C2 found the device to be strange however, this did not deter him from wanting to use it, "*Yes I don't mind using it. . .strange. . .but I don't mind.*" Conversely, other residents appeared less engaged as they turned away from the device and the group, or presented signs of uncertainty when first noticing the device, as they were unable to recognize it and so were unsure of its purpose. One resident with cognitive decline was especially dismissive expressing annoyance when first seeing the device, "*I get annoyed*" but explained it is because "*I don't know anything about it.*" Furthermore, some residents felt the nature and purpose of the device, as with most new technology, was obfuscated and needed to know more about SoW before engaging with it, or even having it in and around their environment.

> "*I haven't got a clue, because it's strange looking maybe because all these new things are. . .the way they are made. . . we wouldn't know what it is intended for or what to use it for round here.*" [Obfuscated- Uncertainty] (Resident, C4)

Reminiscence

The SoW props such as the telephone handset acted as a recognizable prop. This was evident when asked what residents perceived the device was used for, as many were able to answer '*to make telephone calls*' or *'to speak to people with.'* Furthermore, the shape of SoW was useful in triggering memories for some residents. One resident from C2 felt the device was similar to those that were used to take photographs during their time. Another resident from C2 similarly made comparisons stating, "*Well that's what made me think it looks like a camera,*" with two residents from C4 who corroborated this idea.

One female resident in C2 correspondingly linked the SoW design to a telephone, specifically the old cord telephones she used to have in her home. Another fellow resident claimed it looked similar to the red public telephone booths further supporting this idea. This sparked a conversation among the group of residents in C2 who began to reminisce, and in turn initiated interest toward participating in future video-call activities. Two residents from C3 further suggested the design of SoW should mimic the famous red telephone booths (as seen in London) as they tend to be more recognizable to their age group.

> "*Well I think it reminds me of almost being like the telephone on the walls you know. . .the red booths. . .so you could have that fixed on the wall and 'telephone' written on the side of it or probably the other way round but that's what I think.*" [Recognizable- Triggered memories] (Resident, C3)

After the dress-up of the device and learning that the video-call app Skype is part of SoW, one resident remembered what an iPad was linking it back to SoW. The interaction between the resident and SoW triggered memories of previous encounters of similar technologies.

> "*SKYPEEE. . .Oh OK sorry for interrupting so is that. . .I think I can remember now. . .something miniature that you carry around*

FIGURE 3 | Skype on wheels dressed up.

and write on? No that's a different thing? But you use that for the Skype. . .yes". [Recognizable- Triggered memories] (Resident, C3)

Attitudes Toward Technology

Residents' body language toward SoW reflected the type of attitudes they held. For example, some residents displayed smiles, laughter, excitement and leaned forward, whereas others turned away even after it was explained what the purpose of SoW was. It appeared that residents had set expectations of technology or schemas based on previous experiences that shaped the way they perceived SoW. Many appeared untrusting of technology as residents repeatedly said '*No, no*' and shook their heads at the thought of using SoW for conversations. Two residents felt uncomfortable with the idea of their images being available for others to see in the screen and insisted in knowing how easy it was for the public to access their images. One resident from C2 associated SoW to a spying device "*I don't know. . .I just don't know. . .it's to spy!*". Others appeared to be untrusting of the materials used that formed the actual device (the poles), and felt that it would easily "*break apart as most of these new technologies do.*"

Much of the adverse attitudes toward technology was reflected in the comments made by some residents who clearly just prefer what they know already. One resident in particular from C2 explained that if she was given the opportunity she would have her old phone to use rather than new advanced phones. Similarly,

TABLE 2 | Final themes with corresponding categories and codes.

Themes	Categories	Codes
1-Estrangement	Obfuscated	*Uncertainty Dismissive*
2-Reminiscence	Recognizable props	*Triggered memories Initiate interest*
3-Attitudes toward technology	Expectations of technology	*Untrusting technology Aging stigma Prefer what they know Purposeful design Usefulness Activity orientated Age appropriate*
4-Anthropomorphism	Humanized	*Fables Attach names*
5-Personalization	Acceptability and usability	*Aesthetic simplicity Attractive design Adaptable Sensory design*
6-Need for socialization vs. fear of socialization	Social presence	*Peer support Hide reality Inter-socialization*

another two residents from C4 agreed that they preferred using technologies that they were familiar with, as they felt more "*confident in using what's always been used.*"

Attitudes toward residents' technology use was also evident among care staff who participated as facilitators. Some care staff appeared more enthusiastic about residents engaging with SoW and were encouraging interactions through words such as "*don't be scared of it,*" "*you might enjoy it just give it a try,*" and "*this can be fun for you.*" Nonetheless, there was an underlying, but clearly unintentional, ageist stigma attached to residents being able to engage with technology from some care staff. Care staff believed that residents would not be able to understand or be able to interact with SoW because they were unable to use other technologies such as mobile phones. This belief remained even after care staff were able to witness that residents were engaging well with SoW.

Many of the residents did not know what the purpose of SoW was which was difficult to ascertain simply through its appearance. One resident from C1 likened it to a mirror with the sole purpose of reflecting, "*Oh it's some new way of putting up a mirror to reflect what's going on in the room.*" Another resident from C1 explained, "*at the moment it's a bit bare and unfunctional…what's its use?…give a use.*" Similarly, residents from C2 felt SoW was something they could not use as it lacked an appropriate function, "*Well you can't…what purpose for…can't use for anything…useless poles.*" It appeared that because SoW did not aesthetically resemble a communication device, residents deemed the device as unsuitable and useless. The telephone handset was relatable which was important to residents as it helped them to recognize something familiar and distinguish its key feature of tele-communication, however, this clearly was not enough for all residents.

> "*Well I don't think it looks like a telephone really…it's like what they say it's strange looking, wouldn't use that…what can it even be useful for?…No…that's not what telephones do…look like…far too big can't carry that…where to put it? It's not connected up…I think it's a bit useless. If you're making a phone call…you just put that in your hand [handset] and talk…you're not watching that you're just listening for the sound*". [Expectations of technology- Untrusting technology, Usefulness, Prefer what they know] (Resident, C2)

In C3, once residents had a closer look and feel of SoW, they began to understand its use. One resident at first expressed the view that the device was just an "*iron bar,*" however, when she began to handle the device she changed her outlook suggesting that small changes could improve its aesthetic purpose.

> "*It feels just like an iron bar…an iron bar in the piece and that of course is just plastic. Yes this is nice and light actually [touches the handset and iPad], yes I can see it…I can see its fine it's a wonderful thing…and I suppose link that part and being able to have it and see it [see into the iPad camera so it shows the resident's face] would make it look better for the purpose*". [Expectations of technology- Purposeful design, Usefulness] (Resident, C3)

Along with the need for SoW to have clear design features to highlight that its purpose is for communication, residents in C2 felt the design should also show its appropriateness for adults rather than children. One female resident during the dress-up phase expressed that the device needs to be designed in a way that its purpose is clearly apparent to be for adult use, in case children come across SoW and damage it.

> "*You don't want to make it too colorful because it's for us over here…maybe for children…if you had it for children they would probably mess it up and pull things off, use it for something else…then the whole idea the function its purpose is gone and you start over…its look should be for us here*". [Expectations of technology-Age appropriate, Purposeful design] (Resident, C2)

The idea that SoW should be linked to or represent an enjoyable activity was present among residents in C4. Once residents were reminded that the purpose of SoW was to act as a means of communication to connect with distant family and the public, residents became excited at the thought of this and asked if it could be a regular activity. Furthermore, the idea of engaging in activity to improve understanding of SoW and future usability was evident across all four care homes. The majority of residents did not initially understand the purpose of SoW prior to dress up, but better grasped its use after the dress up activity and were keen to continue engaging with SoW in this way. Finally, care staff from C1, C2, and C4 all mentioned that if residents, especially those with a cognitive impairment or physical disability, were able to interact with SoW through activities then it would improve their understanding of technology and increase their likeability of the device.

> "*It's clear actually that if they just interacted with this* [SoW] *in a fun way…like it is more of an activity which is fun and not some scary thing w'ere pushing onto them…you know…because then if it's a fun activity this thing* [SoW] *it has a need for them…it's not some random thing…I think we will see a lot more people here remember what it is and want to KEEP using. I think let's plan this as activities.* [Expectations of technology-Activity orientated, Purposeful design] (Care staff, C4)

Anthropomorphism

During the 'dress-up' phase of the focus groups, older people began to attribute humanized features and characteristics to the SoW device. Even despite the materials resembling animal and human traits (such as the butterfly wings and eyes and mouth stickers), older people used the materials in a way that the device appeared to be less of a standardized technology instrument and instead an animal or human character. Residents from C1 and C2 dressed up the device to emulate animal and human characteristics, which then developed into stories or fables. C2 residents created a story about '*Rupert the rabbit,*' which was artistically hand crafted by a female resident who appeared to have poor dexterity (care staff reported and observations made). Furthermore, another two residents from C2 were keen on attaching the wings to SoW as one resident told a story about a 'flutterby' (a butterfly) from her childhood to the group. The resident then referred to SoW as "*the flutterby that calls,*" and decided to give it a face to make it appear more 'real.' The remainder of the group suggested that the device would now be associated with the made up character "*Rupert Rabbit*" so they can better remember what the device was.

> "*Well it's supposed to be a man…well a rabbit and that's a log he's carrying…that's its ears…I used to do a lot of patchwork so this would be useful…it's no trouble at all really. Just twist this…its nothing too complicated to spruce it up* [SoW]*…this is my handiwork no trouble…let's have another look of it once we stick it on there* [on top of the iPad on SoW]. *I don't like evil looking ones. He's a nice fluffy bunny that will sit on this making it nice to look at*". [Humanized-Fable] (Resident, C2)

Residents from C1 used materials that represented human features such as eyes, a nose and even referred to the SoW as having feet, "*that's for putting on the feet.*" Residents began to decorate SoW to resemble a human as they dressed the device with a bowtie and wrapped a flower necklace around its neck.

Personalization

Each care home, and some individual residents within each focus group, preferred to dress-up SoW to suit their needs and likeability. This person-centered approach improved the acceptability and usability of SoW where residents appeared far more positive about SoW after dress-up, "*I like this…looks better now,*" "*I think we can say good morning to it* [SoW] *every time we walk past it,*" and "*OK so that's what Skype is…yes I am keen.*" Furthermore, residents in C3 and C4 made use of the sticky letter materials to add words onto the device such as 'Skype,' but also their personal names. This increased a sense of personal connection to the device, with residents claiming "*now I have a personal connection to it.*"

In terms of technological design, residents had a preference for aesthetic simplicity, which they expressed would be more advantageous among their age cohort. One resident from C4 explained that "*technologies these days get too confusing to look at, I would make this look just simple…just add color…it's better for our age.*" Additionally, a common word iterated among almost all four groups was the word '*neat.*' Residents continually expressed the need for the device to look neat which can translate to simplicity. Importantly, residents with mild to moderate dementia agreed the device should look neat and simple, and not so '*busy.*'

Because residents were living in a care home environment, both care staff and residents believed that SoW could easily get lost or go unnoticed in a large busy setting, blending into the background. Therefore, there was a need to make the device more perceptible but with an attractive design that was agreeable to all. Residents from C2 liked the idea of decorating the device with purple colors as the care home and its care staff uniforms were purple, "*Purple is our home.*" Furthermore, residents from C1 explained that bold colors would be eye-catching making the device more interesting, yet also a useful way to remind the residents that the device is in their home.

> "*Well it's different isn't it….looks like a fairground…very bright…attractive design. It's far more interesting to the eye, will be able to remind us of this SKIEE is it? Oh yes…Skype*". [Acceptability and usability-Attractive design, Aesthetic simplicity] (Resident, C1)

After dressing up SoW some residents suggested that the design should be interchangeable. Not all the residents agreed on the materials that were placed onto SoW, especially from C1 and C2, so as a group it was agreed that these materials could be changed later. Also, the device body should be adaptable for shape and size to better match the residents' preferences.

As the focus groups progressed, residents increased their touching and feeling of SoW. They made comments on the texture such as '*cold*' and '*hard.*' Residents selected materials that were soft and appealing to their senses and so *sensory design* became an important indicator of person-centered design.

> "*I do like, it's like a soft brush…feels like feathers. It's nice, lovely and soft so we can wrap this [on to SoW] going around the long bar in the middle…yes that's nice they're warm aren't they…to the touch.*" [Acceptability and usability- Sensory design, Attractive design] (Resident, C3)

Need for Socialization vs. Fear of Socialization

Two residents from C4 expressed the desire to interact with others, "*Oh so I can see other people's faces through this like a mirror? Yes that would be delightful to see a new face*" and "*We don't get out much because of this wheelchair I don't see many people. It could be useful* [SoW]." Some residents in C2 and C3 were especially keen to get started with using SoW for communication so that they began to discuss where a suitable spot would be to place it in their care home, and ways to 'dress up' the device to make it easier to make and receive calls. Although a number of residents stated they would like to reconnect with distant relatives through SoW, some were apprehensive and worried that their relatives would not want to.

> "*Oh my gosh. Oh yeah…yes…I've got a granddaughter yes. I could give it a go. I don't know about her thought…maybe. They wouldn't want to possibly.*" [Social presence-Hide reality] (Resident, C3)

In addition to stimulating the desire to connect to others through SoW, the focus group activity initiated socialization within the care home among the residents. The dress-up of SoW enabled residents to interact and work together where they normally would not have due to the lack of such group activities available to them. Some residents found the activity to be very enjoyable and saw it as a peer game.

> "*Well it wouldn't look better on anything else. . .so where on there? Would you like it on you* [turns to fellow resident*]? Alright OK...Where's* [fellow resident], *do you think he will like it on him? I didn't know you were into this sort of thing. . .never seen you so interested.* [Social presence-Peer support, Inter-socialization] (Resident, C2)

Alternatively, a number of residents appeared displeased with the thought that others would be able to see their faces through the iPad screen. Some residents presented signs of insecurity toward their own image, "*Well I can barely see my own face . . .which I don't like*" and" *I've got a big nose and bump on my nose, oh I'm not good looking. . .I wouldn't want anyone to see this, no*" and "*I look too fat on that and big.*" Other residents expressed they would not want to use SoW with family members because their surroundings and environment would be too revealing to others. They preferred not to have close relatives "*see into MY world.*"

DISCUSSION

The findings highlighted that there are negative views toward a new or unknown technology such as SoW for older people; however, after a short period of engagement older people are likely to accept the new technology. Overall, discussions about and interacting with SoW directly, improved the acceptability and usability of the device for both residents and care staff. Our study supplements previous research that has investigated older people's attitudes and perceptions toward a broad set of new technologies (Mitzner et al., 2010). Other studies have focused on one specific technology such as tablets, and have also incorporated a more hands-on interactive element to the focus group to help participants understand the technology (Vaportzis et al., 2017). Our study gives insights, which should be taken into account when tailor making, or designing novel technology solutions aimed at an older population.

The data analyzed produced themes that are consistent with the literature, corroborating other qualitative research findings. Participants in similar studies with older adults have expressed 'frustrations,' 'limitations,' 'usability concerns,' and have often mentioned how technology can look and be overly complicated (Mitzner et al., 2010; Heinz et al., 2013). These themes closely relate to our theme of 'estrangement.' Other researchers have also noted that higher anxiety, fear, or lack of confidence in using technology results in lower use of the new technology (Czaja et al., 2006). Our findings suggest the opposite as residents who first appeared uninterested or indifferent, later and quite quickly warmed up to the idea of video-calls. This can be explained as a result of residents familiarizing themselves with SoW through direct interaction with the device, filling in gaps in their understanding of its purpose and so reducing any fears or confusion they might have. This is also consistent with other research suggesting that the perceived potential benefits are more indicative of technology acceptance than the negative perceptions that can induce fear or lack of usability. Rogers's (2010) theory of diffusion of innovations supports this notion indicating that older adults are less likely to adopt new technologies unless they have a clear understanding of the benefits of using them.

A focus group with an embedded activity that used creative materials demonstrated the artistic skills that older people can bring toward technology design, and highlights the need for basic elements of design to begin right at the outset of implementation. The idea of person-centered designs, bricolage and collaborative working with participants is increasingly becoming the desired standard in implementation research (Zamir et al., 2018). For technology interventions, a large sum of money is spent on changing the interfaces or key features to better match the user-needs of the older person (Newell et al., 2011; Boman et al., 2012). The current study drew on low-cost materials and techniques (a simple group activity) to allow older people to personalize a new technology (becoming 'bricolers') rather than completely re-designing it.

Anthropomorphism is the attribution of human-like qualities and form to non-human objects (Bartneck et al., 2009). We used that term to classify the focus group's attribution of animal or human-like characteristics to the SoW. Social robotics has an extensive literature on this topic distinguishing between biomorphic [devices with features of biological origin, such as animal ears or noses (Klamer and Allouch, 2010)], zoomorphic [devices completely identifiable as a known animal (Moyle et al., 2019)], and anthropomorphic. Our study reinforces other work that biomorphic, zoomorphic, and anthropomorphic characteristics are likely to improve their acceptability and possible usability.

A key theme of reminiscence came through in the dataset. Not only was reminiscence useful as a means to help residents to recall technologies of their own time, but also allowed them to connect to new forms of technology on a deeper level that is personalized to their life experiences, in turn improving its acceptability and future usability. However, there is a need for follow-up studies to see examine how effective personalization was in triggering memories over a longer period.

Socialization was split across the need to engage with others, and the fear of socialization. The latter was attributed to poor self-image exhibited by some residents. Currently, there is not much literature to substantiate or validate this finding of poor self-image in relation to technology acceptance. It would be expected that poor self-image would result in not wanting to use video-calls for socialization. However, those who displayed poor self-image and so presented negative emotions toward SoW later warmed up to the idea of participating in future video-call activities. Future research should investigate whether themes of self-image are an important indicator of engaging in video-call socialization with older people.

The study included people with dementia to ensure that the research was inclusive and representative of all residents. However, upon reflection it was difficult to clearly, and effectively capture the interactions and comments of those with more moderate to advanced stages of dementia. The dynamics of a focus group are fast moving with multiple conversations and interactions that begin to overlap and so this could be a reason why this task seemed difficult. Other researchers have included people with dementia in their focus group research and have also found challenges of varying degree (Stephan et al., 2018), but that is not to say that we cannot include people with dementia in focus groups. Participation of people with dementia in this study was still incredibly valuable as it proved that they are able to, with some assistance, interact with a new technology and provide useful suggestions on its design.

The current study has further limitations that need to be acknowledged. Most participants did not have experience in using similar technologies such as an iPad or even modern mobile phones. The answers that they gave were largely based on the general views they had about technology rather than video-calls specifically. Other researchers have experienced this and suggest that although this should not be disregarded, future research should present older adults with detailed scenarios or case studies in order to further investigate the topic at hand (Mehra et al., 2016).

It can be argued, with some justification, that the bricolage approach is (sometimes literally) taking a sticking plaster to a product design that was ageist by not involving older people (including those with dementia) in the first place. Thousands of products are being used around the world by older people with sensory or other impairment with 'added' labels, stickers, and 'blue tack' to work around initial design problems. Ideally, usability studies in the development of products will identify designs that suit all potential users but we recognize that businesses will design for the market that they think will bring them profit. Our study was of a physical device (the SoW chassis); we had no control over the proprietary iPad or the Skype software. The focus group exercise served the dual purpose of gaining more immediate acceptability for the devices while indicating possibilities for future design. The bricolage approach can help achieve that in many situations but the needs of these with less consumer power require protection with legislation.

Our study was based on a convenience sample of 28 participants – about 1 in 4 residents in four care homes. Individual characteristics such as previous occupations, and levels of schooling were not documented. Our participants were mainly white caucasian women. A larger, more systematically selected sample from care homes with more diverse population may have given different results and allowed exploration of differences by demographic and clinical characteristics. Nonetheless, the methodology used demonstrates that interactive focus groups using low-cost materials to dress-up technology can be an adopted activity in all care homes.

CONCLUSION

The results from this focus group study suggest that the interactive methodology employed enabled older people to describe and demonstrate what they preferred a new technology to look like. Dressing up the device using low cost materials improved residents' understanding of what the technology was, improved the acceptability of a new technology, and increased the likelihood of the new technology being used in the near future. Further exploration of the materials does, however, need to be done to validate the idea of a humanized technology. The current focus group research was sufficient to be tasked as a step one or first activity for residents to undertake to improve intervention implementation within a complex care environment.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Plymouth. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SZ led on the design of the project, recruitment of participants in collaboration with care staff, data collection at each site, analysis and interpretation of data, and wrote the first and final drafts of the manuscript. FA assisted with the qualitative analysis, identification of the codes and final themes, and contributed toward the critical revision of the manuscript. CH assisted with the development of the methods, identification of the qualitative analysis method, and contributed toward the critical revision of the manuscript. AT assisted with the development of the methods, and contributed toward the critical revision of the manuscript. RJ led for the project, led on the conception and design of SoW, is the supervisor for the main author SZ, and provided critical revision of the manuscript drafts. All authors read and approved the final manuscript.

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Technological Ecosystems That Support People With Disabilities: Multiple Case Studies

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Advances in technology, research development, and teaching practices have brought improvements in the training, levels of autonomy, and quality of life of people who need support and resources appropriate to their circumstances of disability. This article focuses on empirically analyzing the usefulness of treatments that have been supported by technology to answer the question "How do technological ecosystems being used help people with special educational needs?" The multiple case study methodology was used to address six categories of analysis: project data, objectives, processes, outputs and outcomes, technologies, and impact. The processes, open in communication, were characterized as transversal, ethical, and sustainable. The results yielded various technological ecosystems that support people with disabilities, deliver the help they need to improve their health, and provide enjoyable user experiences. At the same time, they promote the training and improvement of teaching methodologies and involve families in order to improve their knowledge, attitudes, and care of children, young people, and adults with functional diversity.

Keywords: technological ecosystems, educational innovation, case studies, higher education, research

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INTRODUCTION

Knowledge management works best through learning models in an inclusive and participatory society, where technologies offer substantial support to ecosystems that link software, hardware, and people. Technological ecosystems are sets of people and software components relating to each other in a physical environment that supports information flows (García-Holgado and García-Peñalvo, 2018). The opening of access to knowledge is important for ecosystems to have a greater impact on learning, information, and research (García-Holgado and García-Peñalvo, 2019; Ramírez-Montoya, 2020). Technological ecosystems exist in various sectors, including health, society, and education.

Technological ecosystems in the medical field have improved the quality of life of people with disabilities, helping with diagnosis, rehabilitation, and access to medicines. Harlaar and Lankhorst (1998) state that technology can systematize information about disabilities, facilitating the physician's access to such information for better diagnoses and decision-making. Elsaesser and Bauer (2012) argue that technology enables relevant data to be gathered to improve rehabilitative interventions. For example, the Assistive Technology Service Method, the Assistive Technology Device Classification, and the Person and Technology Matching provide an evidence-based, standardized, and internationally comparable framework for effective interventions that are satisfactory to end-users. In this regard, Wuang et al. (2011) identified that technology positively affects individuals in rehabilitation. In a study of children with Down syndrome, the authors observed that virtual reality in Wii games proved beneficial in improving sensory and motor functions, compared to traditional rehabilitation. In another study, Façanha et al. (2019), seeing that people with vision problems may have difficulty accessing medications, worked on mobile applications that helped them identify medications. Such assistive technology has led to direct or indirect improvements in the medical conditions of disabled people.

In the integration of technologies in environments with people in special education, it is important to consider the characteristics that occur in various contexts, depending on the location. There are differences in the schooling of children and young people with disabilities; sometimes they are located in specific centers, special education centers, or an ordinary center, in which case they are considered as special needs – the needs are contextual and are special to the extent that they are not foreseen by the schooling modality (Warnock, 1978). In Nigeria, Iliya and Ononiwu (2020) identified that contextual factors, such as personal, social, and environmental factors, enable or hinder the empowerment of people with disabilities. In addition to these contextual factors, there are management systems with the use of technologies for the care of people with disabilities. In Tanzania, Lwoga et al. (2020) worked with an electronic hospital management information system to improve care for vulnerable patients, help collect important data on disability and maternal health, and improve overall hospital data management, and the findings located improvements in the quality of care for women and people with disabilities. Contextual factors and the use of technologies are presented as key factors in finding possibilities for care.

At various latitudes, efforts are being made to capitalize on the use of technology in the care of people with disabilities. For example, in Taiwan, a social business model for people with disabilities was introduced based on Eden's mobile service platform for barrier-free transportation, where information and communication technology (ICT) is integrated with transportation service providers and government resources to meet the transportation needs of people with disabilities (Wu et al., 2020). In Spain, the need for ICT training in these environments was located through a study where professionals perceived a low level of training and knowledge of teachers regarding the use of ICT with people with disabilities, so the need to design and implement didactic training to empower teachers was identified (Fernández-Batanero et al., 2020). Similarly, in Australia, they identified that better integration of assistive technology with ICT will improve the quality of people with communication disabilities, and they also found that improved accessibility with affordable high-speed broadband Internet can provide the services that people with disabilities need (Ali et al., 2020). Government support has also been important in bringing technologies closer together as was the case in the Maldives where its importance was identified in improving speech and language therapy services. The government provided financial assistance to persons with disabilities that could be used to access accessible ICT services and parents as agents of service and support delivery (Zahir et al., 2020). However, Setchell et al. (2020) caution that it is important to recognize that well-intentioned attempts to promote the use of ICTs can be counterproductive if they lead to experiences of marginalization and that, to avoid this, inclusive practices could focus beyond access to and the ability to use devices to include considerations of multiple socio-emotional effects. In the search for possibilities for the care of people with disabilities, it is important to locate contextual and social factors.

Social-assistance technological ecosystems seek to improve the interactive capabilities of individuals with disabilities. Cincotti et al. (2008) state that, depending on the type of disability, assistive technology can improve an individual's communication and mobility. For example, providing brain–computer interfaces in a technological system composed of various devices helps the person perform simple activities independently. However, Pape et al. (2002) argue that the successful integration of technology depends on the individual's psychosocial and cultural issues. Therefore, it is necessary to explore the meanings they attach to technological devices, their expectations regarding assistive technology, the expected social costs, and the ways of understanding their disability. Along these lines, Riemer-Reiss and Wacker (2000) identified that disabled individuals tend to accept the use of technological support devices when they find a good cost–benefit ratio and have confidence in their ability to help them. The use of assistive technology must be tailored to the disability, context, and cultural conditions of the individual being helped.

Finally, concerning technological ecosystems in the educational field, their design must generate the necessary conditions to guarantee inclusion. Seale et al. (2015) mention that disabled students feel disadvantaged because they have to work harder than other students, managing both their disability and study. Students with disabilities increasingly find themselves in general education settings, so educational institutions must have instructional technology and universal design to develop educational products and services that are usable by individuals with the widest possible range of functional abilities (Edyburn, 2013). Cook and Polgar (2014) state that these designs that include special-needs-education technology should anticipate the person, task, context, environment, inclusion, technological tools, and desired outcome. Brodin and Lindstrand (2003) also report that solutions for special education needs are primarily based on the way teachers understand disability, how it relates to their work, and their digital competencies. Implementing technology in educational environments diminishes the differences that disabled students perceive in their educational processes *versus* other students, so the institution and the teachers must ensure the necessary conditions that render equality of circumstances.

The technological ecosystems helping people with disabilities provide medical, social, and educational assistance. Moser (2006) states that assessing the impact of technology on people with disabilities involves analyzing various enabling and disabling interactions. In the medical field, Alston et al. (2014) state that assistive technology emerged when health professionals advocated for additional resources to help people with disabilities adapt and reintegrate into society after hospitalization. In social services, according to Phillips and Zhao (1993), assistive technology devices help people with disabilities achieve levels of independence that let them participate in society. Finally, concerning the educational field, Burgstahler (2003) states that educational assistive technology is more about universal learning design through electronic and computer technology that facilitates the development of products that everyone can use, whether or not they have a disability.

Technological ecosystems are developed to help people with disabilities according to the conditions of each context. The overall development of technology in daily life facilitates responding to specific needs using common supports such as tablets or smartphones. Therefore, it is increasingly common to talk about different ways to participate, learn, or perform in various contexts, giving way to the concept of functional diversity.

This article focuses on empirically analyzing the usefulness of treatments that rely on technology by answering the question "How do the technological ecosystems help people with special educational needs?" The article starts with a conceptual basis that describes the technological ecosystems that support training for people with special needs. It presents the case study methodology on which this research is based, discussing three case studies in the European community, and closes with an analysis and discussion of the findings and opportunities for further work in the area.

MATERIALS AND METHODS

The case study was the method that guided this study. Stake (2007) and Yin (2006) mention that a case study is an integrated, "bounded" system, an object, rather than a process. It is something specific and complex in operation. A case can describe people, institutions, attributes, and relationships. Specifically, in this study, we present cases emanating from research in the European community. The article describes the attributes given in certain studies and analyzes the actions, interactions, scenarios, technologies, and impact.

The cases can be studied from the particular to the multiple. The description of the cases includes the project data, the background and institutions developing it, the objective, the processes (how it was carried out, its activities, methods, and instruments), production and results (contributions of the project), technologies employed, and impact on specific sectors. Three transversal elements are also described: (a) ethical processes in the research, including ensuring the participants' privacy, (b) visibility (how the project was communicated), and (c) sustainability (how project continuity is ensured). **Figure 1** is the methodology schematic of this research.

The cases presented are Erasmus + KA2, European Union projects in the educational field aimed at teachers' and students' training. When the need is detected, it also allocates training and advises other people related to the participants, such as other professionals with various training levels, managers, service personnel, families, and caregivers. It focuses on collaboration and innovation so that knowledge is generated and good practices are exchanged.

These financed projects are designed to have lasting and positive effects in the participating institutions' communities and are intended to benefit the greatest number of people. The management of most actions is centralized in the Education, Audiovisual, and Culture Executive Agency based in Brussels. Actions are carried out through Alliances for Knowledge, Alliances for Sectorial Competencies, and the strategic associations that are decentralized in the National Agencies. In Spain's case, these are in the OAPEE, the Autonomous Body for European Educational Programs.

These projects are designed to respond to the need for specialized training, paying attention to functionally diverse students and their specific needs. From a professional point of view, this attention is essential to achieve full inclusion. Organización Naciones Unidas [ONU], 1948; Unesco, 2009; Agencia Europea Para el Desarrollo de la Educación Especial [EADSNE], 2010; Organización Mundial de la Salud [OMS], 2011; Schleicher, 2012; Agencia Europea Para las Necesidades Educativas Especiales y la Inclusión Educativa, 2014; and OECD, 2019; have issued manifests that show the rights of disabled persons and the reality that there is a growing number of these students that must be educated according to their characteristics and needs.

In the projects presented in **Table 1**, researchers from different fields and universities collaborated and created international, interdisciplinary work teams.

CASE STUDIES

DESCA

Case A. DESCA: Development of Effective Coping Strategies for VET trainers to provide reliable training to learners affected by psychological disorders (DESCA, 2018).

Participating institutions: Universidad Complutense de Madrid (UCM), Spain; Kartaltepe Mesleki ve Teknik, Anadolu Lisesi, Turkey, MTAL; Istanbul Milliegitim Mudurlugu, ILMEM; Sdruzenije NA Raboteshtite Uvrezhdaniya, Plovdiv, Bulgaria; NARHU.

Objective: To provide training and strategies for teachers who have students with psychological problems.

Processes: A preliminary study was done to know the situation in several countries. Observing the lack of training to help students with different problems, the researchers designed the project to detect the current needs. It is a reality that regardless of the severity of their problem, disabled persons are often affected by psychological disorders; they face learning difficulties and require special support. Many trainers do not have sufficient experience and skills to adequately deal with people's behavioral attitudes and psychological disorders (EUFAMI, 2013). Consequently, they cannot always adopt appropriate

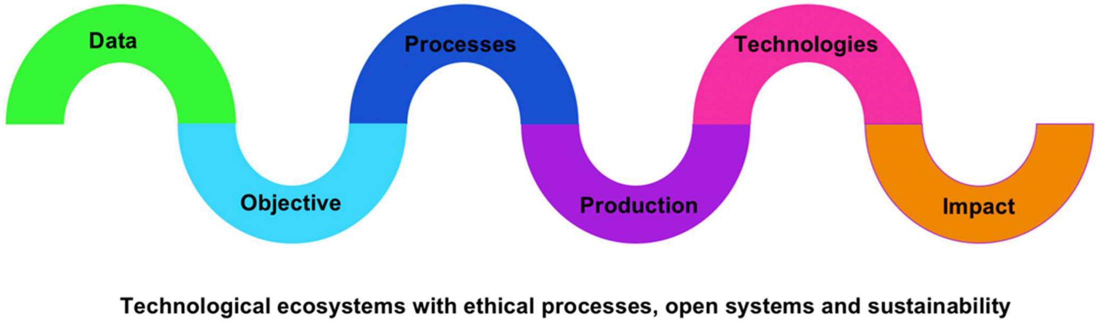


FIGURE 1 | Multiple case study method applied in the study.

TABLE 1 | Case studies.

Project title	Financing	Institutions	Duration	Number
DECSA Development of effective coping strategies for vet trainers to provide reliable training to learners affected by psychological disorders	UNIÓN EUROPEA Erasmus Plus Project. 20145 KA2 Strategic Partnerships. Supportive training course and innovation development	4 institutions: Spain, Anadolu – Turkey, Istanbul – Turkey, Bulgaria	Start date: December 27, 2018 Duration: 24 months	2018-1-TR01-KA202-058893
DEMOER The importance of the improved competences of non-formal adult caregivers of elderly people with dementia around Europe and our contribution to their training and support	UNIÓN EUROPEA Erasmus Plus Project. KA2 Strategic Partnerships Erasmus + Programme of the EU Commission Measure: strategic partnership for development of innovation in adult	5 institutions: Spain, Turquia, Bélgica, Chipre, Bulgaria	Start date: November 1, 2019 Duration: 24 months	2019-1-ES01-KA204-063975
INCLUEDUSEX Supportive training course and self-help groups of parents of youth with physical and learning disabilities on sexual education, techniques, and appropriate behavior	UNIÓN EUROPEA Erasmus Plus Project. 20145 KA2 strategic partnerships supportive training course and innovation development	5 institutions: Spain, Bulgaria, Greece, Belgium, Austria	Start date: December 3, 2018 Duration: 24 months	2018-1-ES01-KA204-050062 999874546

responses or use tools and methodologies particular to this population's needs. This situation causes a feeling of loss of control and great frustration among students and teachers. It undermines the success of the training and the results of the trainers' work. As part of the preliminary study results, some characteristics of young people with psychological disorders have become known, such as memory and attention span problems. Others include apathy, physical appearance changes, changes in attitude toward teachers, feelings of sadness or depression, confused thinking, reduced ability to concentrate, excessive fears or worries, feelings of guilt, ups and downs, and other mood changes.

Production and results of the DESCA project are:

- A manual for vocational trainers who deal with students affected by psychological disorders. It aims to raise awareness about their behavioral characteristics and associated learning difficulties.
- A manual with coping strategies to offer highly reliable training to students with different psychological disorders
- A concept map presenting possible teaching strategies to intervene with people affected by psychological disorders
- Policy recommendation guidelines to improve the professional training of people affected by psychological disorders

The manual is enriched with thematic sections dealing with specific topics related to intervening and treating people affected by psychological disorders in professional training settings. Thematic sheets that focus on specific issues about how to deal with psychological disorders are included. Based on a common general framework in English, the national documents' content is translated to each partner's language and adapted with particular references to the partner organization's context. The final result aims to improve the training of people affected by psychological disorders and facilitate their inclusion both at the professional and social levels. These documents provide knowledge, establish general principles and fundamental legitimate rights, and help overcome the discrimination and stigmatization often suffered by people with disabilities. Miranda de Sousa and Antón (2018) point out that this represents a fundamental paradigm shift to generate new views on integrating this population.

Technologies: Technologies were important from the planning through the project's elaboration phases, starting with the search and then organizing the shared information in Dropbox. Questionnaires were applied and validated, and results were analyzed. Each participating institution created a project webpage with translations to the different languages of the participating countries. Materials, methodologies, videos, and bibliography were presented. Useful contributions for teacher training and socio-educational application are detailed in Gútiez and Antón (2017a,b). Communication was maintained by e-mail, video conferences, team meetings, Gútiez and Antón (2016) and presential international meetings, all according to the established and scheduled plan. The contributions, progress, and analyses presented in these meetings generated comments, debates, and agreements.

Impact: Numerous trainers will benefit from the contents to appropriately and sufficiently address the behavioral attitudes of students with psychological disorders. They will have the responsive skills to adapt their methodologies and resources to the needs of this group. They will feel empowered by the acquired knowledge and competencies to intervene in memory and attention problem cases. The trainers will be aware of students' apathy or reduced ability to concentrate, physical appearance changes, and attitudes toward teachers and classmates. They can observe if the students have feelings of sadness, anxiety, depression, confusion, excessive fears or worries, feelings of guilt, and mood swings. Their awareness and sensitivity will help reduce situations that cause frustration and improve the classroom climate and the results of the teaching–learning process.

INCLUEDUSEX

Case B. INCLUEDUSEX: Supportive training course on sexual education, techniques, and appropriate behavior, and self-help groups comprised of parents of youths with physical and learning disabilities (INCLUEDUSEX, 2018).

Participating institutions: Coordinated by Universidad Complutense de Madrid (UCM), Spain; Austrian Association of Inclusive Society, Vienna Austria; PHOENIXKM BVBA, Kortemark, Belgium; National Association of Professionals Working With People With Disabilities, Plovdiv, Bulgaria; Kotsiras Anastasios-NURBS, Athens, Greece.

Objectives: To equip parents with an appropriate sex education program and training materials that enable family members and professionals to contribute to the process of "educating" young people with disabilities to understand and manage their sexuality and express themselves appropriately. To enable parents to guide young people with disabilities to experience full human capabilities. To prevent the potential risks of sexual assault, inappropriate exploitation, sexually transmitted infections/diseases, and unplanned pregnancies at a disproportionately higher rate than the rest of the population.

Processes: To bring together families who have physically disabled children to collaborate on improving their quality of life is the project's objective. After undertaking a needs analysis, we followed the Optional Protocol in the Convention on the Rights of Persons with Disabilities, Organización de Naciones Unidas [ONU] (2006). As primary educators, parents do not provide enough sex education to their children, but parents or guardians should be the first and foremost educators of children's sexual health. What parents say and do can have a powerful influence on developing healthy sexuality in their children. Most young people with disabilities lack the opportunity to learn about sex and protective behaviors appropriately. It became evident that there is a need to train parents of young people who have some disability to educate them that sexual development is natural, part of becoming an adult, so they gain self-confidence and express their sexuality appropriately.

Production and results of the INCLUEDUSEX project were:

- A parental sexual education training course
- A sex education guide to help parents of children with disabilities support professionals in sexual education
- The manual "How to create and manage an autonomous parental group on the subject of inclusive sexual education"
- An inclusive Android-based mobile application offering 24/7 help with solutions to specific queries and problems regarding sex education

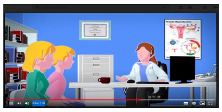
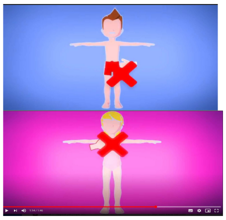
Technologies: These were a valuable resource before, during, and after the process. Communication was maintained by e-mail, video conferences, team meetings, and presential international meetings according to the established and scheduled plan. The meetings were used to present the contributions, report progress, and generate and propitiate analyses, comments, and debates. The documents and data collected were shared in Dropbox. Questionnaires were applied and validated, and results were analyzed. Each participating institution elaborated a project webpage and translations into the different languages of the participating countries. Due to this project's characteristics and specificity, 12 short, 2-min videos were created using each participating country's information and languages: German, Belgian, Bulgarian, Spanish, and Greek. The videos provide information and animated illustrations on different topics (see **Table 2**).

Impact: In addition to training young people with disabilities to understand and manage their sexuality and express it appropriately, the parental sexual education training course covered the following types of disabilities:

- Autism spectrum disorders
- Cerebral palsy
- Deafblind
- Intellectual disabilities
- Learning difficulties
- Physical disabilities
- Spina bifida
- Spinal cord injury

The results will provide resources to training professionals, coordinators, developers, parents, and relatives of disabled people, social workers, beneficiaries, children, and youth with disabilities, teachers, NGOs, psychologists, and pedagogues. It

TABLE 2 | Videos of the INCLUEDUSEX project.

Video topic	Message	Images
Sexual protection	Safe sex is important. Teach your child about sexual protection, before it is too late	
Hygiene (girls) Hygiene (boys)	Taking care of your body is very important	 TAKING CARE OF YOUR BODY IS VERY IMPORTANT!
Preparing for the doctor's visit (girls) Preparing for the doctor's visit (boys)	Going to the gynecologist is very important Going to the urologist is very important	
Public masturbation	Knowing the right place to masturbate is very important	
Contact rules for girls Contact rules for boys	No one can touch your genital área, and no one can make you touch	

is especially relevant to provide sex education to people with disabilities. They are among the most susceptible groups to abuse and need to know how to avoid sexually transmitted diseases and unwanted pregnancies. The project results are useful for professionals who work with disabled people and other relevant-sector professionals. The proposal is innovative and can generate synergies with future studies, projects, and training courses, both for formal and informal education.

Case C. DEMOER: Innovative mobile adult training for family members of people with dementia (DEMOER, 2019).

Participating institutions: Universidad Complutense of Madrid. (UCM), Spain; Uluslararasi Sumul Dernegi, Istanbul, Turkey; PhoenixKM BVBA, Kortemark, Belgium; G.M. Eurocy Innovations Ltd., Strovolos Lefkosia, Cyprus; Sdruzenije NA NA Raboteshtite S Hora S Uvrezhdaniya, Plovdiv, Bulgaria.

Objectives: To support people in the acquisition and development of basic skills and key competencies; to provide open education and innovative practices in the digital age; to extend and develop the competencies of educators and other staff supporting adult learners.

Processes: We started with searches and consultations in publications, international documents, and reference sources. Based on the data obtained and the state-of-the-art analysis, we planned the response to the current needs (OCDE, 2009; OECD, 2019). According to the World Health Organization (Organización Mundial de la Salud [OMS], 2011, 2020), dementia is a syndrome that involves the deterioration of memory, intellect, behavior, and ability to perform activities of daily living. Dementia is not an inevitable consequence of aging. The number of people with dementia is increasing rapidly. Alzheimer's disease, which is the most common form of dementia, accounts for 60 to 70% of cases. Dementia is one of the leading causes of disability and dependence among older people worldwide. Most caregivers of people with dementia are family members. Dementia affects about 50 million people worldwide, about 60% of whom live in low- and middle-income countries. About 10 million new cases are reported each year. It is estimated that between 5 and 8% of the general population aged 60 years or older suffers from dementia at any given time. The total number of people with dementia is expected to reach 82 million in 2,030 and 152 million in 2,050. Much of this increase can be attributed to the fact that low- and middle-income countries are experiencing increasing numbers of dementia cases. Data linked to countries participating in this project indicate that the number of patients with dementia will also increase (estimated at 12% in the next 10 years in Spain and 20% in the next 10 years in Bulgaria and Turkey) as a result of the growing proportion of older people in the population (OECD, 2019). The most common causes of dementia in the European Union are Alzheimer's disease (about 50–70% of cases) and stroke due to multiple heart attacks or arteriosclerosis (about 30%); other dementia forms include Pick's disease, Binswanger's disease, Lewy body dementia, and others.

Production and results of the DEMOER project are:

- A guide for adults: "How to support a family member with dementia"
- An open, wizard-style mobile application offering 24/7 help on solutions to specific problems
- An orientation toolkit for adult trainers with methodological support in the delivery of the DEMOER course

Technologies: These were key to developing all the activities involved in the project, from its genesis, progress, and analyses, starting with the search and organizing the shared information in Dropbox. Questionnaires were applied and validated, and results were analyzed. Each participating institution elaborated a project webpage. Work was done in English, and then the information and documentation were translated into the different languages of the participating countries. Communication was maintained by e-mail, video conferences, team meetings, and presential international meetings, all according to the established and scheduled plan. In the different sessions, contributions, progress, comments, and proposals were presented, and a climate of analysis and debate was fostered. In this case, a wizard-style, Android-based mobile application was provided through the learning repository portal. It offers 24/7 help on solutions for each specific problem. The mobile application through the portal serves as a 24/7 resource and training center where adults can study and remember the information contained in the

Intellectual Output 1 and 3. The mobile content further integrates the content that the partners already produced in their previous initiatives, namely, the modular content in the P3 Alzheimer's portal and the P5 DEMOER portal. Based on Moodle, the mobile application also provides the possibility to connect and ask professionals and caregivers questions about the care of a family member with dementia (see **Figure 2**).

Participation of adult peers: The application provides mobile training and allows users to contribute case studies themselves and, after "approval," share them as useful material; this application is innovative in Europe. The innovation is the adult and peers sharing content, opinions, comments, and materials with other users. All content entered online can be published directly on the mobile application, ensuring easy maintenance and updating. It also allows users to share content with social networks, including Facebook, YouTube, Vimeo, and Twitter.

Impact: The greatest impact is the awareness of the importance of providing training and information to family members to understand and provide better support to their family members with dementia. The application includes tips and strategies to use in cases of family member memory loss caused by dementia, which can lead to changed situations and consequences. Cognitive impairment affects memory processes, language, attention, thinking, orientation, calculation, and problem-solving skills. It creates difficulties for the performance of daily life activities like hygiene, clothing, walking, orientation, driving, and eating. It causes behavioral problems like personality changes, bad social behavior, emotional changes, hallucinations and delusions, aggression, depression, and agitation. The manuals support the development of key transversal competencies in the adult population in an informal environment. They provide reliable materials to adult volunteer organizations that support caregivers of people with dementia or those concerned. The manuals are written to be understood easily and facilitate content reflection without any previous medical or psychological background. The availability of online, mobile learning materials with reliable training is a solution to avoid misleading information that often appears on the Internet about the topic. It decreases the emotional and economic burden on patients' families and helps adult learners (16–29 years old) who take care informally of their family members affected by dementia, trainers and adult educators, and coordinators and directors of volunteer NGOs who provide non-formal care services. The beneficiaries of the improved services are people with dementia, their families, NGO staff, unions of disabled and older adults, and policymakers in the health and social services fields.

Transversal Processes in the Cases

Ethics

The innovative projects are carried out under responsible research principles, preserving people's privacy and data protection. The values and professional deontology are implicit in all the actions performed, a requirement of great importance: "In this sense, we researchers have to commit ourselves to increase the scientific and professional knowledge of the different aspects that influence training, in the broad sense of the concept. We must assume the responsibility of working with rigor, honesty, integrity, transparency, responsibility, and ethics, favoring studies and results are disseminated and used for professional improvement of people's lives and, consequently, the betterment of society" (Antón Ares, 2018, p. 40).

Dissemination of Results and Open Access

The social benefits derived from research make up a large part of any advanced society's well-being and improvement. The projects financed by EU Erasmus are available in the Results Platform (European Commission, 2014, 2016, 2020). The database gives open access to descriptions, results, and contact information of projects funded by the Erasmus + program. As indicated on its webpage, inspiration can be found in the set of good practices and success stories, i.e., the projects that distinguished themselves in terms of policy relevance, communication potential, impact, or design. In addition to the Web, other ways that the results and fruits and benefits can be shared include publications, congresses, courses, manuals, videos, and conferences. The channels of open dissemination vary from one project to another. The various participating organizations need to reflect on what types of dissemination are the most appropriate to use and adapt to their level and context to obtain the best use of the activity. The purpose is to enable and expand the benefits of work to improve and modernize education, training, and youth systems.

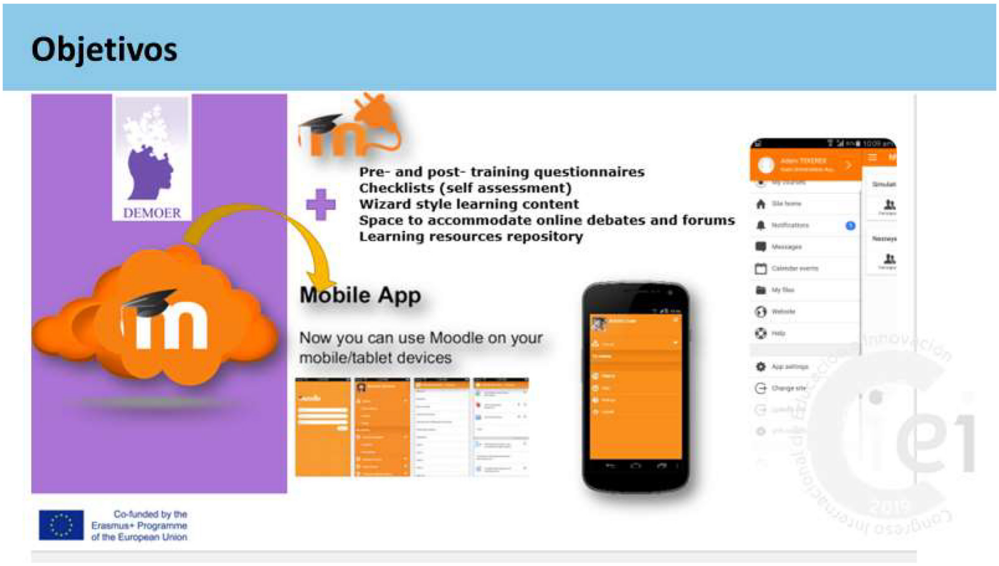
Sustainability

Sustainability means that the financed actions of the developed projects will continue. In Europe, the DEMOER results can be projected to be used during and after project completion to promote lifelong learning in education, training, youth, and sports, supported by European policies. In this sense, dissemination and use are linked, promoting continuity and long-term service and allowing others to benefit from the activities and experiences of the Erasmus + program. The results of each project can serve as an example and inspire other actions sustainable in the future.

DISCUSSION AND CONCLUSION

This article asked the question "How do the technological ecosystems being used help people with special educational needs?" Three cases were presented of ecosystems that developed and linked software, hardware, and people working collaboratively to provide solutions for people with disabilities. These ecosystems use open-access technologies that have a large-scale impact, with results that support people with disabilities and provide an enjoyable user experience, in addition to helping them improve their health. The results are consistent with authors who advocate for technological ecosystems that integrate software, hardware, open-access technologies, and people (García-Holgado and García-Peñalvo, 2019; Ramírez-Montoya, 2020).

Technologies facilitate the planning, implementation, and dissemination of work designed to improve the training and care of people with disabilities. They enable solutions to be



Objetivos

Pre- and post- training questionnaires
Checklists (self assessment)
Wizard style learning content
Space to accommodate online debates and forums
Learning resources repository

Mobile App

Now you can use Moodle on your mobile/tablet devices

FIGURE 2 | Mobile application for dementia care.

provided for detected needs, adapting to different contexts, and sometimes very diverse environments. They help generate common and specific projects. Moser (2006) invites us to consider the impact of technology on people with disabilities. To know, researchers must analyze the role that technologies play in the various enabling and disabling interactions. In the cases presented, technology helped improve the teaching methodologies, which involved family participation and provided other perspectives, leading to new approaches that contribute to changes in the knowledge, attitude, and attention of children, young people, and adults.

The training and the various content materials allowed the trainers to increase their knowledge, competencies, and sensitivity about the behavior and learning difficulties that disabled students experience, making it possible to implement coping strategies. The acquisition of knowledge helped improve the learning process and avoid school dropout situations due to an incorrect and unadapted implementation of teaching and learning strategies. From this perspective, Cook and Polgar (2014) point out that designs that include special education technology must consider the person, the task, the context, the environment, the technological tools, and the outcome. In the cases presented, the results were developed and disseminated to be adapted to different environments' needs and transferred to new areas or be useful in influencing future policies and practices. Their results can be maintained after the end of the funding period.

The study identifies some limitations that can be taken into consideration, for example, the differences between the target groups in the different participating countries. There is heterogeneity, all in legislative, institutional, organizational, and cultural aspects, and in other circumstances that affect the fact that the results do not have the same application nor similar effects. In this sense, there are differences in the schooling of children and young people with disabilities; in some cases, they are in specific centers, special education centers, or an ordinary center, in which case they are considered to have special needs; the needs are contextual and are special to the extent that they are not foreseen by the schooling modality (Warnock, 1978). They are seen as a reality which, in turn, through the training and information generated by the intellectual contributions of the research, will be useful to broaden and raise awareness and improve realities and horizons. Another consideration that should be given is the issues related to access to these technologies, considering the social class of children with special needs.

Among the strengths can be placed having clearly and accurately designed the road map, which is of great help. Having established the frequency of meetings and follow-up of the development of the projects also contributes to the sharing of possible problems or complications that may arise and to the search for alternatives and solutions, without losing sight of the objectives. The strength of the results is the variety of recipients and the many people who will benefit as direct recipients as well as their effect. It would be desirable that, on the basis of this work, other projects which complement, extend, and provide new applicable and beneficial knowledge are opened.

The research and training results generated positive changes in the self-esteem, valuation, autonomy, and quality of life of people with some functional disability. They likewise provided resources in different formats, conceived and designed with their needs in mind, processes in which technologies became a valuable resource. They also promoted awareness of people's needs in vulnerable situations, vulnerable either by one circumstance or another, or their personal characteristics. The case projects considered that their purpose was to improve disabled students' autonomy and quality of life. Technological advances allow people who have been disenfranchised because of their disability to participate. The general use of these technological resources has also benefited even other users who were not expected to need support. Behind this is the idea of inclusiveness, where considering the needs of a segmented population allows developing more complete proposals that benefit the whole community (Ainscow et al., 2006). There is still a long way to go in terms of technological ecosystems that support people with disabilities. This paper is an invitation to continue collaborating for societal welfare and inclusivity.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

MR-M contributed to conceptualization, methodology, project administration, writing (final draft), review, and editing. MR-M, PA-A, and JM-G contributed to formal analysis, investigation, and writing (original draft). MR-M and PA-A contributed to funding acquisition. PA-A and JM-G contributed to validation. All authors contributed to the article and approved the submitted version.

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Digital Fabrication and Theater: Developing Social Skills in Young Adults With Autism Spectrum Disorder

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An action research project was carried out, using theater workshops and basic digital fabrication technology workshops to improve social skills—such as the expression of emotions, communication, self-control, and teamwork—in a group of 10 young individuals with autism spectrum disorder (ASD). This article focuses on the digital fabrication workshops, where participants worked on the fundamentals of electronics and programming, as well as 3D design and printing, to make props that were later used on stage in the theatrical performances in which they participated. These workshops were systematized through observation guides. According to the results, it was evident that the participants not only enjoyed and gained technological knowledge, but that their social skill development needs were addressed. Professionals from the Special Education Faculty and the Fab Lab Kä Träre, both from Universidad Estatal a Distancia in Costa Rica, were in charge of the study during its first phase, executed in 2016 and 2017.

Keywords: autism spectrum disorder, social skills, digital fabrication, scratch, theater

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INTRODUCTION

Persons with autism spectrum disorder (ASD) have difficulty in developing social skills, an impairment that continues throughout their lives. According to the Organización Mundial de la Salud (2019), one out of every 160 children in the world has an ASD that persists into adulthood. This deficit affects them in different ways and, depending on each individual, impairs their functioning. Furthermore, due to their condition, individuals with ASD often experience stigmatization, discrimination, and inadequate access to services.

During their adolescence and young adulthood, individuals with ASD need support resources to help them develop new skills, a need that arises from the limited opportunities available to them to relate to peers outside the educational system and to access employment opportunities (Neary et al., 2015).

This paper describes the experience of a theater project for the development of social skills in people with ASD, that integrates elements of technology from a digital fabrication space. For this purpose, a review of previous works where art, technology and attention to disability are combined is made, to subsequently expose the work methodology used and the results achieved.

First of all, the use of theater to improve social skills is explored, as it has been documented that it is a practice that can enhance the behavioral and social environment of young adults with ASD (Corbett et al., 2016). Some of the best known theater projects used with this population are the Shakespeare Heartbeat project (Mehling et al., 2016; Loftis, 2019), the Miracle Project (Kim and Boyns, 2015; Feinstein, 2016; Ferguson, 2019) and the SENSE Theater approach (Corbett et al., 2014, 2019). In Costa Rica Universidad Estatal a Distancia (UNED) engaged in a similar project which resulted in the creation of the Rompecabezas Theater Group. This project was created based on the idea that theater, together with digital fabrication, was not only an option to work on social skill development, but could also be used as an educational and recreational space beyond the formal educational system, since most of the participants had already finished or were close to finishing their secondary education.

The project from which the Rompecabezas Theater Group emerged had the objective of helping participants develop some social skills by working with both theater and technology. The first of these skills, expressing emotions, was understood as the capacity of appropriately conveying to others what is being experienced by the self. The second skill, communication, was approached considering all components, from the explanations provided by the workshop facilitators to the questions asked by the participants. The third skill, self-control, especially self-regulation, was understood as the need to concentrate on the task at hand and to manage frustration throughout the different phases of the process and errors encountered. The fourth and last skill, teamwork, was identified as the capacity to work with other people in order to achieve a goal.

Rather than working from the perspective of what a person with a disability lacks, there are proponents who seek to work with these people's talents and their development. This is Smagorinsky's (2016) position, who states that young people with autism require the context to be adapted or constructed for them to make their greatest contributions. Among his proposals, this author emphasizes that theater and drama are an option for people with autism to relate to others with or without such condition and to themselves and their own needs. Interpreting other personalities allows for the construction and manifestation of one's own personality which could otherwise remain unexpressed due to lack of context or the lack of possibility to do so.

According to Sherratt and Peter (2002), who were among the first to propose this type of intervention and on whom later interventions have been based, theater as art allows expressing meanings and feelings to an audience, as well as recognizing the fact that the world is ever changing, diverse and unpredictable. Furthermore, theater performance helps develop other skills like patience, confidence, control, self-exploration, language sharing, personal space sharing, respecting other's time, and others.

Under this premise of using theater for youth with ASD to work on their social skills, several interventions have been implemented in educational centers (Kempe and Tissot, 2012; Neufeld, 2012; Calafat-Selma et al., 2016; Rivas, 2016) and groups created to work in theater (Casado, 2013; Guli et al., 2013; Kempe, 2014; Blanco et al., 2016). These experiences have been specific, have taken place in a reduced number of contexts, and have not been replicated.

Nonetheless, three large theater projects that have worked with individuals with ASD to develop their social skills served as the background to this project. These projects included Sherratt and Peter's (2002) proposals in their references. The oldest is The Miracle Project, which uses a format of 22 sessions or one camping week, with the participation of people with ASD and the support of non-diagnosed young individuals; their families are involved in the logistics of presenting a musical show at the end of the process (Kim and Boyns, 2015; The Miracle Project, 2017).

The second, the Shakespeare Heartbeat approach, consists of 10 sessions and does not include a final presentation of a play, but uses acting methods, volunteer support and Shakespeare's texts to play games (Mehling et al., 2016). Finally, the SENSE Theater utilizes several formats (3 months, 2 weeks camps, or 10 intensive sessions) ending with two public presentations of a theatrical play after engaging in theater games and acting exercises (Corbett et al., 2014).

All these projects are geared toward young individuals, do not have continuity after the program sessions conclude, and do not provide any instruction in or support with technology to the young participants to prepare for their performances. Overall, the use of technology in theater is infrequent, but it can be used to offer a modern and innovative perspective about theater (Sánchez et al., 2014).

In everyday practice, it is evident that people with disabilities often experience exclusion from adult educational opportunities and, especially, from the possibility of exploring artistic interests (Delgado and Humm-Delgado, 2017) even though Article 30 of the Convention on the Rights of Persons with Disabilities, ratified by Costa Rica by Law 8661 (Asamblea Legislativa de la República de Costa Rica, 2008), includes their right to develop and utilize their creative and artistic potential. This is addressed by the Rompecabezas Group's proposal, which does not remain only in the artistic aspect, but also bets on the development of social skills through the overall experience in the theater and in the field of manufacturing.

Just like theater, technology is often used to help people with ASD in different environments (Cuesta and Abella, 2012); however, they are not usually provided with spaces to explore technologies like the ones used for digital fabrication on their own. In general, using this type of technologies enables the development of a sense of independence and creativity in the people that interact with them and motivates them to solve their problems and even tackle their own needs and the needs of other individuals.

On the other hand, García (2016) explains that fabrication spaces, like makerspaces, hackerspaces, fab labs, among others, have the common characteristic of acting as catalysts for encounters, production, and socialization; they all function as stimuli to their users, enabling them to establish relationships beyond the space itself, which was one of the objectives of this project.

The combination of art and technology is a trend that has been incorporated in different domains, including the STEAM (Science, Technology, Engineering, Arts, Mathematics) approach to learning. Within this new approach, the maker movement, from which fabrication labs derive, can play a fundamental role in the interaction among arts, science, and technology (Cilleruelo and Zubiaga, 2014).

UNED has a fabrication laboratory called Fab Lab Kä Träre, an open space that promotes empowerment by taking ownership of open technologies (Red de investigación, 2018) and other tools used in digital fabrication. Fabrication laboratories, like UNED's, are part of the maker movement which promotes the creation of informal learning options that influence learning spaces by promoting their visitors' active participation (Rosenfeld and Sheridan, 2014). The participation of the Fab Lab Kä Träre in the project "Developing Social Skills in People with ASD through an Artistic Experience: Theater" opens the possibility of integrating workshops on digital fabrication technologies into the initial project proposal.

Prior experiences have integrated technologies and programming in the work done with persons with disabilities. For instance, Scratch is a programming language that allows accessing programming from a basic level in a playful, significant, and social manner. According to different experiences (López-Escribano and Sánchez-Montoya, 2012; Munoz et al., 2016; Gribble et al., 2017), this program has been used to work with persons with disabilities, including people with ASD. Learning through a program like Scratch is accomplished via problem-solving by discovering solutions at each person's own pace (Sáez-López et al., 2016). In fact, the program is designed in such a way that all people, regardless of age or condition, can use it (Marcelino et al., 2018).

Although there could be real difficulties to teach these new technologies to these populations, persons with disabilities have a right to learn about them. According to the United Nations Convention on the Rights of Persons with Disabilities (Organización de Naciones Unidas, 2007), they have the same right to have access to education and information technologies as people without disabilities. Similarly, the Convention upholds their right to access all recreational opportunities and to develop their creative and intellectual potential. However, according to the Organización Mundial de la Salud (2011) most recent report on disabilities, persons with disabilities are less likely to access technology and information than those who do not have any disability.

According to Quirós (2017), progress has been made in Costa Rica as projects, both public and private, strive to improve the access of persons with disabilities to information and communication technologies, but, in general, limitations to access cell phones and computers still exist. According to this author, inclusion regarding the use of technology required not only access, but also empowerment for the people with disabilities to be able to use different types of technologies. More openness is needed to bring such knowledge to that particular population.

Graphic programming environments have become an affordable option to teach programming in a straightforward manner. They are popular because they make programming languages available in an easy-to-understand way, especially block-based languages which omit programming syntax and focus on creation (Hill, 2015).

Graphic- and block-based programs in environments like Scratch have proven accessible to working with persons with special educational needs, such as intellectual disabilities, autism, motor disabilities, and visual disabilities (López-Escribano and Sánchez-Montoya, 2012).

At the beginning, Scratch's goal was to bring programming to people who have never viewed themselves as programmers, so that they could promote their creativity and expression through this activity. To accomplish this, the approach focused on overcoming the difficulties of previous programming teaching methods and became more customizable, meaningful, and social than other programming environments. That is why it is characterized by its ease of use (which allows individuals to develop their own projects) and by making a webpage available to be used as a platform to share projects with others and discuss their development (Resnick et al., 2009).

López-Escribano and Sánchez-Montoya (2012) cite two experiences of people diagnosed with autism using this type of tools. The first is Adams (2010) who compiled his Scratch programming camp experiences for young persons with ASD. He reports on a 14 years old boy with high functioning autism who had verbal outbursts when he got excited or frustrated yet was able to create his own video game during the camp.

The second experience is from Vicki Gold at a high school where she has been using Scratch to work with young students with Asperger since 2006. Her compilation of experiences states the importance of providing individualized supervision to each student instead of just guiding them with highly structured classes that do not attract their attention (Scratched Team, 2011).

Vallejo (2018) adds that the possibility of creating through programming can also promote innovation. Providing opportunities for creation, collaboration, and innovation is also part of what is promoted by the maker movement, where "doing" is a way of learning (Rosenfeld and Sheridan, 2014). This is how co-creation spaces, like the fabrication laboratories located in formal or informal educational environments, seek to empower individuals not only to use technology, but also to build it (Blikstein and and Krannich, 2013). It is important to emphasize one of the primary characteristics of the fabrication laboratories: that of being open to any person. García (2016) explains that they are available as community resources that provide open access to individuals to develop programs and projects.

Objectives like "co-creation," "empowerment," and "knowledge sharing" could create reluctance toward using these kinds of approaches with persons with ASD because of the basic criteria to diagnose this condition: persistent deficits in social communication and interaction across multiple contexts; restrictive patterns of behavior, interests, or activities (American Psychiatric Association, 2014).

Additionally, the interventions for the ASD population usually prioritize objectives related to improving communication skills and making their behavior more flexible, as well as regulation of emotions and self-control (Martos-Pérez and Llorente-Comí, 2013). These social skills were contemplated in the Rompecabezas Theater Group project and were tackled not only from the theater stages, but also from the use of technologies in the Fab Lab Kä Träre. The activities included in both spaces allow them to learn and perform in environments different from their daily spaces, work in teams to set up a play, solve exercises or build materials for the play, face frustration when a scene or a program did not work as expected, experience many other situations that came along and became opportunities to improve their social skills.

It was precisely the combination of all the opportunities and experiences provided by their participation in the theater and the Fab Lab Kä Träre which allows the members of the Rompecabezas Theater Group to be the main characters in a play and to create and share their knowledge about new technologies, but, above all, allows them to develop new social skills to perform better in all areas of their lives.

MATERIALS AND METHODS

Approach

The project started in March 2016 and used a qualitative approach with an action research methodology (Hernández et al., 2010) and with the involvement of UNED (through its Department of Special Education and the Fabrication Laboratory Fab Lab Kä Träre), La Máscara Theater, and the persons with ASD and their families.

The first phase of the project lasted 2 years, 2016–2017, during which the same group of young individuals with ASD participated in theater workshops and three technology workshops. The theater workshops continued for an additional year with the performance of a new play by the original group. A new group received acting lessons as well.

A group made up by three professionals in special education, a language therapist, an educator and actress, and a psychologist were in charge of the research in the theater. In turn, the Fab Lab Kä Träre staff was in charge of developing the first technology workshop and providing assistance and support for the second and the third workshops. To do this, the research group trained the laboratory staff in ASD, who, in turn, participated in several training sessions in electronics, 3D modeling and programming.

Analysis Units

The group started with 10 young participants with ASD—3 women and 7 men—with an average age of 17.01 (*SD* = 4.01), who lived in the Great Metropolitan Area. One of them was attending elementary school (12 years old), 8 were in high school, and one had completed secondary school. The inclusion criteria required all of them to have been diagnosed with ASD by a specialist who had worked with them in the past; they had to be between 12 and 20 years old; and all needed to work on improving their social skills. The exclusion criterion was not being able to work independently from a caretaker or support teacher. The invitation to participate in the project was made first through professionals working with persons with ASD, and then by disseminating information about the project in the mass media.

All participants or their legal guardians signed the research informed consent approved by UNED's Vice Presidency of Research, under registration code PROY0048-2016, which included the theater workshops and the technology sessions.

Once the group was complete, the theater workshops started with weekly one-and-a-half-hour sessions at La Máscara Theater. During 2016, they took acting classes and performed in a play as actors and actresses at the end of the year. In 2017, two productions were presented, which increased the complexity for the youth with ASD. In other words, one theatrical play was produced in 2016 and two in 2017. Before each of the performances, a technology workshop—for a total of three—was organized:

- Workshop on basic digital fabrication: it took place at the Fab Lab Kä Träre between May and June 2016. Prior to this workshop, the families participating in the project had the opportunity to visit the place and see the technologies the young individuals would be utilizing. The workshop consisted of eight 1 h work sessions filled with playful activities to approach concepts like circuits, resistors, 3D printing, 3D modeling, as well as creation activities, among others. Other technologies included Makey-Makey, led lights, lithium batteries, jumper cables, copper tape, and other electronic materials (**Figure 1**). Each hour-long session was dedicated to a specific activity and guide. Four facilitators from the laboratory planned and directed the experience. The workshop's objective was to create laser cut masks, personalized with lights and 3D printed elements to use them in their first theatrical performance (**Figure 2**).
- Workshop on Scratch programming: This workshop was taught at the computer lab of UNED's University Center in San Jose between February and March 2017. It consisted of seven 1 h work sessions where the participants learned the core principles of Scratch programming. Each participant worked individually in a computer to generate his or her own animations following working guides to learn how to make animations provided by the Scratch platform itself (**Figure 3**). Each one developed the guides at their own pace throughout the hour-long session, until, for those who were able, they generated their own animation. The sessions were taught by three facilitators: a special education teacher, a language therapist, and a psychologist that had been trained by the Fab Lab Kä Träre staff. This workshop's objective was for each student to make an animation of animals interacting with each other inspired in the production they would be putting on stage in June 2017, where all characters were animals in a planet threatened by pollution.
- Workshop on mBlock programming: it was held in November 2017 and took a 3 h session where participants used the knowledge acquired in the workshop on Scratch to program and personalize the illumination of a Christmas lamp that they had to use in the third play where they portrayed the inhabitants of a town going out at night looking for invaders that came to disturb their Christmas. A Digispark ATTINY85 board for Arduino IDE was also

used. The materials and the programming were planned in advance in the Fab Lab Kä Träre, where the lamps were designed and the type of circuits and programming to be used was selected (**Figure 5**). The workshop was taught by two of the project researchers, a special education teacher and a psychologist, with the support of two volunteers, professionals in education, in a classroom of the University Center in San José.

In order to carry out the workshops with this specific group, it was necessary to make some modifications with respect to how these types of spaces are usually taught. First, the Fab Lab's staff conducted a training and awareness session on ASD, to learn about the characteristics of the population and unlearn myths about what to expect from the group. Secondly, a previous session was held with the mothers of the participants so that they could get to know the fabrication lab space and the facilitators.

For the execution of all the workshops, detailed work guides were developed, which were presented in three different formats, appealing to the different ways of communication so that each participant could take advantage of the one they understood best: verbal instructions, a printed sheet with written instructions and photographs, and the projection of the instructions on the blackboard. The Scratch guides that were specific to the program were not modified but were delivered to them in the same way by different means. In addition, there were four facilitators per session, a larger number than usual, in order to provide more personalized attention and reduce waiting times. The profile of the facilitators was also varied, given that a professional in psychology or education was always present along with the laboratory staff, in addition to the support of other special education teachers.

Efforts were also made to reduce distractions in the space to avoid visual and auditory overstimulation. For example, no other computers were on and no 3D printing unrelated to the workshop was performed while the workshop was in progress. Finally, it is important to consider that entire sessions were devoted to tasks that in other groups would have been only part of the session, for example, learning how to build a circuit or following an animation guide in Scratch.

Data Gathering Techniques

The youngsters' progress during the project was recorded through observations and field logs. In the specific case of the activities that were held using technological resources, three instruments were used:

- A work log for the Fab Lab Kä Träre sessions: a narrative was recorded at the end of each session on the log, which detailed each participant's performance, behavior, and comments during the session.
- A compliance log for the Scratch activities and skills: the facilitators used the log to record the tasks completed by the participants and their behavior during the sessions using a checklist to show whether or not they completed the activities.
- Photo journal: it consisted of a set of photos and videos of the projects that integrated different technologies created in the Fab Lab Kä Träre workshops by the participants.

The three instruments included categories that were operationalized to have a clear understanding of what behaviors were indicators for each of the aspects under study: self-control, expression of emotions, communication, and teamwork.

Analysis

A content analysis of the photos and logs was performed to classify them according to the previously defined categories in order to assess how the technology work sessions had contributed to the development of the participants' social skills. These categories are the following:

- Expression of emotions: verbal and non-verbal manifestations of how the participants felt toward the exercises, whether these expressions targeted their peers or the facilitators.
- Communication: verbal expression of ideas, opinions, or questions addressed to their peers or the facilitators, either about the technology they were working with or about personal matters.
- Self-control: frustration management to deal with errors, on-task behavior, and control of anxiety when facing new activities.
- Teamwork: providing or requesting assistance from peers to conclude the tasks assigned.

FIGURE 1 | Workshop participants experiment with Makey-Makey and make their own masks with lights. This image is for the exclusive use for the purposes of this research.

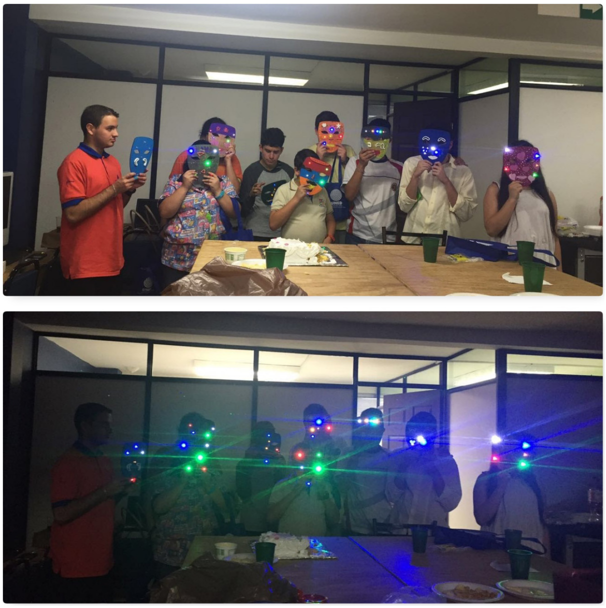

FIGURE 2 | Workshop participants show off their finished masks with lights. This image is for the exclusive use for the purposes of this research.

FIGURE 3 | Participants in the Scratch programming workshop. This image is for the exclusive use for the purposes of this research.

The work log was read to separate each behavior and comment recorded according to the four work categories. Then, the content units for each category were grouped to discuss, based on the theory, the progress observed in each area. The photos and compliance logs served as supplement to triangulate the young individuals' participation during the workshops.

FIGURE 4 | Expression of emotions of the participants during the basic digital fabrication workshop. This image is for the exclusive use for the purposes of this research.

FIGURE 5 | Participants in the mBlock programming workshop. This image is for the exclusive use for the purposes of this research.

RESULTS

After the technology workshops organized in the first 2 years of the project, it was possible to identify a series of behaviors related to each of the social skill categories defined in the project objectives. Progress identified through content analysis of photographs and logs is presented below. First, the results in the fabrication workshops, classified according to categories, and second, other progress identified in the subsequent programming workshops.

Regarding the expression of emotions, all the participants expressed at some point after the workshops had started, either verbally or non-verbally, how they felt with the activities at hand: happy for the results accomplished or sad and upset about the difficulties encountered. As the sessions went on, the expressions of emotions related to the fabrication work performed increased. Below are some examples of behaviors for this category (**Figure 4**).

When working with LittleBits: one of the participants became excited with the blocks. He really liked comparing them with Legos because he said he had 35 boxes of Legos at home. He constructed a whole circuit with them (Laboratorio de fabricación Kä Träre, 2016).

On the last day of the lab activities, one of the participants painted a butterfly like the one she had made for the mask and said that what she had liked the most was 3D printing. Then, she hugged everyone good-bye (Fab Lab Kä Träre, 2016).

In turn, communication skills were assessed in two areas: interaction among the participants and facilitators and interaction among the participants themselves. At the beginning of the process, the relationship with the facilitators solely involved asking questions about how to complete a task, but as the sessions progressed, they queried about more personal topics. Although at the beginning they were silent, as the sessions progressed, the frequency with which they talked to each other about what they were doing increased.

In summary, there were improvements in how to ask questions to the facilitators, how to talk and comment on personal issues, and how to communicate with other people who came to the lab even if they were not part of the workshop. Some examples of behaviors in this category are the following.

When the Makey-Makey board was shown to them, several participants asked how it worked (Fab Lab Kä Träre, 2016).

While creating a basic electrical circuit, one of the participants frequently interacted with one of the lab facilitators by asking questions and calling for help. This participant talked a lot while developing the circuit (Fab Lab Kä Träre, 2016).

The behaviors observed related to self-control were diverse. Some were necessary to perform the activities, like waiting for one's turn, following directions, and persevering in their attempts to complete the tasks assigned, without presenting behavioral outbursts like crying, complaining, or yelling. At the beginning it was more frequent to observe frustration behaviors (giving up on the work, demanding attention, moving forward without waiting for instructions) and as the sessions went on it was more frequent for them to wait their turn, follow verbal instructions to carry out the activities and ask for help to carry out the work.

Other self-control behaviors were related to the participants' behavior during the sessions. There were participants who at the beginning interrupted with topics of their interest outside the workshop, but as the sessions went on, they interrupted less with other topics during the work sessions. Also, some learned to like not talking about unrelated topics, self-directing, and tolerating annoying environmental distractions, like the noise in the lab (3D printers and computers) that initially caused the most discomfort. In specific cases, improvements were made in regulating what topics they could talk about (such as not asking invasive personal questions) or removing personal items that made them feel safe to be in the space (such as one young woman who by the fourth session removed a purse that she never left).

It was also possible to see that each participant's concentration span on the tasks at hand increased session after session. In the first sessions, activities took 10 min, while by the end, they were able to focus on a single 40 min activity. Teamwork was encouraged; this made it possible for them to share, in several sessions, materials to complete their tasks and work in groups of up to four people per table. In the last session, they did not have an activity structured for them in advance; instead, they were asked to choose what to do, regulating their own work process for about half-an-hour which would not have been possible at the beginning of the process.

Some examples of behaviors for this category are the following.

During one of the technology exercises circuits, one of the participants wanted to do a different activity before working on the mask. So, he was told that this could only be possible after the mask was completed which caused him some anxiety (Fab Lab Kä Träre, 2016).

One of the highlights of the process was the free activity where they were asked to create a collage with different materials; the fact that they did not destabilize when asked to do something on their own was positive. At the beginning of the process (the workshops) they had to be told what to do step by step; however, at this time the group evidenced their empowerment regarding the space and the activity. The teamwork category was the most complicated to observe due to the fact that tasks were to be performed individually for the most part or at least under individualized attention. However, they also worked in pairs in a more or less successful way; they learned to correct each other when they were doing something wrong, to explain to each other how to do something, and to share materials to carry out a task.

As for teamwork, it was enhanced by making it possible, in several of the sessions, to share materials to complete the tasks, as well as sharing work tables among up to four people. This helped them learn to share materials even though at the beginning they asked to have their own. They also developed exercises together in pairs, something they had not done before, and developed skills to correct or explain to the person next to them what they were doing (**Figure 6**).

All behaviors observed in the three technology workshops are summarized and classified by category in **Table 1**.

During the sessions in electronics and 3D printing, the participants' progress was observed with respect to how they asked the facilitators questions, how they spoke about and commented on personal topics, how they communicated with lab visitors, how they expressed joy when a task was completed, how they followed oral directions to do what was required and, in specific cases, how they controlled what topics to talk about and let go of personal objects which had usually given them

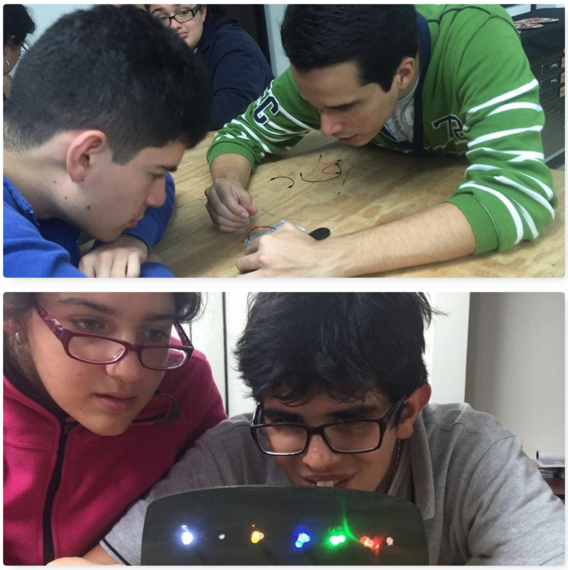

FIGURE 6 | Examples of teamwork during the basic digital fabrication workshop. This image is for the exclusive use for the purposes of this research.

confidence (e.g., the young girl that by the fourth session let go of her purse, something she had not done before).

New progress was evidenced in the Scratch work sessions and the generalization of behaviors learned in the previous workshop was observed. Some of the participants had to learn to express their discomfort with the exercises that were difficult for them, without an emotional outburst; while others expressed their joy through laughter and comments whenever they completed a programming task. Regarding communication, they replicated appropriate forms of attracting others' attention and asking for help that they had started to use in the previous workshop. Additionally, they worked on self-control by taking turns to receive personalized attention. Regarding this category, it should be pointed out that working with Scratch allowed each of the participants to follow a programming work guide and advance at their own pace promoting self-regulation.

Since each participant was working with one computer and his or her own specific programming guide, there were fewer possibilities to work in teams. Sometimes, however, when directed by the facilitators or upon the initiative of a classmate, some of those who were more advanced approached others to explain how they had done the task.

Finally, in the session to make and program the lamp, priority was given to working on self-control and in teams. Each participant was assigned a specific time to program and practice the skills of following directions and taking turns to work on their program. While they were waiting, they had to work in sub-groups sharing the materials to paint and make their lamps. Thus, it was possible to observe, throughout the 16 sessions, the participants' progress in the four categories analyzed.

The outputs from each of the technology workshops are presented in **Table 2**.

One of the participants left the project before finishing the basic electronics workshop; therefore, only nine participants finished their mask. In 2017, eight individuals participated in the Scratch workshop, but only six were able to make the animation, three of them actually completed it. The lamp workshop was voluntary, and only six of the group members participated; they all finished the lamps with all the details: customized painting and lighting effects.

DISCUSSION

Developing social skills is one of the main objectives when seeking to improve the quality of life of persons with ASD.

TABLE 1 | Behaviors recorded in the technology work sessions by category.

Category	Behaviors observed that appeared during the course of the technology workshops
Emotions	Smiling and making comments of joy when completing exercises
	Asking for forgiveness when they were wrong
	Manifest that they were sad because the workshops were over
	Laughing and clapping during a social sharing activity held at the end of the process
	Formulating complaints about the difficulties they encountered in any exercise
Communication	Asking the facilitators for help
	Inviting others to see the result of their work
	Asking the facilitators questions about the exercises
	Asking peers how they did something
	Asking for more information about the technology they were using
	Asking the facilitators personal questions
	Commenting about their daily activities
	Taking the initiative to speak with visitors (outsiders) who came to the workshops
Self-control	Reducing tantrums related to the exercises or activities
	Increasing the on-task concentration spam
	Repeating tasks until accomplishing the expected result
	Waiting for their turn when working in groups or asking questions
	Following oral instructions about their work
	Following a work guide
	Continuing with the work in spite of intense noises
	Leaving personal questions or games to the end in order to focus on the task at hand
	Getting away from objects that gave them confidence (e.g., a participant was able to let go of her purse in the last sessions to do her work)
	Giving directions to themselves aloud (e.g., "I will not go on with this topic.")
	Choosing a free activity to do without guidance
Teamwork	Completing exercises in pairs
	Correcting peers when they made mistakes in the exercises
	Sharing materials with peers to complete the tasks
	Explaining to their peers how a task had to be done

Proprietary elaboration.

TABLE 2 | Outputs of the technology workshops.

Workshop	Number of participants	Outputs
Basic electronics	10	Nine masks with five led lights in a circuit and two 3D-printed accessories as ornaments
Scratch	8	Three complete, animated scenarios Three unfinished scenarios
Lamps	6	Six customized painted lamps with programmed lighting effects

Proprietary elaboration.

Theater has become an option to work on these skills. Therefore, based on this premise, a project was developed at UNED which led to the creation of the Rompecabezas Theater Group.

As has already been mentioned, this project's objective was to improve the social skills of youth with ASD, using not only theatrical plays, but also other novel options, like the Fab Lab Kä Träre. Then came the challenge of working on the same skills that were to be improved using theater (expression of emotions, communication, self-control, and teamwork) through experiences in other areas that are not easily accessed by this population, such as those that offer the possibility of interacting with digital fabrication technologies.

This 16-session experience brought about results that make us think that working with young persons with ASD using these technologies is also a way of promoting social skill development and that they have great potential in areas that this population had not accessed before: programming, 3D printing, basic electronics.

This research is considered to have provided a valuable contribution. Most of the other interventions are concrete programs for populations with ASD developed in clinical or academic contexts that usually use classical behavioral and cognitive techniques (Martos-Pérez and Llorente-Comí, 2013) or focus on different fields or techniques, like soft skills for daily life, referential communication, agendas, social stories, and others (Olivar and de la Iglesia, 2009).

People with ASD vary in terms of the difficulties they face; therefore, it is not easy to generalize what type of interventions are more suitable for them. Although there are clinical interventions that have proven efficient (often considered to be evidence-based), it is methodologically difficult to verify the efficacy of all interventions. Many of them are designed to be used at a clinical or academic level, but not at a community or everyday level (McLeod et al., 2015).

This research proposes combining theater (Sherratt and Peter, 2002; Corbett et al., 2014; Kim and Boyns, 2015; Mehling et al., 2016) with the digital fabrication as an intervention for individuals with ASD, a novel approach not used in other theater-based intervention studies. There is no background work in basic electronics, 3D printing, and others. Regarding fabrication labs and block programming environments, there have only been two specific experiences using Scratch with individuals with autism (López-Escribano and Sánchez-Montoya, 2012).

This situation evidences the novelty of the proposal that was successfully put into practice, which, through observation and logs, allowed identifying behaviors that evidenced the participants' progress in the skills under study. What this project proposes, then, is that it is indeed possible to open varied and challenging spaces for the youth with ASD to learn and interact with new technologies and, in turn, that the interaction with other people in a significant learning context like this one, favors the actual use of the social skills they are developing.

It has been evident that the specific features of a program like Scratch make it accessible to all people, beyond their skills to understand a programming language (Resnick et al., 2009) and that block programming environments increase the possibilities for people to access the benefits that studying programming create (Hill, 2015).

Technology is not foreign for people with ASD or other disability conditions. It is many times used as a facilitator to provide support tools for the person to face his or her difficulties (Cuesta and Abella, 2012). However, this proposal aims at giving them access to technology for their education and entertainment and, as evidenced, to improve their social skills at the same time. These opportunities are necessary because, as they move away from the formal educational system of their childhood and adolescence, people with ASD face difficulties to find this type of learning and workspaces (Neary et al., 2015); therefore, this could create a wealth of new possibilities.

To continue in this line of work, it is necessary to find new, more accurate approaches to assess the participants' progress in the workshops, both in terms of their social skill development and their use of technology. It is necessary to replicate the experience of working with electronics and programming with more groups, more young individuals, and for a longer period of time in order to gather specific information that can guide the assessment of the intervention to determine its efficacy. The results of this study show that there is a possibility of working on these skills in this type of learning space, but further research is needed to pinpoint the relationship between the methods used and the progress observed.

Working with theater and technology allowed bringing art and technology together to provide opportunities for young people with ASD who found in this combination a space of interest for recreation and learning. Demonstrating the possibility of implementing this proposal and observing progress in the participants is a first step already taken by this study.

Learning about digital fabrication technologies – electronics, programming, and 3D printing – opened a space where the participants were able to express their joy for the good results and their sadness and concerns for the difficulties faced. They were able to communicate with the facilitators and the other group members. The program also facilitated the development of self-control strategies like following directions, taking turns, managing frustration, and persevering until the task was completed. It opened up teamwork spaces where they were able to share and help each other. All this was recorded through observations and photo journals throughout the 16 working sessions.

Although this is not the first research using theater for social skill development, it is novel in its use of technology as part of the process. Based on the results of this experience, it is convenient to develop more research proposals along this line, either theater integrating technology or technology workshops designed for persons with ASD. The approach could even be expanded to include people with other disability conditions that could present similar needs.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the UNED's Vice Presidency of Research, under registration code PROY0048-2016. Written informed consent to participate in this study was provided by the participants, and/or where necessary, the participants' legal guardian/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

Both authors, from their areas of specialization and work at the University, participated in both the research and the elaboration of this article.

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MINI REVIEW
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Knowledge Gaps in Mobile Health Research for Promoting Physical Activity in Adults With Autism Spectrum Disorder

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A growing body of research highlights that adults with autism spectrum disorder (ASD) have poor health outcomes, yet effective health interventions are lacking for this population. While mobile health applications demonstrate potential for promoting physical activity (PA) in adults with ASD, scientific evidence for supporting this tool's long-term effectiveness on PA behavior change remains inconclusive. This study aimed to provide the latest information on PA research and the prospective role of mobile health applications for promoting PA in adults with ASD. A literature review demonstrated that a few available studies show contradictory results regarding PA levels in adults with ASD, and behavior change techniques and gamification-guided mobile health applications can be promising tactics to leverage autism's strengths and increase PA in these individuals. Optimizing design decisions based on needs analysis and user feedback is crucial to identifying and developing a sustainable mobile health intervention for PA promotion in adults with ASD.

Keywords: mHealth application, physical activity, adults with autism, behavior change techniques, gamification

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INTRODUCTION

Autism spectrum disorder (ASD) is a pervasive neurodevelopmental condition characterized by social interaction and communication deficits, as well as restricted or repetitive behavior patterns and interests (American Psychiatric Association, 2013). According to a recent report from the Centers for Disease Control and Prevention (CDC)'s Autism and Developmental Disabilities Monitoring Network in 2020, the estimated prevalence of ASD has continuously increased since its first surveillance in 2007. Currently, 1 in 54 children in the United States have been identified with ASD, a nearly 10% increase from a previous estimate of 1 in 59 children reported in 2018 (Baio et al., 2018; Maenner, 2020). A recent modeling study conducted by Dietz et al. (2020) provided the first surveillance data on the estimated prevalence of adults with ASD in the United States using multiple national data sets. The study estimated that approximately 2.21% of United States adults (18 years and older) were living with ASD in 2017, and the prevalence was higher in adult males than females, as consistent with previous findings on children with ASD (Baio et al., 2018; Kogan et al., 2018). As remarked in the study, however, research on autism in adulthood is still a challenge because psychometrically validated tests for screening adults with ASD are currently unavailable (Dietz et al., 2020). Additionally, those who live independently with typical cognitive function may not be accurately monitored due to a lack of connection with public or community settings (e.g., schools, therapeutic entities, etc.), as well as an absence of surveillance systems to address this issue (Dietz et al., 2020).

Despite the relatively little attention paid towards adults with ASD, research on risk factors for developing autism and understanding the condition's impact on health outcomes has increased significantly over the past two decades (Wolff, 2004; Pellicano et al., 2014). Importantly, the existing literature has been consistent in showing that adults with ASD have poorer outcomes across health domains than those without ASD. Croen et al. (2015) studied a large sample of adults with ASD (n = 1,507) in the United States and highlighted that these individuals are at a higher risk for nearly all mental and physical health conditions (e.g., depression, anxiety, obesity, and diabetes) compared to adults without any ASD diagnoses. Furthermore, adults with ASD are more than twice as likely as their neurotypical counterparts to die prematurely (Hirvikoski et al., 2016). It is predicted that the shortage of resources and the existing health disparities for this population will likely expand (Tyler et al., 2011; Krahn et al., 2015). This descriptive mini review aimed to provide the latest information on physical activity (PA) research and the prospective role of mobile health applications for promoting PA in adults with ASD. Four electronic databases (Google Scholar, PubMed, Scopus, and Web of Science) were searched for studies published between October 2000 and September 2020. Search terms included "physical activity," "mobile application," "autism," and a combination of these keywords and close variants (e.g., Asperger's syndrome, mHealth, fitness app, etc.). The search was limited to articles published in English.

PA IN ADULTS WITH ASD

There is little information on PA as a preventive health behavior in adults with ASD (Reinders et al., 2019). Most research in this area has been conducted in children and adolescents, and the findings indicate that they are less physically active (Pan, 2008; Stanish et al., 2017) or engage in similar levels of PA participation as their typically developing peers (Sandt and Frey, 2005; Bandini et al., 2013). More importantly, moderate to vigorous PA (MVPA), which is the level of activity associated with health outcomes, significantly decreases with age in this population (MacDonald et al., 2011). Nonetheless, PA has been used with moderate success as a social or behavioral intervention in young individuals with ASD (Sowa and Meulenbroek, 2012; Schmitz Olin et al., 2017). A previous systemic review found that PA or exercise may be effective at reducing negative behaviors (e.g., aggression, elopement, and stereotypy) and increasing positive behaviors (e.g., academic responding, on-task behavior, and motor performance) in both children and young adults with ASD (Lang et al., 2010), although the relatively small sample (n = 64) and varying methodological quality in existing studies make it difficult to draw a solid conclusion about the effects of PA on behavioral outcomes in this population.

National and international health organizations recommend that adults should participate in at least 150 min of moderate-intensity PA or 75 min of vigorous-intensity PA throughout a week, or an equivalent combination of MVPA, to see health benefits (Piercy et al., 2018; World Health Organization, 2019). While the benefits of regular PA (e.g., improvement in muscular and cardiorespiratory fitness, reduced risk of cardiovascular diseases and mental disorders, and weight control) have been supported by numerous studies (Warburton et al., 2006; Warburton and Bredin, 2017), insufficient PA or physical inactivity is a leading risk factor for coronary heart disease and global premature mortality (Autenrieth et al., 2011; Lee et al., 2012). To date, there exist only a few available studies on PA in adults with ASD, and they have shown contradictory results (Eaves and Ho, 2008; Lalonde et al., 2014; Garcia-Pastor et al., 2019). Eaves and Ho (2008) used parent proxy reports and found that adults with ASD engaged in MVPA on average once per week and spent about 13 h/day sitting. Lalonde et al. (2014) were the first to use pedometers as an objective measure to promote walking activities in a small sample of adults with severe ASD. A walking program, along with goal setting, feedback on performance, and reinforcement, was effective at increasing daily steps to a desired level (e.g., >10,000 steps/day) in all participants. As a pilot surveillance study, Garcia-Pastor et al. (2019) used uniaxial accelerometry and found that Spanish adults with ASD met the recommended PA guidelines of ≥150 min of MVPA a week, but they were also highly sedentary. It is important to note that, however, sample characteristics in these studies were described as having moderate to severe autism symptoms and relatively low levels of cognitive function, needing high levels of support. Most of the study participants attended segregated schools or lived with parents, in supported group homes, or foster care. Moreover, the methodological heterogeneity in PA assessment (i.e., proxy survey reports vs. objective measures) makes it difficult to synthesize previous findings. As such, it is inconclusive how PA is associated with varying levels of cognitive function and the concordance between subjective and objective measures for PA assessment in adults with ASD.

MOBILE HEALTH APPLICATIONS FOR PEOPLE WITH ASD

Mobile application is an attractive modality for behavioral intervention in people with ASD because human-technology interaction enables visuospatial learning, which is often noted as a particular strength in those with ASD (Samson et al., 2012). It also presents a lower social burden compared to traditional face-to-face interaction, an area in which those with ASD struggle, as technology provides a predictable and consistent social platform (Kientz et al., 2013). With the increased accessibility and affordability, the use of mobile applications for people with ASD has been widespread across a range of domains focusing on visual cues as a supplementary intervention. Autism-friendly mobile applications are particularly designed to accommodate the unique characteristics of autistic users (e.g., avoidance of social situations and strengths in logical reasoning; American Psychiatric Association, 2013; Shah et al., 2016). A number of user-centered educational applications have gained popularity in the autism community by providing leaning opportunities for social and communication skills, emotional regulation skills, and occupational functioning (e.g., appropriate behavior in the workplace or school and problem-solving skills; Ayres et al., 2013; Hourcade et al., 2013; Gay and Leijdekkers, 2014).

However, there exist almost no similar attempts to use mobile applications to address PA disparities in individuals with ASD. The only related effort has been a video modeling mobile application, Exercise Buddy, that was developed to help children with ASD acquire and improve fundamental motor skills consisting of locomotor (e.g., walking, running, and jumping), balance, and object control skills (Bittner et al., 2017). With supportive visual and auditory instructions, this video modeling program effectively increased heart rate and energy expenditure in children with ASD while they performed locomotor skill tasks (Bittner et al., 2017). However, there was no *post hoc* investigation on the functional outcomes in relation to actual motor skill acquisition/improvement after the intervention and any consequent impact on PA or other daily living activities in real-world settings. In addition, the system focused on children with limited cognitive function and required substantial assistance for proper execution; thus, it cannot be applicable to adults with ASD who live independently and make their own choices in their health behaviors.

Although the evidence supporting their long-term effectiveness on health behavior change is unclear, mobile health applications can have small to moderate effects in the short term (e.g., up to 3 months) on self-monitoring or changing PA and sedentary behavior in overweight and sedentary neurotypical adults (Turner-McGrievy et al., 2013; Romeo et al., 2019). PA in adults with ASD may be best stimulated by using gamified mobile applications, particularly considering reports that adults with ASD use technology devices over 4 h/day, primarily playing games (Lee et al., 2018). Gamified behavioral interventions have rapidly expanded the technological potential to monitor and improve PA participation in a playful way (Zuckerman and Gal-Oz, 2014; Alahäivälä and Oinas-Kukkonen, 2016), which leverages the merits of a heightened sense of autonomy, as well as feelings of fun and continuation desire (Deterding et al., 2011; King et al., 2013). Also, an emerging body of research suggests that behavior change techniques (BCTs)-guided mobile health interventions can be useful to increase PA in inactive or sedentary individuals (Direito et al., 2017; Sullivan and Lachman, 2017). The importance of incorporating evidence-based BCTs should be amplified when designing health behavior change interventions for those with ASD, considering their restricted repertoires of behavior patterns and low social motivation (Dawson et al., 2005; Chevallier et al., 2012).

BCTs AND GAMIFICATION FOR PA PROMOTION IN ADULTS WITH ASD

BCTs are a systematic, evidence-based health behavior change strategy for altering or redirecting causal processes that regulate healthy behaviors (Abraham and Michie, 2008; Michie et al., 2013). For example, some intervention strategies can be designed to monitor and promote PA participation, smoking abstinence, a healthy diet, or consistent sleep patterns by augmenting facilitators and/or mitigating barriers for behavior change (Carey et al., 2019). Since Abraham and Michie (2008) structured the first cross-behavior taxonomy of 22 BCTs, this strategy has been extensively adopted across the globe to design, implement, and evaluate behavior change interventions. On the basis of a systematic review and refinement, a current taxonomy of the BCTs includes 93 hierarchically clustered techniques, including self-monitoring of behavior, social support, goal setting, feedback on healthy behavior, action planning, incentives, etc., that offer multidisciplinary acceptance and use for developing effective behavior change interventions (Michie et al., 2013).

Effective behavior change interventions generally leverage multiple BCTs to implement health behavior change, and a mobile application enables researchers to deliver diverse BCTs in a time- and cost-effective way in real-world settings (Bird et al., 2013; Middelweerd et al., 2014; Crane et al., 2015). Currently, there are more than 325,000 health applications specifically designed for promoting physical fitness and PA in major application stores such as Google Play and the Apple App Store (Research2Guidance, 2017). Some of the available applications have empirically demonstrated the potential to enhance users' PA engagement, but only a minimal number of the applications have been developed or evaluated through scientific methods, while most are not guided by evidence-based health intervention strategies such as BCTs (Cowan et al., 2013; Pagoto and Bennett, 2013).

Conroy et al. (2014) examined 167 top-ranked PA-promoting applications on the commercial market to verify the prevalence of BCTs among the popular PA applications. Specifically, they characterized the BCTs by analyzing the applications' online descriptions and functions on the basis of the BCTs taxonomy. Among others, provision of instruction for behavior performance, demonstration of behavior, provision of contingent feedback on performance, behavioral goal-setting, and plans of social support or change were the most commonly adopted BCTs in the included applications (Conroy et al., 2014; Yang et al., 2015). Importantly, the majority of contemporary PA-promoting applications lacked BCTs as a theoretical background for the developmental process (Conroy et al., 2014). Due to the scarcity of systematic assessment within the contemporary PA applications, it is unclear how the incorporated BCTs affected and changed users' health behavior, as well as how any positive health outcomes after the application use were associated with varying intrinsic or extrinsic motivation factors (Sullivan and Lachman, 2017).

Despite the limitations, gamified behavior change interventions in particular have presented promising results to promote PA in adults with and without ASD. Gamified interventions leverage game-like elements such as leaderboards, animated avatars, problem-solving, and attractive storylines to elevate the level of motivation and user engagement (Alsawaier, 2018). Chen and Pu (2014) deployed "HealthyTogether," an interactive mobile fitness application, which focused on gamified social interaction among users leveraging social incentives and a point reward system. The research team found a significant relationship between

PA and the number of messages that participants exchanged, implying the importance of cooperative social interaction in gamified PA contexts. The success of Pokémon Go, an augmented reality-based application that links a Pokémon character hunting game to location tracking technology, further heightened the emerging potential of using gamification techniques to promote achievable PA (e.g., walking) in real-life settings, even though the intervention effect was short-term (Althoff et al., 2016; Howe et al., 2016). Furthermore, Lee (2020) reported that "PuzzleWalk" a gamified, BCTs-based mobile application, can be effective at increasing user engagement and potentially PA in adults with high-functioning ASD. Their preliminary deployment study compared PuzzleWalk to a commercially popular PA-tracking application, Google Fit, to evaluate the efficacy of both apps on increasing PA in adults with ASD who do not have intellectual disability, but struggle with daily living skills using a randomized controlled trial design ($n = 24$). Findings indicated that PuzzleWalk users spent significantly larger amounts of time on application use compared to Google Fit users throughout a 5-week intervention period. Even though statistical significance was not reached, PuzzleWalk also demonstrated the potential for increasing MVPA in the short term and reducing sedentary time in adults with high-functioning ASD (Lee, 2020).

Taken together, a growing body of research supports the potential of gamification and BCTs-guided mobile applications for promoting PA in diverse population groups, including adults with ASD. However, despite the increasing popularity of using these promising tactics in commercial PA applications, evidence-based mobile health interventions are lacking, and only a few attempts have been made to address the unique characteristics and health needs in adults with ASD. Furthermore, more research is warranted to better understand the impact of varying degrees of cognitive abilities and sociability on health behaviors in adults with ASD.

CONCLUDING REMARKS

This brief review has revealed that there is a critical need for interventional studies that leverage autism's strengths to address preventive health and reduce health disparities in adults with ASD. Despite the seemingly successful expansion of mobile health applications for promoting PA in both adults with and without ASD, most of the existing health and PA applications on the commercial market are not designed using scientific evidence or health behavior theories such as BCTs (Middelweerd et al., 2014; Yang et al., 2015). It is also crucial to note that reports on the success of gamified applications are largely based on anecdotal evidence, and there is insufficient scientific evidence to support their long-term effectiveness in inducing voluntary behavior change, including PA engagement (King et al., 2013; Lister et al., 2014). The use of gamification principles in most popular PA applications does not adhere to any industry-standard or professional guidelines (Lister et al., 2014). Although BCTs and gamification are promising tactics for increasing user interest and PA motivation, it is inconclusive whether these features can lead to sustained behavior change. Furthermore, due to an absence of versatility in addressing the unique behavioral and social preferences of individuals with ASD (e.g., adherence to routines and visual preference for social stimuli; Leekam et al., 2011; Crawford et al., 2016), general mobile health applications are less likely to enact a successful PA behavior change in adults with ASD who tend to have relatively low self-esteem and intrinsic motivation for health behavior change (Koegel and Mentis, 1985; Cooper et al., 2017). To develop a sustainable mobile health intervention that promotes PA in adults with ASD, it is critical to optimize design decisions based on an in-depth understanding of the target users and iterative inquiry regarding user feedback and behavior patterns (i.e., user-centered design) to facilitate the use of and adherence to interventions (Mummah et al., 2016; Lee et al., 2020).

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SYSTEMATIC REVIEW
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Assistive Technologies in Dementia Care: An Updated Analysis of the Literature

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Objectives: Technology can assist and support both people with dementia (PWD) and caregivers. Recently, technology has begun to embed remote components. Timely with respect to the pandemic, the present work reviews the most recent literature on technology in dementia contexts together with the newest studies about technological support published until October 2020. The final aim is to provide a synthesis of the timeliest evidence upon which clinical and non-clinical decision-makers can rely to make choices about technology in the case of further pandemic waves.

Methods: A review of reviews was performed alongside a review of the studies run during the first pandemic wave. PsycInfo, CINAHL, and PubMed-online were the databases inspected for relevant papers published from January 2010.

Results: The search identified 420 articles, 30 of which were reviews and nine of which were new studies meeting the inclusion criteria. Studies were first sorted according to the target population, then summarized thematically in a narrative synthesis. The studies targeting technologies for PWD were categorized as follows: monitoring and security purposes, sustaining daily life, and therapeutic interventions. Each category showed potential benefits. Differently, the interventions for caregivers were classified as informative, psycho-education programs, psychosocial-supportive, therapeutic, and cognitive/physical training. Benefits to mental health, skills learning, and social aspects emerged.

Conclusions: The evidence shows that technology is well-accepted and can support PWD and caregivers to bypass physical and environmental problems both during regular times and during future pandemic waves. Nevertheless, the lack of a common methodological background is revealed by this analysis. Further and more standardized research is necessary to improve the implementation of technologies in everyday life while respecting the necessary personalization.

Keywords: dementia, technology-assistive/supportive, COVID-19 pandemic, quality of life, caregivers, psychology

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INTRODUCTION

According to recent statistics, a demographic revolution is currently underway: the average life expectancy is rising worldwide, and the population of persons aged over 60 is going to continually grow until 2050 (United Nations, Department of Economic and Social Affairs, and Population Division, 2020; WHO | Global Action Plan on the Public Health Response to Dementia 2017–2025, 2020). Even though aging is part of human development, one of the main risks associated with it concerns dementia: 5% of the world population aged over 65 is affected by some types of dementia, and this prevalence doubles around every 5 years (Corrada et al., 2010).

Recently, assistive technologies (ATs) have become one of the fundamental pillars of health strategies. They include "*any product or technology-based service that enables people of all ages with activity limitations in their daily life, education, work or leisure*" (Association for the Advancement of Assistive Technology in Europe [WorldCat Identities], 2018). Regarding dementia, ATs can increase motor autonomy and reduce the risks associated with wandering thanks to their GPS technology (Liu et al., 2017); they can also sustain people's cognitive abilities—those required to accomplish necessary daily activities (Nishiura et al., 2019). Again, ATs play a role in supporting the policies surrounding *aging in place*. Indeed, they can delay people's institutionalization or reduce the number of severe clinical cases requiring admission to care homes (Brittain et al., 2010). Besides, technology is useful when admission into a care facility becomes mandatory or is the person's preferred option. In these cases, ATs allow for easier communication between residents and relatives and overcome social barriers (Winstead et al., 2013).

Furthermore, ATs increase people's safety by sustaining independence while respecting dignity (Brittain et al., 2010). Finally, ATs are associated with benefits when conveying rehabilitation and psychosocial interventions (Peek et al., 2014). Technological devices are cheap and affordable (Al-Oraibi et al., 2012). Intuitive interfaces support the users' sense of control by highlighting cause–effect relations between tasks and actions (Leng et al., 2014). Thanks to personalized items and control processes focused on responding to specific needs and preserving abilities, they increase users' participation in interventions (Smith and Mountain, 2012; Darcy et al., 2017). Finally, technology promotes remote support and assistance by overcoming environmental barriers (Azad et al., 2012).

On the other hand, ATs often present a few limitations. Devices might be experienced as intrusive and invading the users' privacy (Dorsten et al., 2009). Again, they can be obstructive and increase the stigma that sometimes comes with the disease (Pritchard and Brittain, 2015). Moreover, complicated features, or intense learning sessions, might underline cognitive abilities loss, leading to frustration and rejection of technology (Peek et al., 2014).

Recently, the remote feature has begun to characterize ATs more and more, as it becomes useful to bridge the distance between people (Cuffaro et al., 2020). Capitalizing on the positive evidence about AT and dementia (Meiland et al., 2017), it may be conceivable to assume that ATs might play a key role in the attempts to alleviate the future burden lockdowns might bring with them (INDUCT, 2020). At the same time, to keep people safe, technological devices might support people with dementia and caregivers during the months of lockdown (Meiland et al., 2020).

Timely with respect to the pandemic, the present work reviews the most recent literature reviews on ATs in dementia contexts together with a review of the new studies adopting ATs during the virus outbreak.

The current work's final aim is to provide a tangible summary upon which clinical and non-clinical decision-makers can base their choices about which technological intervention tools they can deploy to directly compensate/improve specific dysfunctionalities affecting either people with dementia or caregivers even during future pandemic waves.

METHOD

Data Collection and Strings Definition

PsycINFO, PubMed, and CINAHL were the online databases where we sought peer-reviewed papers published from January 2010 to October 2020 (**Table 1**). The research query combined keywords from three different research strings (A, B, C) through the Boolean operators "AND" and "OR" (**Table 2**). String A included the studies that were related to technology in general. Due to the lack of standardized terminology (Roest et al., 2017), several terms were derived from the APA thesaurus. String B selected the target population. String C filtered for the methodology of interest.

Typology of Review and Eligibility Criteria

To summarize the most recent literature related to the use of technology, the present review combines the review of reviews methodology (Smith et al., 2011) with a literature review including the most recent studies on the topic that are still not reviewed.

Inclusion Criteria

The included studies are those that are as follows: peer-reviewed, published from January 2010 to October 2020, available in English or Italian, and those that deal with any technological devices. The studies analyze interventions on both people diagnosed with dementia and their caregivers. Moreover, we ascertain any method: experimental, quasi-experimental, or single-case studies.

TABLE 1 | Initial search data.

Database String	PsycINFO	PubMed	CINAHL
A	49,933	66,372	147,950
A AND B	354	592	1,082
A AND B AND C	109	111	197

TABLE 2 | Complete query used.

PsycINFO	PubMed	CINAHL
(KW (technology or technologies) OR KW telemedicine OR KW assistive device OR KW App OR KW computer OR KW tablet OR KW telecommunication OR KW web-based OR KW online OR KW internet OR KW (telecare or "tele care") OR KW (ehealth or e-health or electronic health) OR KW (telehealth or "tele health") OR KW digital OR KW (videotelephone or "video phone") OR KW video chat OR KW video communication)) AND (KW (dementia or alzheimer)) AND (TI intervention OR KW intervention OR AB intervention)	((((technology[Other Term] OR technologies[Other Term] OR telemedicine[Other Term] OR assistive device[Other Term] OR App[Other Term] OR computer[Other Term] OR tablet[Other Term] OR telecommunication[Other Term] OR web-based[Other Term] OR online[Other Term] OR internet[Other Term] OR telecare[Other Term] OR tele care[Other Term] OR ehealth[Other Term] OR e-health[Other Term] OR electronic health[Other Term] OR telehealth[Other Term] OR tele health[Other Term] OR digital[Other Term] OR videotelephone[Other Term] OR video phone[Other Term] OR video chat[Other Term] OR video communication[Other Term])) AND (dementia[Other Term] OR alzheimer[Other Term]))) AND ((intervention[Title/Abstract]) OR intervention[Other Term])	((SU (technology or technologies) OR SU telemedicine OR SU assistive device OR SU App OR SU computer OR SU tablet OR SU telecommunication OR SU web-based OR SU online OR SU internet OR SU (telecare or "tele care") OR SU (ehealth or e-health or electronic health) OR SU (telehealth or "tele health") OR SU digital OR SU (videotelephone or "video phone") OR SU video chat OR SU video communication)) AND SU (dementia or alzheimer))) AND (TI intervention OR SU intervention OR AB intervention)

Exclusion Criteria

We excluded studies if the target population was composed of MCI or the authors did not explicitly sort the results between PWD and MCI. Moreover, we do not accept any papers reporting only dementia technological assessments or diagnoses.

Selection Process

The selection process is showed in the PRISMA flow diagram in **Figure 1**. The search brought out 420 papers, 123 of which were removed because of duplicates. Both the title and the abstract of the 297 remaining documents were checked. Ninety-two documents emerged from this former analysis, of which 39 were review papers, and 53 were new studies. Nine reviews were further excluded. Once they were fully read, they did not meet the eligibility criteria: three were excluded for the target population, four were excluded because devices were aimed only at diagnosing, and two were excluded for the methodology.

Out of the 53 new studies, 41 were already in the reviews, and three of them did not meet the inclusion criteria: two of them due to the target population and one for the methodology (i.e., protocol report). In the end, 30 reviews and nine new studies were included in the present work and thoroughly analyzed.

Stages of Analysis

At first, we assessed the quality of the included systematic reviews through either the AMSTAR tool guidance for the systematic reviews (Shea et al., 2009) or the SANRA scale for the non-systematic reviews (Baethge et al., 2019; **Tables 3**, **4**, respectively). A formal assessment of the new studies was not performed, as it was urgent to update the pandemic-related literature, despite the study quality.

Moreover, we aggregated the new studies to calculate the overall risk ratio (Balduzzi et al., 2019). A risk ratio (RR) >1 signifies that the intervention groups manifest better outcomes than the control ones. The packages *meta* and *metasens* within the freely available statistical environment R facilitated ratio calculation (Schwarzer et al., 2015; R Core Team, 2019).

Yielded works were parsed according to the target population (PWD and/or caregivers). In **Table 5**, we classified the data from the reviews about PWD. In **Table 6**, we instead reported the data about the new studies (i.e., sample size, characteristics, settings, and intervention length). In **Table 7**, we summarized the data from the reviews about PWD caregivers. In particular, **Tables 5**, **7** display data about the types of conducted interventions, focus, used methodology, main results, and review conclusions. Hence, a thematic analysis of the outcomes was performed to classify the papers according to the aims underpinning the technological devices studied. Narrative synthesis integrates and appraises the quantitative and qualitative findings and the inclusion of studies using different methodologies. Two authors (AP and GO) reviewed and discussed the inclusion potential studies, and any discrepancy was resolved by a third reviewer (RC) through discussion until an agreement was reached. Thematic analysis was performed as an iterative process. Studies were read and re-read by the researchers, and key themes were identified for each paper and then amalgamated and integrated across studies.

RESULTS

Results are sorted into two main sections, one per target population involved. As shown in **Table 3**, 12 out of the 30 reviews are related to online interventions targeting caregivers, 16 of them concern PWD, and two reviews target both PWD and caregivers. On the other hand, all of the nine new studies address PWD issues.

Quality Assessment of the Included Reviews

The quality assessments regarded the extent to which the 23 systematic reviews and seven reviews met the inclusion criteria.

All the systematic reviews received an AMSTAR score between 5 and 9, with a mean score of 7.4 (standard deviation = 1.2). All reviews were designed a priori (AMSTAR item 1); more than half of the analyzed works indicated that study selection and data extraction were performed by two authors minimum (item 2); all the reviews were based on electronic searches (item 3); 14 reviews included the status as an analyzed criterium (item 4);

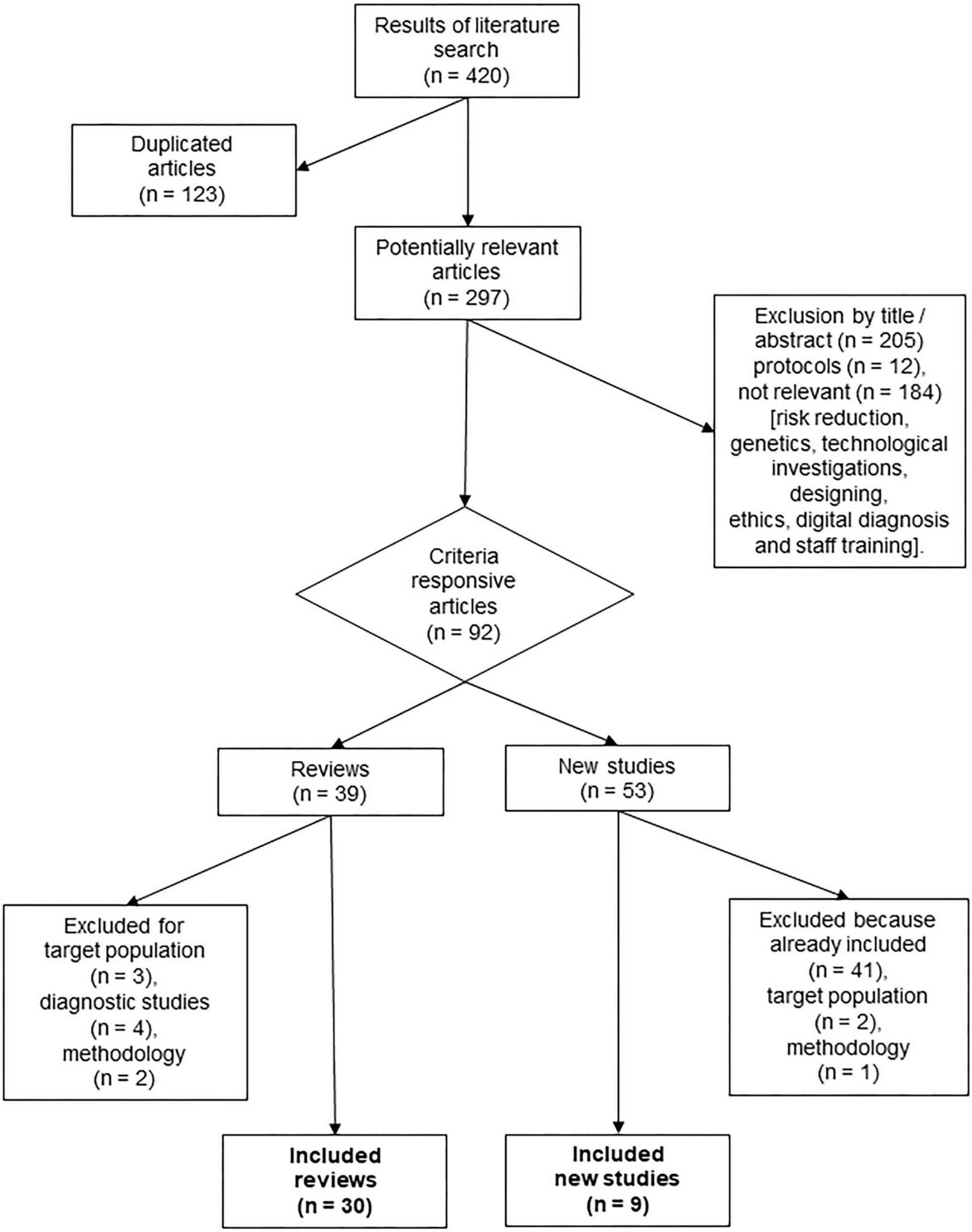

FIGURE 1 | Revision flow chart.

TABLE 3 | Quality assessment of systematic reviews using AMSTAR.

Review	A priori design	Duplicate study selection and data extraction	Comprehensive literature search	Publication status criteria	List of included and excluded studies	Characteristics of included studies	Quality assessment	Study quality used appropriately in formulating conclusions	Appropriate methods used to combine studies	Publication bias assessed	Conflict of interest stated	Total
Boots et al. (2014)	Y	CA	Y	N	N	Y	Y	Y	NA	N	Y	6
Brims and Oliver (2019)	Y	N	Y	Y	N	Y	N	Y	Y	Y	Y	8
Daly Lynn et al. (2019)	Y	Y	Y	Y	N	Y	N	Y	NA	N	Y	7
Dam et al. (2016)	Y	Y	Y	Y	N	Y	Y	Y	NA	Y	Y	9
Egan et al. (2018)	Y	Y	Y	N	N	Y	Y	Y	NA	Y	Y	8
El-Saifi et al. (2018)	Y	Y	Y	Y	N	Y	N	N	NA	N	Y	6
Fleming and Sum (2014)	Y	CA	Y	N	N	Y	Y	Y	NA	N	N	5
García-Casal et al. (2017)	Y	CA	Y	N	N	Y	Y	Y	Y	N	Y	7
Godwin et al. (2013)	Y	N	Y	Y	N	Y	N	Y	NA	N	Y	6
Hopwood et al. (2018)	Y	Y	Y	Y	N	N	Y	Y	NA	Y	Y	8
Jackson et al. (2016)	Y	Y	Y	Y	N	Y	Y	Y	NA	Y	Y	9
Lazar et al. (2014)	Y	Y	Y	Y	N	Y	N	Y	NA	N	Y	7
Leng et al. (2020)	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	9
Liapis and Harding (2017)	Y	CA	Y	Y	N	Y	Y	Y	NA	N	Y	7
Lucero et al. (2019)	Y	Y	Y	N	N	Y	Y	Y	NA	Y	Y	8
Maia et al. (2018)	Y	Y	Y	Y	N	Y	Y	Y	NA	Y	Y	9
McKechnie et al. (2014)	Y	CA	Y	Y	N	Y	Y	Y	NA	N	Y	7
Parra-Vidales et al. (2017)	Y	Y	Y	N	N	Y	N	Y	NA	N	N	5
Pinto-Bruno et al. (2017)	Y	Y	Y	N	N	Y	Y	Y	NA	N	Y	7
Ruggiano et al. (2018)	Y	Y	Y	Y	N	Y	Y	Y	NA	N	Y	8
Scott et al. (2016)	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	9
Tyack and Camic (2017)	Y	Y	Y	Y	N	Y	Y	Y	NA	N	Y	8
Waller et al. (2017)	Y	Y	Y	Y	N	Y	Y	Y	NA	Y	Y	9
Total yes per item	23	16	23	14	0	22	17	22	4	10	21	

Scores: CA, can't answer; N, no; NA, not applicable; Y, yes (Shea et al., 2009).

TABLE 4 | Quality assessment of non-systematic reviews using SANRA.

Review	Justification of the article's importance for the readership	Statement of concrete aims or formulation of questions	Description of the literature search	Referencing	Scientific reasoning	Appropriate presentation of data	Total
Brando et al. (2017)	2	2	2	2	2	1	11
Dove and Astell (2017)	2	2	2	2	2	2	12
Klimova and Maresova (2017)	2	2	2	2	1	1	10
Lorenz et al. (2019)	1	2	1	2	2	2	10
Neubauer et al. (2018)	2	2	2	1	2	2	11
Rathnayake et al. (2019)	2	2	2	2	2	2	12
Yousaf et al. (2019)	2	2	2	2	2	2	12
Total	13	14	13	13	13	12	

Scores: 0–2 (Baethge et al., 2019).

no reviews provided a list of excluded studies (item 5); all the reviews but one provided tables displaying the characteristics of the analyzed studies (item 6); 17 out of 23 reviews performed the study quality assessment (item 7); all the reviews but one based their conclusion on study quality levels (item 8); only four reviews performed a meta-analysis (item 9); 10 reviews reported publication bias (item 10), and 21 reviews discussed the conflicts of interest (item 11).

The reviews not analyzed via AMSTAR scores were subjected to the SANRA process (Brando et al., 2017; Dove and Astell, 2017; Klimova and Maresova, 2017; Neubauer et al., 2018; Lorenz et al., 2019; Rathnayake et al., 2019; Yousaf et al., 2019). Overall, the studies achieved a score of 11.1, with a standard deviation of 0.8. Across the items (i.e., justification of the article's importance for the readership, statement of concrete aims or formulation of questions, description of the literature search, referencing, scientific reasoning, and appropriate presentation of data), and no study scored 0.

Finally, we performed a risk ratio and a forest tree calculation to understand the effectiveness of the new studies. If the risk ratio was calculated higher than one, the study's technologies have an effective impact on the target (**Figure 2**).

Interventions for PWD

We classify the interventions targeting people with dementia into the four following macro-categories. Monitoring and security included studies with remote technologies aimed at detecting risky behavior and compensating for environmental obstacles. Daily living sustainment contains studies investigating devices supporting the PWD's cognitive functions. The therapeutic technology-based interventions were split between the studies that investigated cognitive aspects and the ones addressing psychosocial care.

Monitoring and Security

The interventions regarding monitoring and security appear to be analyzed in 10 reviews and one new study from our analysis. Lorenz et al. (2019) underline how technology targeting PWD living in their homes is mainly aimed at monitoring them or increasing the environment's security. The most used devices for achieving this purpose are video cameras. These devices might be used to ascertain the person in real time or record tapes for later analysis (Lorenz et al., 2019; Yousaf et al., 2019). The included reviews also reveal how video monitoring allows us to increase medication compliance in people with dementia (Fleming and Sum, 2014; El-Saifi et al., 2018). Video monitoring also leads to relevant benefits inside care homes, and it happens when it is combined with bed sensors. Both these technologies allow us to reduce intrusive check-ups overnight from healthcare professionals by avoiding sudden and unnecessary awakenings. Despite a few technical issues and the false alarms that emerged during the studies, the devices lead to a positive quality of life-related outcomes and high levels of acceptance from either PWD, their caregivers, and staff members (Maia et al., 2018; Daly Lynn et al., 2019). Finally, one review suggests the adoption of the actigraphy technique as having potentially worth in helping to monitor people in care home settings (Favela et al., 2020).

Other relevant devices for monitoring are the position trackers and locators. These are usually based on GPS technology featuring most of the ordinary smartphones. Neubauer et al. (2018) analyzed monitoring technologies for PWD and reported that GPS devices are usually implemented in wearable items, such as belts or wristwatches. *CANDEROID*, for example, is a system based on a wrist sensor combined with a smartphone App allowing the caregiver to monitor and track the position of the PWD in real-time (Brando et al., 2017). Benefits to the perceived security and quality of life emerge from using these technologies by PWD and informal caregivers (Lorenz et al., 2019). Moreover, as some of the devices imply the active roles

TABLE 5 | Interventions for PWD.

References	Focus	Methods	Interventions	Results	Conclusions
Brando et al. (2017)*	Analysis of the advantages and disadvantages associated with the implementation of technology into works with PWD and caregivers.	Literature Review. 30 studies, 27 on PWD.	Cognitive rehabilitation using technologies (videogames, VR setting, smartphone, computer and tablet). Cognitive assessment using digital tests.	Cognitive rehabilitation leads to a large generalization of the benefits. Significative outcomes on cognitive and depressive symptoms using videogames. Greater results on self-efficacy, perceived improvement, involvement and cognitive symptoms using VR rehabilitation than traditional activities. Positive effects on QoL using everyday technologies. Using digital tests for the assessment allow to standardize the administration process and the presentation of stimuli.	Cognitive rehabilitation using technologies has advantages over traditional rehabilitation. Further RCT studies are required to compare the advantages associated with different devices.
Brims and Oliver (2019)	Analysis of the effectiveness of ATs in improving the safety of PWD.	Systematic Review and Meta-analysis. Three RCTs.	Interventions using devices (sensors and tech-armbands) to increase safety in domestic setting.	The probability of a fall occurring was 50% lower in the intervention group [risk ratio 0.50 95% CI (0.32, 0.78); $Z = 3.03$; $p = 0.002$]. Significant fewer risky behavior in 1/3 studies ($p < 0.001$). No significant differences emerged between groups in care home admission, QoL and depressive symptoms.	Current evidence supports the use of safety AT by PwD. Further research is required to infer causality.
Daly Lynn et al. (2019)	Analysis of the ATs used for PWD in residential care settings.	Systematic Review, 61 studies.	Interventions based on technologies. Telecare (23), light therapy (4), pet robots (12), simulated presence therapy (9), leisure activities (8) and ADL (5).	Telecare technologies – improvement in safety and increased PWD's autonomy. Light therapy – Improvement in circadian rhythms. Pet robots – decreased BPSD and depressive symptoms; increased social interactions. Daily living activities – positive effects on cognition, communication and physical activity. ADL – increased autonomy in personal hygiene, decreased stress using digital prompts.	Positive outcomes support the potential of ATs in dementia context. More standardized studies are required to explore the effectiveness of each device.
Dove and Astell (2017)	Analysis of the available motion-based technologies in dementia context.	Literature Review. Thirty-one studies, section of 25/31 on PWD.	Interventions combining cognitive stimulation, physical activity and leisure activities using videogames based on motion sensors.	Motion-based technologies have benefits on general cognition, mobility, balance, fall risks, self-esteem, well-being and social health.	Motion-based technologies are feasible to stimulate PWD. A positive acceptability emerged.

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TABLE 5 | Continued

References	Focus	Methods	Interventions	Results	Conclusions
El-Saifi et al. (2018)	Analysis of interventions aimed at improving medication adherence in PWD.	Systematic Review, 20 studies, one relevant.	Intervention of tele-monitoring during day/night time.	Significative compliance in the intervention group (81%), compared to the control group (66%), $p < 0.05$. Also, unmonitored patients' compliance fell of 12%.	Tele-monitoring was the only intervention able to increase PWD's compliance. Further standardized studies are required.
Fleming and Sum (2014)	Analysis of the effectiveness of ATs in dementia care.	Systematic Review, 41 studies.	Interventions based on ATs to sustain: daily living, safety, therapies and telecare.	ATs for daily life were positively evaluated, but their usage decreased over time. - Safety ATs had potential benefits, but technical issues also emerged. – Positive outcomes on BPSD and circadian rhythms came out using technology-based therapy. -Telecare led to positive outcomes concerning cognitive training and medication adherence.	Mixed results emerged using ATs in dementia care. Further standardized studies are required to assess the effectiveness of technologies for PWD
García-Casal et al. (2017)	Analysis of the effectiveness of computer-based cognitive interventions targeting PWD.	Systematic Review and Meta-analysis.	Computer-based interventions of cognitive training, cognitive rehabilitation, cognitive stimulation and cognitive recreation.	Moderate effects on cognition, assessed with MMSE and HDS-R (SMD -0.69; 95% CI $= -1.02$ a to 0.37; $P < 0.0001$; $I \wedge 2 = 29\%$); greater effects on cognition of computer-based interventions compared to traditional interventions (SMD 0.48; 95% CI = 0.09–0.87; $P = 0.02$; $I \wedge 2 = 2\%$). Small effects in depression, assessed with GDS and CES-D (SMD 0.47; 95% CI = 0.16 a 0.78; $P = 0.003$; $I \wedge 2 = 0\%$). Moderate effects on anxiety, assessed with STAI (SMD 0.55; 95% CI = 0.07 a 1.04; $P < 0.03$; $I \wedge 2 = 42\%$). No significant effects on IADL ($p > 0.05$).	Computer-based cognitive interventions have moderate effects on cognition and anxiety; small effects on depression. Computer-based interventions have greater effects over the traditional ones. Longer-term follow up are required to examine effects' retention.
Klimova and Maresova (2017)	Analysis of the effectiveness of computer-based cognitive training for PWD and MCI.	Mini Review, section of four RCTs on PWD.	Computer-based cognitive training interventions.	1/4 study showed improvement in episodic memory and abstract reasoning. 1/4 study was effective in delaying the progression of the cognitive impairment. 2/4 studies revealed no effects.	Mixed results emerged. Further standardized studies are required to examine the effectiveness of computer-based cognitive training on PWD.

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TABLE 5 | Continued

References	Focus	Methods	Interventions	Results	Conclusions
Lazar et al. (2014)	Analysis of the use of ICTs for facilitating reminiscence therapy.	Systematic Review, 44 studies.	Reminiscence therapy using technologies (videogames, multimedia and digital interfaces).	Technologies accommodate for motor and sensor impairments, using devices as earphones, image projectors or touchscreens. ICTs allow to compensate for memory deficits. Also, ICTs facilitate the administration process using clouds or telecare.	Technologies enrich reminiscence therapy for PWD. Further studies should focus on the effectiveness at different stages of dementia.
Liapis and Harding (2017)	Analysis of the effectiveness of computer-based therapies for PWD.	Systematic Review, section of five relevant studies, one RCT.	Technology-based therapy interventions and leisure activities for PWD.	Interventions have been evaluated as feasible and enjoyable by PWD. No quantitative improvement in cognition emerged using MMSE. People with mild and moderate dementia preferred videogames; people with severe dementia preferred listening to music or watching videos.	Potential benefits emerged, but more standardized studies are required to examine the effectiveness of technology-based therapies for PWD.
Lorenz et al. (2019)*	Mapping technologies for PWD and caregivers, classified by function, target user and disease progression.	Rapid Review, interviews and blog analysis. Forty-seven studies.	Online psycho-social support, cognitive training, psycho-education and remote monitoring of the PWD.	Most technologies target people with moderate and severe dementia living in their homes are focused on safety. Most technologies for PWD living in care homes are focused on care delivery and therapies. Memory aids and daily living technologies mostly target people with mild dementia living in their homes.	Little evidence back up the practical application of the identified technologies. Further researches should examine the impact of a wide range of technologies on the daily living.
Maia et al. (2018)	Analysis of interventions for PWD using ATs to sustain BADL.	Systematic Review, four studies.	Technology-based interventions to sustain BADL (safety, memory aid, monitoring, etc.).	Monitoring sensors has been evaluated as useful by PWD and caregivers; prompt systems facilitated medication adherence and finance management; navigation systems improved PWD's autonomy in movements. 1/4 study reported technical issues.	ATs are feasible to sustain PWD's BADL.
Neubauer et al. (2018)	Analysis of the types of technologies used to manage wandering behavior in PWD.	Scoping Review, 12 studies.	Interventions targeting PWD using sensors, alarms and locators to manage wandering.	26 types of technologies identified (GPS, sensors, alarms, Bluetooth, etc.). 67.7% of the devices were wearable. 7/12 studies reported positive results in managing wandering behaviors. The general acceptability was high.	Technologies can reduce risks associated with wandering behaviors and improve the autonomy in movements of PWD. Further studies are required to increase levels of evidence.

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TABLE 5 | Continued

References	Focus	Methods	Interventions	Results	Conclusions
Pinto-Bruno et al. (2017)	Analysis of the validity and the efficacy of ICT-based interventions to promote social health and an active aging.	Systematic Review, six studies.	ICT-based interventions of reminiscence therapy, leisure activities, cognitive and physical training.	Qualitative – technologies foster social participation in PWD. Quantitative – People in the intervention group made more choices [$t_{(10)} = 3.6717$, $p < 0.05$] and sang more [$t_{(10)} = 2.191$, $p < 0.05$] than the control group. People in the control group spent more time asking questions [$t_{(10)} = 3.13$, $p < 0.01$] and initiated less conversations ($z = 2.03$, $p < 0.05$) than the intervention group.	Initial positive evidence emerged using ICT interventions. Specific outcomes measure to assess social health and social participation are needed for future studies.
Tyack and Camic (2017)	Analysis of the impact on well-being of touchscreen-based interventions for PWD.	Systematic Review, 16 studies.	Intervention using touchscreen devices to sustain reminiscence therapies, leisure activities, safety, communication and prompting systems.	Mixed results. Positive evidence on mood, involvement, perceived well-being and perceived satisfaction. A significant positive correlation emerged in one study between age and impact on mood ($r_s = 0{,}46$, $p < 0.05$), with greater effects on older people. Benefits of social interaction with relatives and on the sense of mastery (technological skills and satisfaction increasing).	Touchscreen-based interventions can improve the psychological well-being of PWD. More rigorous future studies are needed.
Yousaf et al. (2019)	Analysis of the evidence on the use of mHealth application for PWD.	Overview, 17 studies.	Interventions using mHealth Apps to sustain cognitive training, daily living, screening, safety, navigation and leisure activities.	Cognitive domain – available Apps target memory, communication, logical thinking, attention, language abilities and schedule. Screening domain – Apps target dementia detection and cognitive screening. Health/safety monitoring domain – Apps for fall detection and emergency help. Leisure domain – Apps for reminiscence therapy and socialization therapy. Navigation domain – Apps for tracking and location service.	Mobile health Apps are interactive, easy to use and independence promoting. These seems feasible AT intervention for PWD and caregivers.

*These studies are shown both in **Table 5** and **Table 7**.*

TABLE 6 | New studies for PWD.

References	Focus	Setting	Sample	Length	Methods	Interventions	Results	Conclusions
Dethlefs et al. (2017)	Evaluation of the feasibility of computer-based cognitive stimulation using a spoken natural language interface.	Laboratory.	23 people, 13 healthy elderly, 10 PWD (mild to moderate).	20 min.	Pilot study non-RCT.	Computer-based cognitive stimulation (sorting, name recall, quiz and proverbs).	8/10 PWD enjoyed doing the activities. Correct answers and reaction time were similar between experimental and control groups. Quiz and proverbs activities were preferred over sorting and name recall.	It seems possible to convey cognitive stimulation through spoken natural language interface.
Favela et al. (2020)	Assess the benefits and limitations of using activity trackers for BPSD in dementia context.	Residential care facility.	10 PWD (mild to moderate dementia).	14 therapeutic sessions of 30 min.	Mixed methods design.	Cognitive stimulation therapy with the assistance of a social robot and activity trackers.	Activity tracker confirms or complements results obtained from the NPI-NH instrument or interviews with caregivers.	Activity trackers can help dementia research as they allow to gather data continuously and objectively.
Hung et al. (2018)	Feasibility and acceptability of an *iPad* intervention to support dementia.	Hospital.	Four PWD.	14 sessions of 15 min.	Mixed methods design.	Simulated presence therapy (1 min video pre-recorded by a relative).	Positive results in reducing BPSD and increasing mood and treatment adherence.	Simulated presence therapy using *iPad* can help PWD in hospital setting. Videos with a single person and a familiar voice are recommended.
Lancioni et al. (2020)	Smartphone-based intervention to manage goal-directed, walker-assisted ambulation and object use.	Residential care facility.	11 PWD (moderate dementia).	Multiple sessions of 3–5 min.	Mixed methods design.	Smartphone-based intervention to facilitate daily living.	Compared to a baseline of 0: - 2.9 correct target response of overall mean across participants; - over three indices of enjoyment/appreciation of overall mean across participants.	A smartphone-based intervention may be suitable to foster goal-directed, walker-assisted ambulation and object use.
Inel Manav and Simsek (2019)	Analysis of the effects of reminiscence therapy based on internet videos.	Residential care facility.	32 People with mild dementia.	60 min, once a week for 3 months.	RCT.	Reminiscence therapy using selected *YouTube* videos vs. traditional therapy.	Significate differences between experimental and control groups: SMMSE (Standardized Mini-Mental State Examination) ($p < 0.01$); ARS (Apathy Rating Scale) ($p < 0.01$).	Reminiscence therapy using internet-based videos improved the cognitive functions and apathy levels of people with mild dementia.
McCarron et al. (2019)	Analysis of the feasibility and utility of the Social Support Aid (*SSA*) App for PWD.	Domestic setting.	29 PWD, 19 MCI.	6 months.	Pilot RCT.	Intervention using the *SSA* App, combining a smartphone and a smartwatch, to help remembering names and relationships of familiar faces.	Utility – 3.10 (SD 0.63) pt. mean score using a 0–5 Likert scale with 15 items. No significant changes ($p > 0.05$) in quality of social interactions (PES-AD) or quality of life (DQoL). The App has been evaluated as too complex, stigmatizing and with an intricate enrollment process.	The App *SSA* did not improve the quality of life and the quality of social interactions of people with memory loss. More practical devices are required.
McGoldrick et al. (2019)	Analysis of the feasibility and utility of the memory aid App *MindMate*.	Domestic setting.	Three people with mild dementia.	5 weeks.	Three single cases.	Intervention using the App *MindMate* to sustain memory in daily life.	Significant memory improvement ($p < 0.01$) in participant A (from 49 to 93% correct tasks post training) and participant B (from 69 to 95%). Participant C withdrew from the intervention.	Use of *MindMate* seems feasible and effective in supporting memory in everyday tasks.

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TABLE 6 | Continued

References	Focus	Setting	Sample	Length	Methods	Interventions	Results	Conclusions
Moyle et al. (2019)	Analysis of the acceptability of telepresence robots in dementia care.	Laboratory.	Five PWD.	–	Mixed methods pilot study.	Videocall using the telepresence robot *Giraff*.	A sense of authenticity and social connection was experienced by participants. Significantly higher positive (mean score 18.77 ± 4.00) than negative affect (mean score 8.05 ± 1.76) on the I-PANAS-SF, and on the facial display subscale of the ODAS (positive – mean score 15.50 ± 3.51 vs. negative – mean score 4.00 ± 0.00).	Telepresence has potential use as it facilitates social connection in the dementia context. Further standardized studies are required to guide the implementation of telepresence in healthcare practice.
Obayashi et al. (2020)	Analysis of the impact of age, gender and the stage of dementia on an intervention using communication robots.	Residential care facility.	65 PWD.	8 weeks.	Non randomized quasi-experimental study.	Social assistance intervention using com-robots *COTA* and *PALRO*.	Participants aged ≥ 80 and in more advanced stage of dementia benefited more from the intervention ($P < 0.05$) than people younger and in less advanced stage. Selected items from the ICF (International Classification of Functioning, Disability and Health) scale were used.	The overall findings support the use of com-robots within the context of a care team for PWD.

of PWD, they and their caregivers can contact each other to ask for mutual information or help (Lorenz et al., 2019).

Aside from the beneficial impact these devices offer, some technical issues can emerge in GPS-based technologies, such as position inaccuracy or signal instability (Fleming and Sum, 2014). However, due to the technological progression, these problems have been fixed insomuch as they become a useful aid in managing wandering behaviors (Neubauer et al., 2018; Lorenz et al., 2019).

Among security systems, many studies focus on smart-homes technology aimed at reducing risk and increasing the quality of life of the home denizens (Fleming and Sum, 2014; Tyack and Camic, 2017; Neubauer et al., 2018; Brims and Oliver, 2019; Daly Lynn et al., 2019; Lorenz et al., 2019). In domestic settings, automatic sensors are used to detect sudden heat changes, gas leakages, forced doors opening, and so on or to facilitate the management of light switches and water valves (Lorenz et al., 2019). An example is the *COGNOW* program, which capitalizes on a central control panel capable of administrating all the different technological tools implemented in the house (Tyack and Camic, 2017).

Another relevant topic is related to the use of technology for fall prevention. Positive outcomes are observed both with basic support, such as light pathways on the ground or bright handrails, and with a more complex system, such as electronic armbands combined with modern sensors, which send alarms to an assistance center in case of an emergency. Specifically, three randomized controlled studies show that the fall risk featuring the experimental groups is 50% lower than those expressed in the control groups. Moreover, it emerges that the use of ATs decreases the number of risky behaviors, as leaving the home incautiously might result in negative consequences. In contrast, for what concerns the quality of life and the reduced institutionalization, no significant positive outcomes emerged from these studies (Brims and Oliver, 2019).

In care home settings, tagging systems can be implemented: they can be envisioned as intangible spatial barriers that PWD should not overstep during specifically scheduled times; otherwise, an alarm would start ringing (Fleming and Sum, 2014). Tagging technologies are well-accepted both by PWD and healthcare professionals, as they are less obtrusive than physical constraints (Neubauer et al., 2018). Moreover, tagging systems increase both the perceived and the actual safety (Daly Lynn et al., 2019). In contrast, the devices that limit people's autonomy, such as electronic lock doors, are not well-accepted, as they are perceived as dehumanizing despite the improved safety of PWD (Neubauer et al., 2018). In terms of psychological outcomes, non-constraining technologies show positive benefits on the levels of PWD's perceived well-being and anxiety (Neubauer et al., 2018). Lastly, the reviews show that the alarms placed between the rooms are associated with positive qualitative outcomes in care home settings (Yousaf et al., 2019).

Daily Living Sustainment

The issues of interventions regarding daily living sustainment using ATs appear in seven reviews and four new studies from our analysis. Daily living sustainment is the primary purpose

TABLE 7 | Interventions for caregivers.

References	Focus	Methods	Interventions	Results	Conclusions
Boots et al. (2014)	Analysis of the effectiveness, feasibility and quality of Internet interventions for informal caregivers of PWD.	Systematic Review. Twelve studies, three RCTs.	Informative websites providing information and strategies; peer-support/professional support through e-mails and phone calls.	Quantitative – small significant results in 6/12 on depressive symptoms, self-efficacy, perceived competence, decision-making and burden; Qualitative – positive outcomes on awareness, competence, mastery and perceived social support. Better outcomes for interventions combining informative websites with psycho-social support.	General positive outcomes emerged. Further researches are required due to small samples, not standardized designs and examined outcomes.
Brando et al. (2017)*	Analysis of the advantages and disadvantages associated with the implementation of technology into works with PWD and caregivers.	Literature Review (online-caregivers section of 3/30 studies).	Psycho-education online support through videoconference among peers.	Positive qualitative outcomes regarding online social support.	Few online interventions target caregivers. Initial evidence emerged.
Dam et al. (2016)	Analysis of interventions targeting caregivers focused on social support.	Systematic Review (remote support section of 15 studies, 11 RCTs).	Informative/psycho-education websites; peer-support through online forums and videoconferences.	Qualitative – Positive outcomes for the perceived social isolation, social support and the relationship with the PWD. Benefits for the decision-making process using informative websites; benefits for stress, depression, self-efficacy and burden using videoconferences.	Positive qualitative outcomes emerged. Future research should use more standardized designs.
Egan et al. (2018)	Analysis of online interventions targeting caregivers of PWD.	Systematic Review. Eight RCTs.	Psycho-education, psychotherapy (cognitive reframing and relaxation) and cognitive training using forums, videoconferences and selected videos.	Positive evidence on depressive symptoms 2/8, anxious symptoms 2/8, acquired skills 2/8 and self-efficacy.	Positive evidence emerged from heterogeneous designs; more standardized studies are required. No benefits emerged on the QoL.
Godwin et al. (2013)	Analysis of the effectiveness of interventions targeting caregivers of PWD.	Systematic Review. Eight studies, four RCTs.	Informative websites; psycho-social support through forums, e-mails, chats and videos.	Positive benefits on depressive symptoms 4/8 and anxious symptoms 2/8. Mixed evidence on the social support.	Mixed results and heterogenous designs were found. Future standardized RCTs are required.
Hopwood et al. (2018)	Analysis of the effectiveness of online interventions targeting caregivers of PWD.	Systematic Review. Forty studies, nine RCTs.	Psycho-social support in group of peers, using chats, forums, videoconferences and avatar 3D; training on the decision-making process.	Benefits on depressive and anxious symptoms; increased self-efficacy and QoL. Peer-support is more appreciated if conducted through videoconferences; informative interventions are preferred via websites rather than using handbooks.	Mixed results, but mostly positive, emerged. Future studies should better examine the caregivers' specific needs.
Jackson et al. (2016)	Analysis of telephone-based and internet-based interventions targeting caregivers.	Systematic Review. Twenty-two studies, five internet-based.	Psycho-education, psychotherapy and psycho-social supportive interventions.	Qualitative positive results on depressive symptoms, general mental health and QoL.	Interventions combining different programs and devices had led to better outcomes.
Leng et al. (2020)	Analysis of the efficacy of internet interventions in improving health of caregivers of PWD.	Systematic Review and Meta-Analysis. Seventeen RCTs.	Online psycho-social and psycho-educative support.	Significant positive results on depressive symptoms ($SMD = -0.21$; 95% CI -0.31 to -0.10; $P < 0.001$), perceived stress ($SMD = -0.40$; 95% CI-0.55 to -0.24; $P < 0.001$), anxious symptoms ($SMD = -0.33$; 95% CI-0.51 to -0.16; $P < 0.001$) and self-efficacy ($SMD = 0.19$; 95% CI 0.05–0.33; $P = 0.007$). No significant improvements were found in caregiver burden, coping, caregiver's reactions to behavioral symptoms and quality of life.	Internet-based interventions are generally effective at improving the health of family caregivers.

(Continued)

TABLE 7 | Continued

References	Focus	Methods	Interventions	Results	Conclusions
Lorenz et al. (2019)*	Mapping technologies for PWD and caregivers, classified by function, target user and disease progression.	Rapid Review, interviews and blog analysis.	Online psycho-social support, cognitive training, psycho-education and remote monitoring of the PWD.	Most technologies targeting carers are focused on memory sustainment and care delivery.	Little evidence back up the practical application of the identified technologies. Further researches should examine the impact of a wide range of technologies on daily living.
Lucero et al. (2019)	Analysis of the effectiveness on health of ICT-based interventions targeting caregivers.	Systematic Review. Twelve RCTs, 6 internet-based.	Online psychotherapy; informative and educative interventions using websites; cognitive and physical training.	Internet interventions -> increased positive affect ($P = 0.01$), decreased concerns for PWD's behaviors ($P = 0.02$). Internet + telephone -> increased satisfaction ($P = 0.015$), physical activity ($P < 0.01$), self-efficacy ($P < 0.01$); decreased depressive symptoms ($P = 0.02$), anxious symptoms ($P = 0.01$) and stress ($P < 0.05$).	Positive benefits on health emerged from heterogeneous studies. A standardized methodology is required.
McKechnie et al. (2014)	Analysis of computer-based interventions targeting caregivers of PWD.	Systematic Review. Twelve studies, six RCTs.	Psycho-education, psycho-social support among peers, psycho-social support with health care professionals.	Positive significant results ($P < 0.05$) on: depressive symptoms (four studies), general mental health (three studies), burden and stress (five studies), social support (one study), positive aspect of caregiving (one study) and self-efficacy (two studies).	Depression and burden were the most examined outcomes. Future studies should use a standardized methodology and examine the same outcomes.
Parra-Vidales et al. (2017)	Analysis of online psycho-educational interventions targeting caregivers of PWD.	Systematic Review. Seven studies.	Online informative support, psycho-social support among peers and with health care professionals through chat and videoconference; cognitive training.	Positive results on self-efficacy (two studies), acquired knowledge (two studies), functional autonomy (one study), anxious/depressive symptoms (one study).	Outcomes examination is often not reported or not standardized. Online interventions have benefits on the social aspect and are usually perceived as positive.
Rathnayake et al. (2019)	Analysis of interventions based on mHealth-App targeting caregivers.	Integrative Review. Seven studies.	Information, psycho-education, cognitive training and PWD's monitoring.	The main focus areas of mHealth App studies are categorized as: carer education, monitoring and cognitive training.	A theoretical model is required to guide the designing of mHealth App interventions. Further researches should focus more on psycho-education and psycho-social support.
Ruggiano et al. (2018)	Analysis of technology-based interventions targeting caregivers of PWD living in rural areas.	Systematic Review. Thirty studies, 18 RCTs.	Online interventions focused on psycho-social support groups, psycho-education, psychotherapy, monitoring of mental and physical health.	Significant positive benefits ($P < 0.05$) on: depressive symptoms (five studies), anxious symptoms (two studies), other psycho-social aspect (six studies), as stress and perceived support. No benefits on self-efficacy and caregiver's skills emerged.	Few studies identified their sample population as living in rural areas. Future interventions should analyze the needs of the specific population.
Scott et al. (2016)	Analysis of the effectiveness of TB-CBT interventions targeting caregivers of PWD.	Systematic Review. Four studies.	Cognitive-behavioral therapy using the internet and selected multimedia.	Small significant effects post-intervention of the TB-CBT on depression ($P = 0.04$); equivalent to the traditional CBT.	Future studies should analyze long-term effects of the TB-CBT. TB-CBT is an economical alternative to the traditional CBT.
Waller et al. (2017)	Analysis of the acceptability, utilization and effectiveness of ICT-based interventions targeting caregivers.	Systematic Review. Online section of 19 studies.	Online psycho-education, cognitive training, psycho-social support among peers and with health care professionals.	Heterogeneous positive evidence emerged on general mental health, depressive symptoms, burden, positive aspect of caregiving and perceived social support. A positive acceptability emerged.	Potential benefits of ICT-based interventions emerged. High-quality studies are required to detect the most recommended types of intervention.

*These studies are shown both in **Table 5** and **Table 7**.*

of ATs with PWD (Lorenz et al., 2019). Indeed, ATs can support cognitive functions, such as different memory types, spatio-temporal orientation, and language. For what concerns the prospective memory, devices like digital organizers and electronic reminders can improve the quality of life of PWD (Brando et al., 2017; Lorenz et al., 2019; Lancioni et al., 2020). An example is the App *MindMate*, an electronic calendar designed to help PWD remember the daily schedule. The App has been evaluated arranging simple tasks, such as "call the researcher," which people with dementia had to pursue at scheduled times. After 5 weeks of intervention, *MindMate* showed benefits on the prospective memory of the PWD (McGoldrick et al., 2019). Other devices that are used to sustain prospective memories are pill dispensers. Controversial outcomes are associated with these technologies: some authors describe them as functional (Fleming and Sum, 2014; Maia et al., 2018), and others suggest that their usage is too complicated for PWD (Daly Lynn et al., 2019).

Regarding procedural memory, instead, positive outcomes emerge from using prompting systems. These consist of tools giving step-by-step prompts, either in visual or vocal forms, to guide PWD to achieve daily tasks as cooking, washing their hands, and setting the table correctly (Brando et al., 2017; Maia et al., 2018; Daly Lynn et al., 2019). Moreover, some potential benefits emerge from using mobile Apps to guide practical actions (Lancioni et al., 2020).

There is little evidence to endorse the application of ATs to sustain the memory of faces. The only identified intervention in this area concerns a randomized controlled trial (RCT) using an App called *SSA* ("*Social Support Aid*"). The App combines a smartwatch camera with an online database containing preloaded faces labeled with a personalized tag, such as "Emma, daughter." The system aims to match the faces included in the database and the ones caught by the smartwatch camera. Once the match has finished, it notifies the person with the assigned tag in case of a positive match. PWD evaluates the App as too complicated, and it does not increase users' quality of life (McCarron et al., 2019).

For what concerns the spatio-temporal orientation, ATs are useful to sustain daily living. Apart from the already described electronic calendars, other devices are employed with PWD, such as monitors capable of harmonizing night-time awakenings in care home settings. These devices are usually placed in front of the PWD's bed, showing recommendations like "it's night, let's go back to sleep" and similar (Lorenz et al., 2019; Moyle et al., 2019). Moreover, it emerges that robot-assisted navigation can lead to positive outcomes to increase PWD's ability to move autonomously (Maia et al., 2018).

Regarding language, positive outcomes derive mainly from using smartphones in functional manners. In particular, improvements in the semantic component of language emerge when PWD use their smartphones to take notes of words or navigate the internet when they do not remember a definition (Brando et al., 2017). In the same fashion, Lorenz et al. (2019) report positive daily PWD experiences using *SIRI*, a famous virtual assistant. More evidence emerges regarding technologies to support the communication process: PWD answers more frequently to the incoming calls when the telephones are adapted to their perceptual and cognitive needs. Differently, these devices cannot improve the quality of life of the users ultimately, as they cannot solve broader problems such as remembering to call or whom the PWD have spoken to (Topo et al., 2002; Fleming and Sum, 2014).

Another piece of evidence supports the employment of telepresence robots to sustain social connections. It emerged from the pilot study led by Moyle et al. (2019) using the comrobot *Giraff* in an experimental setting with five PWD. *Giraff* is a wheel-based, remotely controlled device carrying a tablet that can convey videocalls. *Giraff* is also of human height, and the upper part of the robot may also be bent forward or tilted left and right, simulating social head gestures. The devices were evaluated as realistic and useful by four out of five PWD. Furthermore, the most appreciated aspect was the possibility to control Giraff remotely to make it move around the room.

Moreover, even some social aspects can be sustained by smart-home devices. Systems like the *PAL4-Dementia* allow both to manage the technological tools implemented in the house and start video calls with relatives or healthcare professionals (Tyack and Camic, 2017).

Although we observe that ATs interventions usually lead to positive outcomes for what concerns daily living, there is also a reported discrepancy between the experimental research and the actual uptake of the devices in everyday life. In fact, in this regard, some authors noted that the use of technology decreases in the follow-up because of disease development, limited financial resources, time- and burden-related constraints (Fleming and Sum, 2014; Lorenz et al., 2019).

Cognitive-Focused Therapeutic Interventions

From our analysis, the interventions regarding therapeutic support emerge in 13 reviews and three new studies. Technological devices, Apps, videoconferences, and software, convey and support different intervention categories targeting the PWD's cognitive functions, i.e., cognitive training, stimulation, and rehabilitation. García-Casal et al. (2017) carried out a review and meta-analysis of 12 computer-based cognitive intervention studies. Once they have analyzed the outcoming effects regardless of the intervention category, they report intermediate results regarding cognition and anxiety and small impacts concerning depression. In contrast, no consequences were observed in terms of the PWD's daily activities.

For what concerns cognitive training, mixed outcomes emerge among the analyzed reviews targeting people with dementia. In a review of four RCTs, Klimova and Maresova (2017) reported that half of the studies do not produce significant outcomes. One of them reported benefits on episodic memory and abstract reasoning, while the remaining study highlighted that computer-based cognitive interventions can slow down cognitive decline. Moreover, it emerges that the *mHealth* App can train, monitor, and self-assess the performance achieved in all the cognitive functions. Indeed, the Apps help PWD function better in their daily lives, especially if the users accept it because it is intuitive (Yousaf et al., 2019).

Technological devices mainly support cognitive stimulation interventions since stimulation is the most appreciated activity by

PWD (Liapis and Harding, 2017; Daly Lynn et al., 2019), and it leads to an extensive generalization of the benefits (Brando et al., 2017).

Our analysis suggests that different stages of the dementia pathway are associated with preferred stimulation activities. People with mild or moderate dementia tend to prefer challenging tasks, such as the ones provided via videogames modality. Among videogames, an example is the software *Big Brain Academy,* which has a positive impact on perception, memory, logical reasoning, and general cognitive functioning (Brando et al., 2017). On the other hand, people with severe dementia prefer more static and sense-based activities, such as listening to music or watching videos (Liapis and Harding, 2017).

Besides, implementing a technological component in stimulation interventions allows us to compensate for sensory deficits thanks to apposite designed interfaces. For example, headphones and image projectors boost the auditory and the visual apparatus, respectively (Lazar et al., 2014). Additionally, many benefits emerge using innovative input systems, such as touchscreens, motion-sensors, and voice user interfaces. Tyack and Camic (2017) report that the interventions based on intuitive touchscreens led to positive mental health outcomes, perceived well-being, and satisfaction, especially in older people. Moreover, the request of learning how to use modern devices increases PWD's involvement, pride, and sense of mastery (Tyack and Camic, 2017). Tablets are also frequent in these programs of intervention. By reproducing multimedia or allowing PWD to express their art capacity, tablets support behavioral symptoms management while sustaining people's creative skills. The App *ExPress Play*, for example, can generate chord-based music thanks to the touchscreen (Tyack and Camic, 2017; Yousaf et al., 2019). In a similar vein, while studying the software recognizing and synthesizing human voices, Dethlefs et al. (2017) report that PWD appreciate voice user interfaces, as can be seen by increased involvement in computer-based cognitive stimulation programs. Again, devices based on motion sensors are highly recommended for PWD because they can compensate for the issues arising from memorizing device button-keys (Dove and Astell, 2017). Moreover, benefits emerge regarding the PWD's cognitive decrease associated with the disease, while enhancing their moods positively, as they stimulate people's movements (Dove and Astell, 2017).

For what concerns cognitive rehabilitation, instead, the literature shows that virtual reality can be a component used to recreate settings that are familiar to PWD or to let them practice with the execution of daily activities, such as cooking or shopping at the grocery shop. The adoption of the virtual setting produces better outcomes on the general cognitive functioning, learned skills, self-efficacy, and motivation, with respect to practicing the same activities within traditional environments. Moreover, by combining virtual reality headset and controller, visuospatial orientation and autonomous movements can increase (Brando et al., 2017).

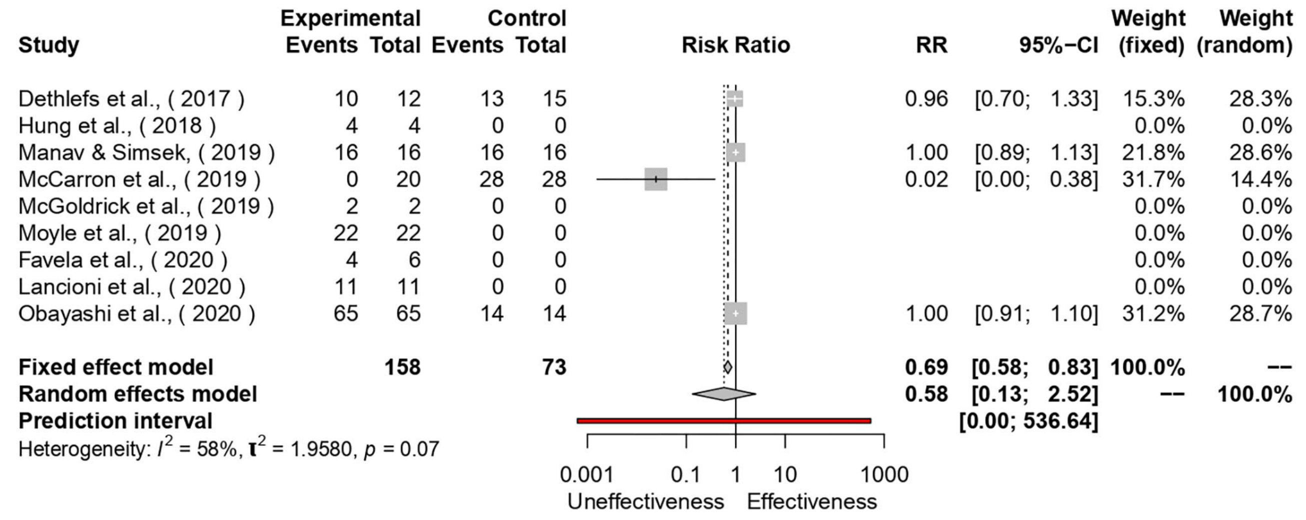
Finally, some evidence related to therapeutic interventions remotely conducted using videoconferences emerge from the literature search. It is revealed that online memory clinics are positively accepted by PWD and mostly by living in rural areas (Weiner et al., 2011; Lorenz et al., 2019). Also, two RCT studies highlight that remote cognitive interventions produce benefits on PWD's general cognitive functioning, attention, memory, calculus, and phonemic and semantic verbal expression (Jelcic et al., 2014). Furthermore, it is revealed that some PWD and their caregivers express specific preferences for remotely conducted interventions since they limit laborious transfers (Fleming and Sum, 2014).

Psychosocial Interventions for PWD

From our analysis, we yield that technological devices can support psychosocial interventions such as reminiscence, light therapy, multisensory therapy, simulated presence therapy, and therapy based on social robots. Lorenz et al. (2019) point out that technologies can easily convey psychosocial interventions in home-care settings. For what concerns reminiscence therapy, technological devices might be useful as they allow you to select personalized multimedia and adequately stimulate the emotional memory (Inel Manav and Simsek, 2019). For example, in an RCT focused on the effects of the reminiscence therapy, *YouTube* videos obtain positive results that concern both PWD's cognition and mood (Inel Manav and Simsek, 2019). Moreover, by integrating a camera in smart-watches devices, it becomes possible to gather pictures or videos during daily living. The collected multimedia becomes useful vehicles during reminiscence therapy sessions (Lazar et al., 2014). Again, as soon as reminiscence therapy meets technological devices, such as with touchscreen interfaces, people's involvement increases. Indeed, people can autonomously feel competent and capable of handling the digital contents (Liapis and Harding, 2017; Tyack and Camic, 2017; Yousaf et al., 2019). Besides, the increased confidence in modern devices represents an opportunity to close the gap between social generations (Yousaf et al., 2019). The "*Computer interactive reminiscence and conversation aid – CIRCA,*" i.e., a program targeting the dyad PWD-caregiver, has led to positive results in the decision-making process and the social involvement and in particular for singing activities (Pinto-Bruno et al., 2017; Tyack and Camic, 2017).

Finally, technology allows to overcome environmental barriers and to conduct therapies from a remote position because they provide the opportunity to both communicate and access the same multimedia simultaneously (Lazar et al., 2014; Dethlefs et al., 2017). Dyads positively accept remotely delivered therapies because they can ameliorate the management of behavioral symptoms (agitation, irritability, and insomnia) (Lazar et al., 2014). In particular, *MyBrainBook* is an online platform aimed at conveying reminiscence therapy. By connecting PWD and their relatives and friends, they can still feel part of a social network. Moreover, as it capitalizes on a cloud environment to gather personalized content, it is useful when implementing the process of reminiscence (Dethlefs et al., 2017). Positive results also came out from interventions using tools to start the required applications for the therapies remotely. Such a strategy allows us to compensate for the lack of technological skills featuring some people (Yasuda et al., 2013; Lazar et al., 2014).

As it emerges for the reminiscence, even light therapies can be aimed at managing behavioral symptoms and they are



Study	Experimental Events	Experimental Total	Control Events	Control Total	RR	95%−CI	Weight (fixed)	Weight (random)
Dethlefs et al., (2017)	10	12	13	15	0.96	[0.70; 1.33]	15.3%	28.3%
Hung et al., (2018)	4	4	0	0			0.0%	0.0%
Manav & Simsek, (2019)	16	16	16	16	1.00	[0.89; 1.13]	21.8%	28.6%
McCarron et al., (2019)	0	20	28	28	0.02	[0.00; 0.38]	31.7%	14.4%
McGoldrick et al., (2019)	2	2	0	0			0.0%	0.0%
Moyle et al., (2019)	22	22	0	0			0.0%	0.0%
Favela et al., (2020)	4	6	0	0			0.0%	0.0%
Lancioni et al., (2020)	11	11	0	0			0.0%	0.0%
Obayashi et al., (2020)	65	65	14	14	1.00	[0.91; 1.10]	31.2%	28.7%
Fixed effect model		**158**		**73**	**0.69**	**[0.58; 0.83]**	**100.0%**	**--**
Random effects model					**0.58**	**[0.13; 2.52]**	**--**	**100.0%**
Prediction interval						**[0.00; 536.64]**		

Heterogeneity: $I^2 = 58\%$, $\tau^2 = 1.9580$, $p = 0.07$

FIGURE 2 | The figure displays new studies' effect size.

mainly conducted in home-care settings. In particular, positive effects followed in the forms of agitation, circadian rhythms, and well-being (Fleming and Sum, 2014; Daly Lynn et al., 2019). Similar benefits come out using multisensory therapies, especially with the Snoezelen Room, which leads to positive results regarding well-being, and behavioral agitation. Despite this evidence, multisensory therapies have emerged to produce fewer effects than the immersion in real natural environments (Fleming and Sum, 2014).

Simulated presence therapies capitalize on technological devices; they involve videos that were pre-recorded by a family member. The videos recorded using spontaneous language lead to well-being improvement, fewer phone-calls during the night-time, and increased adherence to medical recommendations and compliance (Fleming and Sum, 2014; Hung et al., 2018; Daly Lynn et al., 2019).

The therapies based on social robots appear to produce contrasting evidence (Daly Lynn et al., 2019). Fleming and Sum (2014) highlight that adding a mechanical component does not lead to better improvements than therapies using regular pet plushies. Other authors, instead, report positive benefits on behavioral agitation, depressive symptoms, and social interactions, using the pet robots *PARO*, *NeCoRo*, *AIBO,* and *CuDDler* (Daly Lynn et al., 2019). On the other hand, using the communication robots *COTA* and *PALRO*, positive results emerge even with regards to the functional autonomy of PWD, especially for people over 80 with severe dementia (Obayashi et al., 2020).

New Studies Effectiveness

A total of six studies out of 10 did not use a control group. All of them but McCarron et al. (2019) reported the positive effects of technologies. The heterogeneity of the study pool was almost significant (See **Figure 2**). Once all the studies without control groups, with the addition of McCarron et al., were removed, the remaining three works showed a homogeneous risk ratio [RR = 1, 95%- CI: 0.93; 1.08]. As described previously, the study of McCarron et al. showed that no positive social engagement emerged in the 20 people enrolled in the smart-watch use compared to the 28 counterparts.

Interventions for Caregivers

The interventions targeting caregivers capitalize on different web interfaces and services. In particular, Hopwood et al. (2018) highlight how online interventions might be delivered either via private or public services. Private services include online tools available only for a restricted number of people, with access granted upfront invitation and/or after registration. These systems allow for the exchange of personal information, ensuring privacy protection. From our analysis, e-mails (Godwin et al., 2013; Boots et al., 2014; McKechnie et al., 2014; Dam et al., 2016; Hopwood et al., 2018), chats (Boots et al., 2014; McKechnie et al., 2014; Dam et al., 2016; Parra-Vidales et al., 2017; Waller et al., 2017; Hopwood et al., 2018) and videoconferences (Boots et al., 2014; McKechnie et al., 2014; Dam et al., 2016; Scott et al., 2016; Brando et al., 2017; Parra-Vidales et al., 2017; Waller et al., 2017; Egan et al., 2018; Hopwood et al., 2018; Ruggiano et al., 2018; Lorenz et al., 2019) emerge to feature the interventions for caregivers. Moreover, the evidence applying an online virtual setting with 3D avatars was useful to help caregivers communicate with each other while preserving a sense of privacy (O'Connor et al., 2014; Hopwood et al., 2018).

Public services include free-access content at everyone's disposal, such as the frequently used informative websites (Godwin et al., 2013; Boots et al., 2014; McKechnie et al., 2014; Brando et al., 2017; Parra-Vidales et al., 2017; Hopwood et al., 2018; Ruggiano et al., 2018; Lucero et al., 2019). Moreover, other services, such as blogs (Hopwood et al., 2018), forums, or selected social networks (Godwin et al., 2013; Boots et al., 2014; McKechnie et al., 2014; Dam et al., 2016; Parra-Vidales et al., 2017; Egan et al., 2018; Hopwood et al., 2018; Lorenz et al., 2019) and multimedia (Boots et al., 2014; McKechnie et al., 2014; Jackson et al., 2016; Scott et al., 2016; Brando et al., 2017; Egan et al., 2018; Hopwood et al., 2018; Ruggiano et al., 2018; Lucero et al., 2019) might be either private or public, as a function of the privacy settings set by the admin. Finally, it emerges that *mHealth* Apps for smartphones or tablets are used in online-based interventions for caregivers of PWD (Brando et al., 2017; Rathnayake et al., 2019).

Regarding the aims featuring the AT-based interventions, the analysis of the reviews suggests that we group the intervention aims into six groups: informative, psycho-education programs, psychosocial support, psychotherapy, cognitive training, and physical training. Informative interventions are deployed through websites providing information on many issues, such as the treatment and the management of dementia, the risks associated with the disease, and the implication on caregivers' health. Moreover, they provide useful links and contact information for community services (Godwin et al., 2013; Rathnayake et al., 2019) and are usually part of multicomponent programs (Boots et al., 2014; Brando et al., 2017; Hopwood et al., 2018; Lorenz et al., 2019).

Psycho-education programs mainly target caregivers' strategies and coping skills. Private services are preferred over public ones. When people seek help from healthcare professionals, such assistance can arrive through videoconferences or by watching recommended and personalized educative videos (Jackson et al., 2016; Parra-Vidales et al., 2017; Waller et al., 2017). Also, the *mHealth* App attempt was for the same purpose (Rathnayake et al., 2019). As it happens for informative interventions, even the psycho-education ones are often part of multicomponent programs together with psychosocial support or psycho-therapeutic interventions (Boots et al., 2014; McKechnie et al., 2014; Scott et al., 2016; Brando et al., 2017; Egan et al., 2018; Ruggiano et al., 2018; Lorenz et al., 2019; Lucero et al., 2019).

Psychosocial supportive interventions are focused on the improvement of caregivers' emotional well-being and social health through videoconferences among small groups of peers, chats, e-mails, or self-administered personalized multimedia content (Boots et al., 2014; McKechnie et al., 2014; Dam et al., 2016; Jackson et al., 2016; Waller et al., 2017; Egan et al., 2018; Hopwood et al., 2018; Ruggiano et al., 2018; Lorenz et al., 2019; Lucero et al., 2019). The participation of a healthcare professional is not mandatory (Hopwood et al., 2018).

Psycho-therapeutic interventions usually aim to reduce depressive or anxious symptoms and dealing with caregivers' burdens. The cognitive-behavioral approach is popular; meanwhile, cognitive reframing and relaxation are the most frequently applied techniques. For these interventions, the preference for the videoconferences has overcome the one for written communication (Boots et al., 2014; McKechnie et al., 2014; Jackson et al., 2016; Brando et al., 2017; Egan et al., 2018; Lorenz et al., 2019). Besides, the monitoring of the caregiver's emotional state is an essential aspect of the process: through the *mHealth* App, well-being-related symptoms can be self-assessed and shared with care providers together with other medical records (Brando et al., 2017; Rathnayake et al., 2019).

Interventions for caregivers based on cognitive and physical training promote healthy lifestyles and future healthy aging. The cognitive practice usually targets decision-making and problem-solving processes (Boots et al., 2014; Waller et al., 2017; Egan et al., 2018; Ruggiano et al., 2018; Lorenz et al., 2019). On the other hand, physical training pertains to easy motor exercises (Ottoboni et al., 2018; Ruggiano et al., 2018; Lorenz et al., 2019; Lucero et al., 2019). Both types of training are delivered to small groups of users via videoconferences with healthcare professionals or via written chats or forums (Hopwood et al., 2018). Finally, cognitive function and physical health might be self-assessed using specific mobile Apps (Brando et al., 2017; Rathnayake et al., 2019).

Overall, the literature suggests the need to match aims, interventions, and interfaces. Once the purposes are defined through needs and capacity assessment, interventions obtain better results if they fit with the appropriate interfaces (Ajzen, 1985). Informative websites are preferred over handbook instructions and seem to be the best way to provide fast and straightforward resources (Hopwood et al., 2018). Differently, videoconferences are the preferable interventions to improve caregivers' emotional well-being and to communicate in small groups of peers either in public forums or through private messaging (Dam et al., 2016; Parra-Vidales et al., 2017; Waller et al., 2017; Hopwood et al., 2018). Moreover, peer support seems to entail the best way to improve decision-making processes and increase caregivers' confidence in their choices. Finally, it appears usually more appreciated when it integrates multicomponent programs (Godwin et al., 2013; Hopwood et al., 2018).

As seminally suggested elsewhere (Moniz-Cook and Manthorpe, 2009), even here, the interventions that are capable of combining different modalities lead to better outcomes. The combination of videoconferences with phone calls and/or informative websites produces higher positive effects than those obtained using a singular channel. In particular, positive outcomes emerged related to emotional well-being, self-efficacy and perceived satisfaction, and self-efficacy and perceived satisfaction (Boots et al., 2014; Jackson et al., 2016; Lucero et al., 2019). Indeed, in general, interventions provided positive results. The main benefits regard emotional well-being (depression, anxiety, stress, and burden), learned skills (decision making, knowledge, self-efficacy, and strategies), and social aspects (perceived support and positive aspects related to caregiving, such as bonding with your relative; (McKechnie et al., 2014; Dam et al., 2016; Egan et al., 2018; Ruggiano et al., 2018). Moreover, despite the few quantitative analyses and the limits concerning the adopted methodologies, results highlighted the benefits online interventions have for what concerns caregivers' quality of life (Boots et al., 2014; Waller et al., 2017; Leng et al., 2020).

DISCUSSION AND CONCLUSION

The present review analyzes the role of technology in the interventions addressed toward both PWD and their caregivers. The final summary aims to provide tangible support to decision-makers in deciding which ATs may better compensate for the dysfunctionalities featuring many dementia contexts.

The quality of the analyzed literature was high. Both the AMSTAR and the SANRA scores returned adequate standard levels, notwithstanding the reported methodologies' heterogeneous quality.

From our analysis, it emerges that in dementia contexts, the use of ATs is increasing. Such technologies can facilitate daily living, either for what concerns daily activity and the possibility to connect people that are geographically distant. Connections are particularly relevant in the case of difficulties associated with psychological states, personal injuries, and orographic features. In all these cases, technology can compensate for the limitations imposed on traditional human interactions. It represents a useful resource to stay in touch with relatives, friends, and physicians or therapists, too (Novitzky et al., 2015; Cheung and Peri, 2020).

In this light, ATs can become useful even to face social distancing occurring during further pandemic waves. Monitoring technologies, such as video-cameras or GPS-based systems, meet the visit restrictions and thus contagion by reducing the number of check-ups both in residential settings and PWD's homes (Fleming and Sum, 2014; Brando et al., 2017; Tyack and Camic, 2017; Neubauer et al., 2018; Lorenz et al., 2019). Simultaneously, ATs can compensate for the distress associated with the resulting isolation through communication tools designed to keep people remotely "in-touch." Phone-calls, chat interfaces, videoconferences, and remote therapies, for example, can connect family members, physicians/therapists, and communities of peers (Weiner et al., 2011; Jelcic et al., 2014; Dethlefs et al., 2017; Lorenz et al., 2019; Cheung and Peri, 2020). Moreover, telepresence robots may be useful surrogates during isolation by increasing daily stimulation activities. In the same vein, even multimedia, Apps offering interactive gaming or automatic prompting systems can either stimulate cognitive functions or sustain PWD daily living and instrumental activities (Brando et al., 2017; Tyack and Camic, 2017; Daly Lynn et al., 2019; Moyle et al., 2019). However, people with dementia are not the only ones who can take advantage of different technological tools. Remote ATs can involve PWD's caregivers by providing them with several types of supportive programs, which, in turn, emerged to have many positive outcomes. If, on the one hand, the number of online or remote supportive tools targeting PWD are few, they are positively evaluated both by PWD and their caregivers (Weiner et al., 2011; Lazar et al., 2014; Lorenz et al., 2019; Moyle et al., 2019). Our analysis also shows some limitations in the existing AT-related literature. The first one is concerned with using heterogeneous methodologies to assess the impact of the use of ATs. Specifically, several devices deliver different types of interventions, the sample size is usually small, research designs barely standardized, and the outcomes were not enough systematized. Unfortunately, such limitations have not improved with time. Both heterogeneity and effect sizes featuring the latest studies showed that technologies need more controlled research to reveal their effectiveness. Furthermore, our analysis shows a possible bias regarding the population defined as the interventions' primary target. For example, many of the interventions monitoring PWD to offering them security services are often described as helpful "for caregivers." Even though these technologies may also assist the caregiving process, we think that they should be labeled as "for PWD," as the actual label does not consider functional autonomy levels still active. The security devices can be used autonomously by PWD until their autonomy has not yet been severely compromised. In this vein, Lorenz et al. (2019) reported a meaningful blog post written by a person with dementia. The post describes how he felt about the transition between the active and passive roles in domestic alarms management. In the first phase of the disease, notifications supported a person's autonomy until he could recognize the different sounds. Later, due to the disease's progression, the person could not understand the source of the sounds anymore. Therefore, when a caregiver's assistance becomes necessary to manage the technological devices, it may be more appropriate to label the technology as "for caregivers": it cannot support any longer the PWD but, instead, the caregiver.

Besides what was discussed, it is also relevant to mention that the theoretical models underpinning technological offers need improvement. Only the review of Rathnayake et al. (2019) highlighted the theoretical backgrounds upon which the designing process of the Apps was based. On top of this, just two of the studies reviewed by them reported a theoretical model. This evidence confirms the need to increase the number of studies on technology that bases their hypothesis on theoretical models. Such an improvement would impact the rate of studies reproducibility, and it can also foster the capability of the research to disentangle which factors cause the observed effects (Kennelly, 2011). These limitations are associated with two consequences. Firstly, the single outcomes featuring each intervention are hard to disentangle and to generalize. Secondly, there is a significant gap between the theory underpinning the research and the implementation of the devices in everyday life, which is due to a lack of attention toward time-related factors and organizational determinants (Christie et al., 2018). Indeed, the inadequate follow-ups and insufficient consideration of the person's ongoing adaptation process provoke an over-time decline in the usage of ATs in the post-trial phases (Christie et al., 2018). Finally, the design of interventions should focus more on developing user-friendly technologies that can be personalized and updated by respecting users' evolving needs. Additionally, there is a limited interest in innovation supplied by national and local health organizations, mainly when the elderly are the target of the technology (Christie et al., 2018). Hence, it is necessary to regularly update the research to develop interventions able to exploit the maximal potential of modern technologies and supportive organizational plans aimed at overcoming the barriers experienced by healthcare professionals and the devices' final users (Meiland et al., 2017).

LIMITATIONS

One of the limitations affecting the present work consists of the use of a heterogeneous methodology chosen. Specifically, to timely respond to the pandemic, we primarily decided to include in this work reviews of reviews. As we noticed that no review discussed the recent outbreak, we welcomed new studies reporting how the technology can support both PWD and caregivers. The second main limitation regards the selection criteria since no we did not analyze any gray literature sources. Although such a decision might have prevented additional evidence from emerging, it secured certified standards.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

AP performed the literature search, outlined the results, and drafted the manuscript. RC discussed the search outcomes and supervised the process. IC and MV reviewed the manuscript. GO performed the literature search, discussed and reviewed the results, drafted the document, and managed the operations. All authors contributed to the article and approved the submitted version.

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Usability and User Experience of Cognitive Intervention Technologies for Elderly People With MCI or Dementia: A Systematic Review

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Introduction: Incorporating technology in cognitive interventions represents an innovation, making them more accessible, flexible, and cost-effective. This will not be feasible without adequate user-technology fit. Bearing in mind the importance of developing cognitive interventions whose technology is appropriate for elderly people with cognitive impairment, the objective of this systematic review was to find evidence about usability and user experience (UX) measurements and features of stimulation, training, and cognitive rehabilitation technologies for older adults with mild cognitive impairment (MCI) or dementia.

Method: The Medline, PubMed, Scopus, ScienceDirect, and PsycINFO databases were searched for literature published in the last 10 years (2009–2019), and three researchers independently reviewed potentially eligible studies, following specific inclusion criteria. A systematic review of the studies was conducted, presenting a qualitative synthesis of usability and UX measures with their outcomes, study characteristics and features of the cognitive intervention technologies.

Results: Ten studies were selected: five were cognitive stimulation and five were cognitive training. Most of them (60%) were computer-based programs with a serious game format. Efficiency and effectiveness were the most frequent measurements used for collecting objective usability data, showing that elderly people with cognitive impairment require more time (45%) and help (40%) but can complete tasks (60%). Regarding UX or subjective usability data, questionnaires and scales were the most used methods, reporting positive experience despite certain difficulties with the interface in five studies.

Conclusion: Measuring usability and UX in cognitive intervention technologies for older adults with MCI or dementia provides an integrated view that can contribute to their development according to the needs and characteristics of the target population. More research is required to include this population group in usability and UX studies, as well as standardized tools and consensus on the relationship of these terms to guarantee the future effectiveness of cognitive intervention technologies.

Review registration: This review was registered in the PROSPERO (CRD42020158147) International Register of Systematic Review Protocols.

Keywords: cognitive intervention, technology, usability, user experience, dementia, MCI

INTRODUCTION

It is currently estimated that every 3 s someone develops dementia, and the annual cost of dementia care is estimated at US $ 1 billion, a quantity that will double by 2030 (Alzheimer's Disease International, 2019). Mild cognitive impairment (MCI) is often a transitional stage from normal aging's cognitive decline to dementia, in which the functional abilities of daily life are not preserved (Petersen et al., 2014). As expected, studies have shown that people who undergo normal aging processes display better cognitive performance compared to elderly people with MCI and those with dementia, the latter group having the greatest difficulties (Lavrencic et al., 2019).

Cognition-based interventions are increasingly considered as an important complement and even an alternative to pharmacological treatments for people with dementia (Bahar-Fuchs et al., 2013). In the MCI population, cognitive interventions have been effective in optimizing cognitive functioning, reducing cognitive impairment and delaying the onset of dementia (Faucounau et al., 2010). There are three main approaches to cognition-focused interventions (Bahar-Fuchs et al., 2013): cognitive stimulation (CS), cognitive training (CT), and cognitive rehabilitation (CR).

Cognitive stimulation is usually used in groups for older adults with cognitive impairment, including a variety of activities to keep cognitive functions active in a general and entertaining way (Woods et al., 2012). It can also be used with healthy elderly individuals (HE) to prevent cognitive decline (Rosell, 2018). CT consists of guided standardized exercises to improve performance in certain cognitive functions (Kallio et al., 2017). It can be used in elderly with or without cognitive impairment (Ledreux et al., 2019), wither individually or in groups (Oltra-Cucarella et al., 2018). CR is an individualized approach aimed at improving the functionality in daily living of older adults with cognitive impairment, thus helping to reduce caregiver burden (Oltra-Cucarella et al., 2018; Germain et al., 2019).

Computer-based cognitive interventions have the advantage of being more accessible to the public at large, and are also flexible, self-administered and cost effective (Faucounau et al., 2010; Toribio-Guzmán et al., 2018). In addition, technology allows cognitive exercises to be presented in new and engaging ways (Kueider et al., 2012). For example, video games have moving images, sounds, and feedback that make them more attractive and rewarding than printed materials (Toril et al., 2014). Some authors use the term serious games for tools aimed at specific purposes, such as cognitive games designed to improve cognitive functions rather than for entertainment alone (Robert et al., 2014).

However, good user-technology fit is essential to prevent technology from being ignored or misused (Meiland et al., 2017). Hence, it is important that technologies have a human-centered design, taking users and usability into account in their development (International Organization for Standardization [ISO], 2019a). Usability is the degree to which a product, service or system can be used with effectiveness, efficiency and satisfaction by certain users in a specific context to achieve an objective (International Organization for Standardization [ISO], 2019b).

Different usability testing methods are available and can be used during all phases of a product's development to ensure that its design can meet high-quality standards, identifying problems and correcting them for easy, efficient and effective user-system interaction (Toribio-Guzmán et al., 2017). Furthermore, usability also assesses satisfaction, which, in turn, involves user experience (UX) (International Organization for Standardization [ISO], 2019a). UX consists of the perceptions, emotions, beliefs, preferences and behaviors of the users that happen before, during and after the utilization of a product, service or system (International Organization for Standardization [ISO], 2019b). UX focuses on subjective, temporal, situated and holistic attributes, and on design and user interaction (Bargas-Avila and Hornbæk, 2011; Roto et al., 2011).

Nevertheless, usability issues in cognitive intervention technologies for people with dementia are scarcely mentioned in research (Meiland et al., 2017). Moreover, there are studies that do not provide an integrated understanding of UX in association with technological devices (Megges et al., 2018), and one study reported that few technology systems are specifically designed to approach the cognitive limitations that affect older adults with cognitive impairment (Wargnier et al., 2018). In a population sector that is already subject to the frustration and lack of confidence that is associated with the limitations of their condition, the impact of unsuitable technological designs can add to such negative feelings (Smeenk et al., 2018).

Technologies aimed at people with cognitive impairment have to take into account their needs, preferences, abilities and limitations, since lack of awareness of their particularities not only affects them, but also their families and society at large, involving a costly burden for the community (Czaja et al., 2019). Given the importance of developing cognitive interventions whose technology is acceptable, usable and relevant to the elderly population with cognitive impairment, the objective of this systematic review was to obtain evidence about usability and UX measures and features of stimulation, training, and cognitive rehabilitation technologies for older adults with MCI or dementia.

MATERIALS AND METHODS

Materials

This systematic review focused on usability and UX studies that address stimulation, training, and cognitive rehabilitation technologies for older adults with MCI or dementia, seeking evidence regarding such cognitive intervention technologies' usability and UX measures and characteristics.

The PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines were followed to ensure the review's transparency and clarity (Liberati et al., 2009). Accordingly, the analysis and presentation of quality evidence-based information allows it to be adequately conveyed to those interested in mental health support technological programs, whose fast and growing development means that not all of them include the characteristics that would be desirable or achieve suitable goals (Baumel, 2016; Baumel et al., 2017).

This review was registered in the PROSPERO (CRD42020158147)[1] International Register of Systematic Review Protocols, whose purpose is also to increase transparency in systematic reviews, avoiding duplication and minimizing bias (Schiavo, 2019).

Procedure

The PROSPERO website was searched for previous systematic reviews on the topic and none were found, which validated the purpose of this review. The Medline, PubMed, Scopus, ScienceDirect, and PsycINFO databases were searched in August and September 2019 using certain combinations of keywords to delimit the search (**Table 1**).

ScienceDirect did not support the truncation symbol, so the term technology was used instead of tech*. In all the databases, results were limited to the last 10 years (2009 – 2019) and to being written in English or Spanish. The search results were exported to the EndNote citation manager. A total of 552 studies were obtained, of which 305 remained after the removal of duplicates. The titles and/or abstracts of these studies were read, and the following criteria were used to find potentially eligible articles:

Inclusion criteria:

- People aged 60 and over with MCI (all subtypes) or with one of the following types of dementia: Alzheimer, frontotemporal dementia, vascular dementia
- Any type of technology mainly or partly aimed at stimulation, training or cognitive rehabilitation
- Stimulation, training, or cognitive rehabilitation technologies where measurements or characteristics of usability and/or user experience are provided
- Journal articles with descriptive, explanatory, experimental or analytical studies as well as clinical trials and pilot studies

Exclusion criteria:

- Older adults with other types of dementia or clinical conditions (Lewy Body, Pick's disease, Creutzfeldt-Jakob disease, alcohol-related dementia, AIDS dementia complex, Huntington's disease, Parkinson's disease, Down syndrome, brain injury) or healthy older adults
- Programs where the use of technology was not intended for therapeutic purposes of stimulation, training or cognitive rehabilitation
- Stimulation, training or cognitive rehabilitation technologies with no description regarding usability or user experience
- Systematic/literature reviews, meta-analyses, editorials, newspapers, magazines, book chapters, and conference papers

This narrowed the selection down to six articles. In order to find more potentially eligible studies, a manual Google Scholar search was conducted based on the terms 'usability technology cognitive stimulation training rehabilitation dementia MCI.' In addition, the reference lists of all the selected studies were screened to ensure that no possible articles were left out. These two steps broadened the sample to 13 articles, whose full-text versions were examined to verify whether they were appropriate for inclusion. Three researchers conducted this process independently, subsequently comparing their results to achieve a consensus on which studies to include or exclude. Finally, a total of 10 articles were included. This search and selection process is summarized in **Figure 1**.

Of the 10 included studies, that by Kyriazakos et al. (2017) addressed the target population and another sample that did not meet the inclusion criteria, but it was not excluded because the results obtained for the target population were presented separately.

Data Extraction

The measures and features to be extracted and analyzed were chosen according to the main characteristics of usability; namely, effectiveness, efficiency and satisfaction (considering the latter

TABLE 1 | Keywords combination.

Usability AND (tech* OR software OR computer) AND "cognitive stimulation" AND (dementia OR "mild cognitive impairment" OR MCI)
Usability AND (tech* OR software OR computer) AND "cognitive training" AND (dementia OR "mild cognitive impairment" OR MCI)
Usability AND (tech* OR software OR computer) AND "cognitive rehabilitation" AND (dementia OR "mild cognitive impairment" OR MCI)
("user experience" OR UX) AND (tech* OR software OR computer) AND "cognitive stimulation" AND (dementia OR "mild cognitive impairment" OR MCI)
("user experience" OR UX) AND (tech* OR software OR computer) AND "cognitive training" AND (dementia OR "mild cognitive impairment" OR MCI)
("user experience" OR UX) AND (tech* OR software OR computer) AND "cognitive rehabilitation" AND (dementia OR "mild cognitive impairment" OR MCI)

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[1] https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020158147

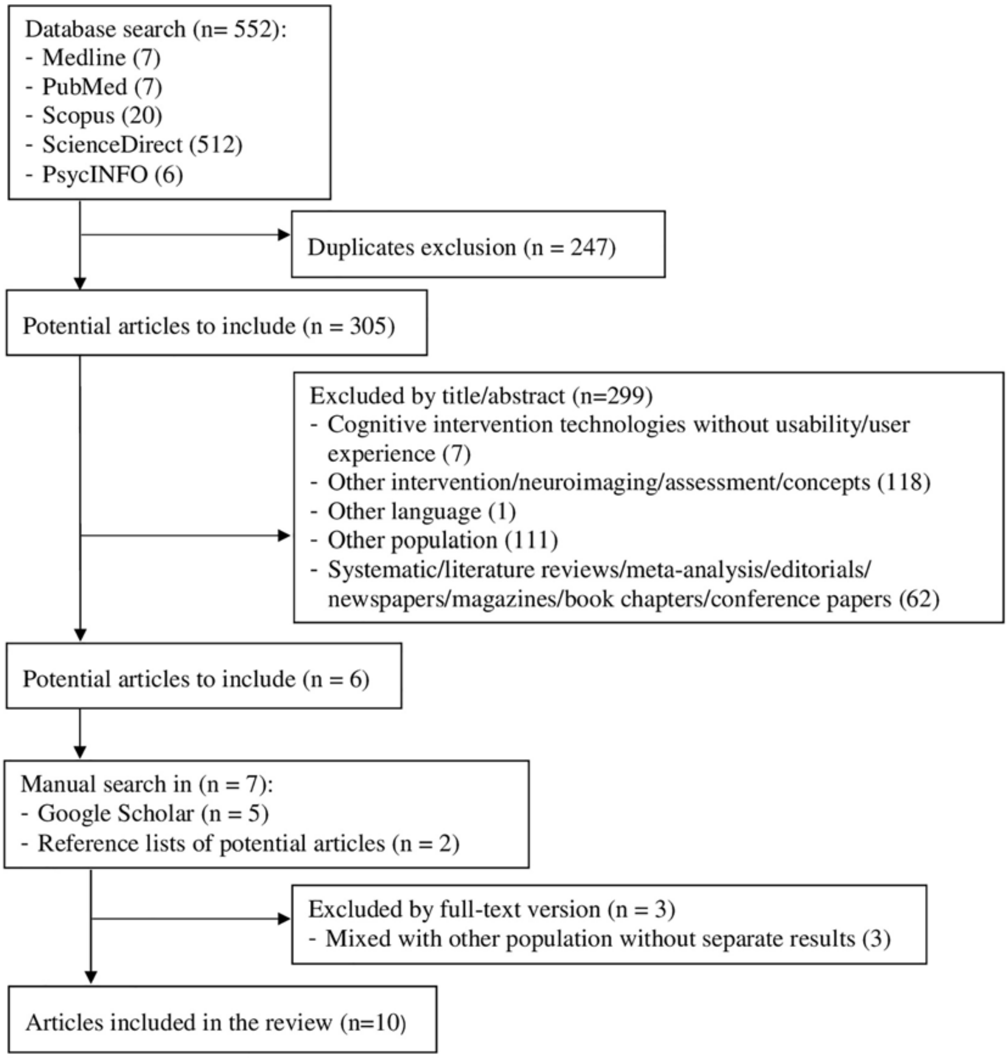

FIGURE 1 | Search procedure and studies selection.

as part of UX), as defined in International Organization for Standardization [ISO] (2019b):

- Effectiveness: accuracy and completeness with which users achieve specific goals
- Efficiency: resources used in relation to the results achieved, such as time, effort, materials and costs
- User experience: perceptions, emotions, beliefs, preferences, comfort, accomplishments, responses and behaviors that happen before, during and after use, as well as the extent to which the user's needs and expectations are met (satisfaction)

Considering the ongoing scientific debate about the overlap between usability and UX, this study approaches UX as an extension of usability, since UX focuses on assessing subjective aspects such as satisfaction (Sauer et al., 2020).

It should be noted that no articles were excluded from this data collection. The analysis was conducted based on the number and type of studies, participants' socio-demographic characteristics, types of cognitive interventions and technology used, measures and features of usability and UX and their main results.

Data Analysis

Due to the different usability and UX measures, as well as the variety of methodologies used in the studies, a qualitative synthesis of the results was performed following the Cochrane guidelines for data synthesis and analysis (Ryan, 2013). Firstly, study characteristics such as design and participants are presented. Then, features such as type, format, software, and hardware of cognitive intervention technologies are reported. Finally, a description is given about the usability and UX measures found in the studies and their outcomes.

RESULTS

Characteristics of the Studies

The search yielded 552 studies, narrowed down to six potential articles after the removal of duplicates and the screening of titles and abstracts according to the inclusion and exclusion criteria. Also based on these criteria, a manual search led to the addition of seven more potential studies. The full-text version of these 13 articles was read, and, finally, 10 articles were included for analysis (**Figure 1**).

The selected papers were eight pilot studies (González-Abraldes et al., 2010; Boulay et al., 2011; González-Palau et al., 2013; Manera et al., 2015; Djabelkhir et al., 2017; Garcia-Sanjuan et al., 2017; Kyriazakos et al., 2017; Tziraki et al., 2017) and two clinical trials (Haesner et al., 2015; Ben-Sadoun et al., 2016). Most of them had been conducted in Europe and the number of subjects that made up their samples ranged from 7 to 180, most of them women aged 60–90 with MCI or dementia (some with mild dementia and others with Alzheimer's disease), as well as HE (**Tables 2**, **3**).

The length of the interventions varied between a single session and 3 months. Sessions were given 1–3 times per week, and each of them lasted between 10 and 90 min. At the beginning, eight of the studies included a trial period for older adults to adapt to the tool (González-Abraldes et al., 2010; Boulay et al., 2011; Haesner et al., 2015; Manera et al., 2015; Ben-Sadoun et al., 2016; Djabelkhir et al., 2017; Garcia-Sanjuan et al., 2017; Kyriazakos et al., 2017) that ranged between 1 session and 2 weeks (**Table 3**).

There were dropouts reported in six of the studies (Boulay et al., 2011; González-Palau et al., 2013; Manera et al., 2015; Djabelkhir et al., 2017; Garcia-Sanjuan et al., 2017; Tziraki et al., 2017), with rates ranging from 4.8 to 31.6%. The most frequent reasons for withdrawal were medical problems (50%), followed by reluctance to continue after the first contact with the technological tool (19.5%), family problems as well as refused to try (11.1% respectively) and, lastly, because they considered the exercise easy or uninteresting (8.3%) (**Table 3**).

Features of Cognitive Intervention Technologies

Regarding the type of cognitive intervention, five were CS technologies: X-Torp (Ben-Sadoun et al., 2016), MINWii (Boulay et al., 2011), Computer Cognitive Stimulation (CCS) (Djabelkhir et al., 2017), Telecognitio (González-Abraldes et al., 2010) and Serious Game (Tziraki et al., 2017); and another five were aimed at CT: Tangibot (Garcia-Sanjuan et al., 2017), Long Lasting Memories (LLM) (González-Palau et al., 2013), eWALL (Kyriazakos et al., 2017), Kitchen and Cooking (Manera et al., 2015), and Web-based CT platform (Haesner et al., 2015). This last study and two others (González-Abraldes et al., 2010; Djabelkhir et al., 2017) were different from the rest because they used technology that already existed to gather information or develop their own. On the other hand, none of the studies included technology aimed at CR (**Table 3**).

In four of the studies the cognitive intervention technologies found consisted of cognitive exercises (González-Abraldes et al., 2010; González-Palau et al., 2013; Haesner et al., 2015; Djabelkhir et al., 2017) and six studies were based on serious games (Boulay et al., 2011; Manera et al., 2015; Ben-Sadoun et al., 2016; Garcia-Sanjuan et al., 2017; Kyriazakos et al., 2017; Tziraki et al., 2017). It should be noted that the games or video games whose purpose was linked to cognitive intervention rather than entertainment were serious games (Robert et al., 2014). On the other hand, several were programs with other functions such as physical training, social interaction, music therapy and assisted environments (**Table 3**).

The most commonly used hardware for cognitive interventions was the personal computer (60%), followed by the Tablet (40%), touch screens or screens (30%, respectively), gamepad/joystick, sensor or smartphone (20%, respectively). The least used were robots, mouse and headphones (10%, respectively). The described characteristics of the software and hardware were those strictly used and mentioned in the cognitive area of the studies found (**Table 4**).

Measures of Usability and UX in Cognitive Intervention Technologies

To facilitate understanding and comparison of the measures found, they were divided into usability and UX, considering UX as an extension of usability that focuses on subjective data. The measures are shown in **Table 5**.

Usability was measured using five main tools: number of completed tasks, number of errors or failed actions, time to complete tasks, number of unnecessary actions, and number of interventions made by the moderator. The first two corresponded to effectiveness, while the last three belonged to efficiency. On the other hand, six tools for UX measurement were found: questionnaires and scales, verbalizations and behaviors, attendance rates, interviews, time spent doing the activity and number of tasks completed. Only one study (González-Abraldes et al., 2010) used a single tool, while the other nine studies (Boulay et al., 2011; González-Palau et al., 2013; Haesner et al., 2015; Manera et al., 2015; Ben-Sadoun et al., 2016; Djabelkhir et al., 2017; Garcia-Sanjuan et al., 2017; Kyriazakos et al., 2017; Tziraki et al., 2017) used a combination of them.

Specifically, in terms of effectiveness, the most commonly used measure was the number of tasks completed by participants, found in four studies (Manera et al., 2015; Ben-Sadoun et al., 2016; Garcia-Sanjuan et al., 2017; Tziraki et al., 2017), followed by the number of errors, in two studies (Boulay et al., 2011; Garcia-Sanjuan et al., 2017). Regarding efficiency, the most frequent measure was the time it took to complete tasks, which appeared in four studies (Boulay et al., 2011; Ben-Sadoun et al., 2016; Garcia-Sanjuan et al., 2017; Tziraki et al., 2017), followed by moderator interventions, in 3 studies (Boulay et al., 2011; González-Palau et al., 2013; Garcia-Sanjuan et al., 2017) and the number of unnecessary actions in only 1 (Garcia-Sanjuan et al., 2017).

The measures mentioned above correspond to objective usability data collection. However, because usability also involves measuring the UX parameter of satisfaction, which involves collecting subjective data (Sauer et al., 2020), the following

TABLE 2 | Participant's sociodemographic characteristics.

Technology	Experimental group			Control group			Country
	Participants	Age (S.D.)	Sex	Participants	Age (S.D)	Sex	
X-Torp (Ben-Sadoun et al., 2016)	4 AD, 6 MCI	82.3 (±6.4)	4 W, 6 M	8 HE	71.4 (±10.1)	5 W, 3 M	France
MINWii (Boulay et al., 2011)	7 AD	88.5 (N/A)	4 W, 3 M	N/A	N/A	N/A	France
CCS and CCE (Djabelkhir et al., 2017)	10 MCI (CCS)	75.2 (±6.4)	7 W, 3 M	10 MCI (CCE)	78.2 (±7.0)	6 W, 4 M	France
Tangibot (Garcia-Sanjuan et al., 2017)	12 MCI, 12 SCI	81.33 (±8.48)	*32 W, 8 M	16 HE	81.33 (±8.48)	*32 W,8 M	Spain
LLM (González-Palau et al., 2013)	52 MCI, 33 MD	81.97 (±9.16) 83.44 (± 5.67)	64 W, 21 M	95 HE	81.87 (±6.84)	70 W, 25 M	Spain
Web-based CT platform (Haesner et al., 2015)	6 MCI	60–70 years (N/A)	3 W, 3 M	6 HE	>80 years	3 W, 3 M	Germany
Telecognitio: two apps (González-Abraldes et al., 2010)	8 MCI	75 (±6.7)	N/A	N/A	N/A	N/A	Spain
eWALL (Kyriazakos et al., 2017)	48: MCI ARI, COPD	Older adults (N/A)	N/A	N/A	N/A	N/A	Austria, Italy, Denmark, Netherlands
Kitchen and Cooking (Manera et al., 2015)	9 MCI, 12 AD	75.8 (±9.1) 80.3 (±6.3)	7 W, 2 M8 W, 4 M	N/A	N/A	N/A	France
Serious Game (Tziraki et al., 2017)	24 Dementia	65 – 90 years (N/A)	15 W, 9 M	14 HE	65 – 90 years	11 W, 3 M	Israel

AD, Alzheimer disease; ***apps****, applications;* ***ARI****, Age-Related Functional Impairments;* ***CCE****, computerized cognitive engagement;* ***CCS****, computer cognitive stimulation;* ***COPD****, chronic obstructive pulmonary disease;* ***CT****, cognitive training;* ***HE****, healthy elderly;* ***LLM****, long lasting memories;* ***M****, man;* ***MCI****, mild cognitive impairment;* ***MD****, mild dementia;* ***N/A****, not apply;* ***S.D.****, standard deviation;* ***SCI****, severe cognitive impairment;* ***W****, woman.*
*******, sex distribution on the entire sample.*

UX measures were considered in this review: participants' verbalizations and behaviors, which appeared in three studies (Boulay et al., 2011; Garcia-Sanjuan et al., 2017; Tziraki et al., 2017), and interviews, also found in three studies (Haesner et al., 2015; Djabelkhir et al., 2017; Garcia-Sanjuan et al., 2017). These were followed by time participants spent on doing the tasks when there was no time limit, which was addressed in two studies (Manera et al., 2015; Ben-Sadoun et al., 2016); attendance rates, considered in one (Djabelkhir et al., 2017); and number of tasks that participants performed when free do as many as they wanted (regardless of whether they were poorly or well executed), also found in only one (Manera et al., 2015).

Questionnaires and scales were the most widely used tools for UX, appearing in eight studies (González-Abraldes et al., 2010; Boulay et al., 2011; González-Palau et al., 2013; Haesner et al., 2015; Manera et al., 2015; Ben-Sadoun et al., 2016; Djabelkhir et al., 2017; Kyriazakos et al., 2017). The standardized tools found were: Technology Acceptance Model (TAM), Positive Affect Negative Affect Scale (PANAS), User Experience Questionnaire (UEQ), Piper Fatigue Scale (PFS) and Technology Commitment Questionnaire. The non-standardized tools that were used tended to be Likert-type scales of satisfaction, motivation, affectivity, sustainability, interest, ease of use and learning.

The most used in UX were satisfaction scales, found in three studies (Boulay et al., 2011; González-Palau et al., 2013; Manera et al., 2015), followed by TAM (Ben-Sadoun et al., 2016; Kyriazakos et al., 2017), PANAS (Manera et al., 2015; Ben-Sadoun et al., 2016), and Motivation Scale (Manera et al., 2015; Djabelkhir et al., 2017) in two studies, respectively. Finally, UEQ (Kyriazakos et al., 2017), PFS (Manera et al., 2015), Technology Commitment Questionnaire (Haesner et al., 2015), Affective Scale (González-Palau et al., 2013), Sustainability Scale (González-Palau et al., 2013), Ease of Use and Learn Scale (González-Palau et al., 2013), Interest Scale (Manera et al., 2015), and an *ad hoc* questionnaire (González-Abraldes et al., 2010) were registered in one study, respectively.

Of the 10 studies, 6 measured both usability (effectiveness and efficiency) and UX (Boulay et al., 2011; González-Palau et al., 2013; Manera et al., 2015; Ben-Sadoun et al., 2016; Garcia-Sanjuan et al., 2017; Tziraki et al., 2017), while four focused on UX (González-Abraldes et al., 2010; Haesner et al., 2015;

TABLE 3 | Methodological and descriptive characteristics of the studies.

		Intervention					
Technology	**Design**	**Type**	**Format**	**Familiarization**	**Total duration**	**Dropouts**	**Other features**
X-Torp (Ben-Sadoun et al., 2016)	Clinical trial	CS	Serious game	2 wks	1 mo (20-80 min/sess, 3 sess/wk)	N/A	Physical training
MINWii (Boulay et al., 2011)	Pilot study	CS	Serious game	1 sess	3 mos (10-20 min/sess, 1 sess/wk)	MP (n = 1); RTC after 2nd sess (*n* = 1)	Music therapy
CCS and CCE (Djabelkhir et al., 2017)	Pilot study	CCS	Exercises	1 sess	3 mos (90 min/sess, 1 sess/wk)	MP (*n* = 1, CCS)	CCS: social interaction CCE: training to use a tablet-PC, social interaction
Tangibot (Garcia-Sanjuan et al., 2017)	Pilot study	CT	Serious game	Before each task	1 sess (3 tasks/4 times each one)	RTT (n = 4); RTC after 1st contact (n = 2)	N/A
LLM (González-Palau et al., 2013)	Pilot study	CT	Exercises	N/A	3 mos (40 min/sess, 3 sess/wk)	MP (*n* = 7); FP (*n* = 4); RTC (*n* = 3)	Physical training
Web-based CT platform (Haesner et al., 2015)	Clinical trial	CT	Exercises	1 sess	1 sess	N/A	Social media
Telecognitio: two apps (González-Abraldes et al., 2010)	Pilot study	CS	Exercises	Before the intervention	4 sess (15 min/each app)	N/A	N/A
eWALL (Kyriazakos et al., 2017)	Pilot study	CT	Serious games	1 sess	6 wks	N/A	AAL; ELEs; AmI
Kitchen and Cooking (Manera et al., 2015)	Pilot study	CT	Serious games	1 sess	1 mo (subjects played it as much as they wanted)	RTC after first wk (*n* = 1)	N/A
Serious Game (Tziraki et al., 2017)	Pilot study	CS	Serious games	N/A	10 wks (20–30 min/sess, 1–2 sess/wk)	MP (*n* = 9); GEU (*n* = 3)	N/A

AAL, active assisted living; ***AmI****, ambient intelligence;* ***apps****, applications;* ***CCE****, computerized cognitive engagement;* ***CCS****, computerized cognitive stimulation;* ***CS****, cognitive stimulation;* ***CT****, cognitive training;* ***CT****, cognitive training;* ***ELEs****, enhanced living environments;* ***FP****, family problems;* ***GEU****, game easy and uninteresting;* ***LLM****, long lasting memories;* ***min****, minutes;* ***mo****, month;* ***mos****, months;* ***MP****, medical problems;* ***N/A****, not apply;* ***RTC****, refused to continue;* ***RTT****, refused to try;* ***sess****, session;* ***wk****, week;* ***wks****, weeks.*

Djabelkhir et al., 2017; Kyriazakos et al., 2017), as can be seen in **Figure 2**.

Outcomes of Usability and UX Measures in Cognitive Intervention Technologies

The measurements found in the studies collected both objective and subjective data, so it is important and interesting to observe the differences or similarities in the results obtained from usability and UX measures. These results are summarized in **Table 5**.

Cognitive Stimulation Technologies

Djabelkhir et al. (2017) presented a CCS program that consisted of cognitive exercises and social interaction, as well as a Computerized Cognitive Engagement (CCE) system that involved training to use a tablet-PC and social interaction. Only UX measures were taken, obtaining similar positive results in both groups of older adults with MCI: everyone attended every session and high levels of motivation were reported before and after the interventions. The main motivations were to resist the onset of Alzheimer's disease and to cope with loneliness. In addition, participants generally found the group sessions engaging and stimulating and expressed a desire to continue on a regular basis.

In the study by González-Abraldes et al. (2010), CS was also performed through cognitive exercises. They introduced two computerized apps for older adults with MCI. The differences were that app A had visual and audio statements, pictures, limited response time and a touch screen; while app B had audio statements, real pictures, no fixed response time, different levels of difficulty and a mouse. Only UX was measured. Both groups reported difficulties in using the exit icon and in remembering the questions to answer them, although those who used app A found more difficulty in both aspects (50 and 100%, respectively). In addition, the app A group reported difficulties associated with the pause icon and stated that there was "very little" time to answer (62.5% respectively). Finally, participants defined the use of the devices as complex: 62.5% of the participants in app A considered

TABLE 4 | Hardware and software of the studies' cognitive interventions.

	Hardware									Software			
Technology	**PC**	**Tablet**	**Smart phone**	**Robot**	**Mouse**	**Screen**	**Touch screen**	**Sensor**	**Gamepad, Joystick, other**	**Head phones**	**Program**	**App**	**Web platform**
X-Torp (Ben-Sadoun et al., 2016)	**Yes**	No	No	No	No	**Yes**	No	**Yes**	No	No	**Yes**	No	No
MINWii (Boulay et al., 2011)	**Yes**	No	No	No	No	**Yes**	No	No	**Yes**	No	**Yes**	No	No
CCS (Djabelkhir et al., 2017)	No	**Yes**	No	No	No	**Yes**	No	No	No	No	No	No	**Yes**
Tangibot (Garcia-Sanjuan et al., 2017)	No	No	**Yes**	**Yes**	No	No	No	**Yes**	**Yes**	No	**Yes**	No	No
LLM (González-Palau et al., 2013)	**Yes**	No	No	No	No	No	**Yes**	No	No	**Yes**	**Yes**	No	No
Web-based CT platform (Haesner et al., 2015)	**Yes**	**Yes**	**Yes**	No	No	No	No	No	No	No	No	No	**Yes**
Telecognitio: app A and B (González-Abraldes et al., 2010)	**Yes** ***	No	No	No	**Yes** **	No	**Yes** *	No	No	No	No	**Yes** ***	No
eWALL (Kyriazakos et al., 2017)	**Yes**	No	No	No	No	No	**Yes**	No	No	No	No	**Yes**	No
Kitchen and Cooking (Manera et al., 2015)	No	**Yes**	No	No	No	No	No	No	No	No	**Yes**	No	No
Serious Game (Tziraki et al., 2017)	No	**Yes**	No	No	No	No	No	No	No	No	**Yes**	No	No

CCS, computerized cognitive stimulation; CT, cognitive training; LLM, long lasting memories; PC, personal computer.
, App A; **, App B; *, Both apps.*

that they had to press the touch screen for too long or that it was inaccurate, while 62.5% of the subjects in app B found it difficult to use the mouse.

Tziraki et al. (2017) engaged in CS via serious games for older adults with dementia and HE. Usability results were positive and, although it took people with dementia longer to complete the tasks, they were able to complete 61% of them and their performance improved with listening cues. Positive results were also obtained in UX for people with dementia, who reported that the games were fun and engaging, listening cues contributing to the latter. In addition, they interacted and spoke to the tablet showing an increase in their self-efficacy, remembering easy and difficult components and developing learning techniques. However, HE found the tool too easy and hardly engaging.

According to the results of X-Torp (Ben-Sadoun et al., 2016), a serious game format with cognitive and physical training, people with Alzheimer's disease and MCI completed fewer tasks and spent more time on them as compared to HE. UX results were consistent with those of usability, as adults with cognitive impairment reported more difficulties (although the results were not significant) and feelings of lack of competence (which increased for everyone). In general, the groups accepted the tool in terms of interest and positive emotions with the difference that people with Alzheimer's disease showed more interest, while HE presented more positive emotions. Furthermore, there was no difference in the time spent by these groups on X-Torp.

As for MINWii (Boulay et al., 2011), which provided CS through a video game and music therapy, all the subjects with Alzheimer's disease held the joystick correctly, 57.1% of them made fewer mistakes and 85.7% took less time to complete the tasks. Few physical and verbal moderator interventions were required. This positive degree of usability was consistent with UX, because participants were generally very satisfied and expressed their desire to continue using it.

TABLE 5 | Usability and UX measures and results of studies in cognitive intervention.

Technology	Usability		UX	
	Measures	**Results**	**Measures**	**Results**
X-Torp (Ben-Sadoun et al., 2016)	Completed tasks	HE > AD, MCI	TAM: Ease of use	-Difficulty: AD, MCI > HE (nss) -Competence: HE > AD, MCI (it increased for all)
	Time to complete tasks	HE < AD, MCI	TAM: Usefulness	Interest: AD, MCI > HE
			PANAS	Positive emotions: HE > AD and MCI
			Time spent doing it*	No differences between groups
MINWii (Boulay et al., 2011)	Errors	4 participants decreased tasks errors	Satisfaction Questionnaire	High satisfaction of all participants
	Time to complete tasks	6 participants decreased the time Everyone held the joystick correctly	Verbalizations and behaviors	Participants expressed a desire to continue
	Interventions by moderator	Verbal interventions decreased Few physical interventions were made		
CCS and CCE (Djabelkhir et al., 2017)	N/A	N/A	Attendance rates	Everyone attended all sessions
			Motivation scale	High levels before and after the intervention by all
			Interviews	Both groups: -Main motivations: resist AD onset and loneliness -Group sessions considered engaging and stimulating -Expressed a desired to continue on a regular basis
Tangibot (Garcia-Sanjuan et al., 2017)	Completed tasks	HE > MCI (nss) MCI > SCI	Verbalizations and behaviors	62.5% of subjects showed enjoyment: HE > MCI, SCI
	Time to complete tasks	HE < MCI SCI ≈ MCI	Questions about whether they liked it - interview	80% of participants liked it: HE > MCI, SCI
	Errors	SCI > MCI, HE HE > MCI (nss)		
	Unnecessary actions	HE < MCI		
	Interventions by moderator	57.5% of participants needed help: SCI > MCI, HE		
LLM (González-Palau et al., 2013)	Interventions by moderator	Needed explanations: PWD, MCI > HE	Satisfaction scale	No differences between groups: -73.0% it met their expectations -66.9% felt confident using technologies -83.7% found it beneficial to health
			Affective scale	No differences between groups: 79.0% had fun
			Sustainability scale	No differences between groups: -78.1% thought it would be worth paying -84% expressed a desire to continue -96.1% would recommend it
			Ease of use and learn scale	-60.1% of participants found it easy to learn -40% of PWD found it harder to use without help

(Continued)

TABLE 5 | Continued

Technology	**Usability**		**UX**	
	Measures	**Results**	**Measures**	**Results**
Web-based CT platform (Haesner et al., 2015)	N/A	N/A	Interviews	MCI subjects would prefer audio-video communication, but not with strangers HE would prefer messages or emails MCI > HE: preference to sessions outside of a classroom environment, have adapted levels of difficulty, receive personal feedback Both groups would like to: Use it on a regular basis for cognitive health Repeat exercises as often as they wished Have a variety of playful exercises Have a preliminary and subsequent progress tests Have not potential distractions: loud noises, bright colors, lots of animations Have cognitive self-educational supplement Have background information about other users Personal data to be handled confidentially Be run by a trusty church, government, medical services
			Technology Commitment Questionnaire	HE > MCI: 44.8/60 and 35.5/60 respectively
Telecognitio: app A and B (González-Abraldes et al., 2010)	N/A	N/A	*Ad hoc* questionnaire	Exit icon difficulty: A > B, 50% and 37.5% respectively Difficulty retaining questions: A > B, 100% and 37% respectively Hardware difficulty: A ≈ B, 62.5% accuracy and pulse time errors on touch screen and 62.5% handling the mouse, respectively App A: 62.5% pause icon difficulty 62.5% considered "very little" the time to respond
eWALL (Kyriazakos et al., 2017)	N/A	N/A	UEQ	MCI participants preferred cognitive exercise, activity and sleep apps
			TAM	
Kitchen and Cooking (Manera et al., 2015)	Completed tasks	70% successfully completed	Satisfaction scale	High satisfaction: AD > MCI
			Interest scale**	It interested them
			Motivation scale**	Intrinsic motivation > external motivation
			PANAS	Positive emotions > negative emotions
			PFS	Not very fatigued
			Time spent doing it*	3h 48 min at home
			Tasks done*	85% done at home
Serious Game (Tziraki et al., 2017)	Completed tasks	61% completed correctly by PWD. Auditory cueing improved their performance	Verbalizations and behaviors	HE: Found it too easy and not highly engaging PWD: Expressed fun and engaging. Auditory cueing improved their engagement Increased their self-efficacy Interacted and spoke to the tablet Remembered certain easy and difficult components Developed learning techniques
	Time to completed tasks	HE < PWD		

*AD, Alzheimer disease; **app**, application; **CCE**, computerized cognitive engagement; **CCS**, computerized cognitive stimulation; **CT**, cognitive training; **h**, hour; **HE**, healthy elderly; **LLM**, long lasting memories; **MCI**, mild cognitive impairment; **min**, minutes; **N/A**, not apply; **nss**, not statistically significant; **PANAS**, positive affect negative affect scale; **PFS**, piper fatigue scale; **PWD**, people with dementia; **SCI**, severe cognitive impairment; **TAM**, technology acceptance model; **UEQ**, user experience questionnaire; **UX**, user experience.*

**, participants were free to do the tasks as much as they wanted.*

***, adapted from Gourlan et al. (2013).*

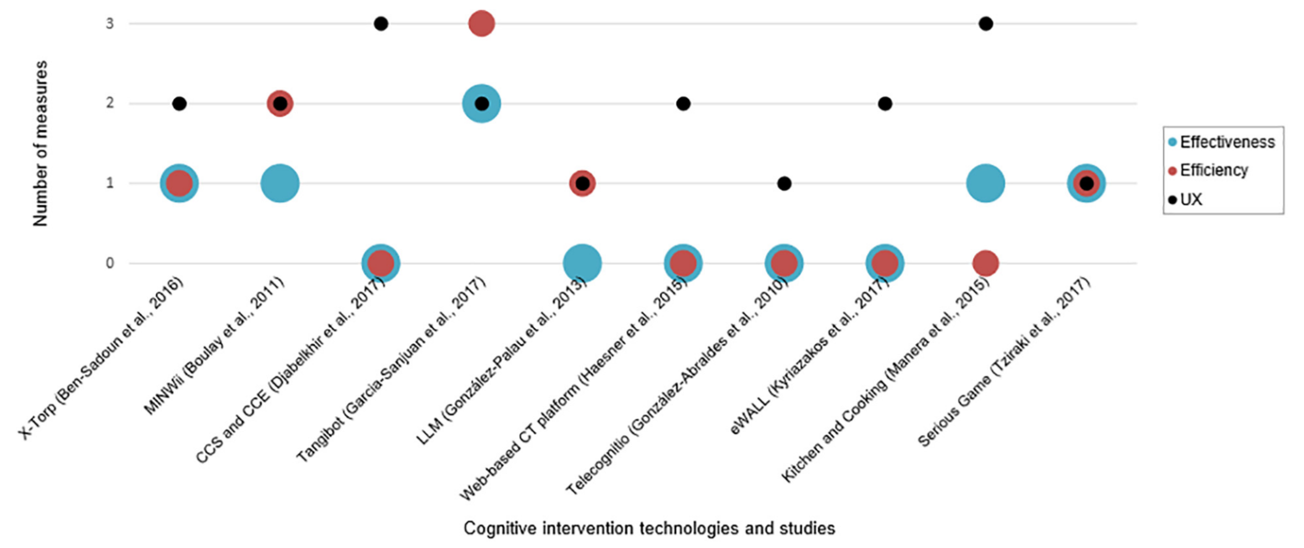

FIGURE 2 | Number of effectiveness, efficiency, and UX measures used in the studies.

Cognitive Training Technologies

In LLM (González-Palau et al., 2013), CT was performed via cognitive exercises to be completed by older adults with cognitive impairment (MCI and dementia) and HE. It also included a physical training function. In terms of usability, subjects with cognitive impairment were found to need more moderator explanations than HE. The perception of some people with dementia coincided with this fact in their UX, as 40% of them found it harder to use without help. However, 60.1% of participants found it easy to learn in general. In addition, the fact that 79.0% of the participants had fun and felt satisfied proved high acceptability of this tool: 73.0% reported that it met their expectations, 66.9% felt confident using technologies, and 83.7% found it beneficial for their health. There were also positive results in sustainability, as 78.1% thought it would be worth paying for it, 84% expressed a desire to continue using it and 96.1% would recommend LLM.

Haesner et al. (2015) used existing CT platforms and social media with older adults with MCI and HE to gather information about their preferences to develop their own web-based CT platform with cognitive exercises. Only UX measurements were taken. Both groups agreed that they would like to use it regularly for cognitive health, repeat the exercises as often as they wished, have a variety of playful exercises, have a preliminary and subsequent progress tests, have no potential distractions (such as loud noises, bright colors or too many animations), have a cognitive self-educational supplement, have background information about other users, have personal data handled confidentially and have the platform run by a trusted institution (church, government, or medical services). On the other hand, the differences between the groups were that HE preferred messages or emails, while MCI subjects preferred audio-video communication, although not with strangers. Likewise, the MCI group expressed a preference for sessions outside a classroom environment and adapted levels of difficulty and would like to receive personal feedback. However, HE showed more engagement with technology than older adults with MCI (44.8/60 and 35.5/60, respectively).

The CT serious game program called Kitchen and Cooking (Manera et al., 2015), was used with older people with MCI and Alzheimer's disease obtaining positive usability results, since 70% of the tasks were successfully completed. UX results were also positive, because the participants were generally interested, did not get very tired, played freely for an average of 3 h 48 min and performed 85% of the scenarios at home. In addition, they were motivated (intrinsic motivation being higher than extrinsic), felt more positive emotions than negative ones and were highly satisfied (people with Alzheimer disease showed more satisfaction than those with MCI).

The eWALL platform (Kyriazakos et al., 2017) provides CT in video game format and also includes home assisted environment functions. Only UX was measured, the results showing that MCI participants preferred cognitive exercise, activity and sleep apps. Finally, in another study (Garcia-Sanjuan et al., 2017), older adults with MCI, severe cognitive impairment and HE received CT in game format through the Tangibot robot. Usability measures showed that subjects with severe cognitive impairment had more difficulties, completed fewer tasks, made more mistakes and needed more help from the moderator. However, the time they spent on completing the tasks was similar to that spent by people with MCI, and 57.5% of the participants needed help. On the other hand, HE performed fewer unnecessary actions, took less time to complete the tasks, and completed more tasks than older adults with MCI. Regarding the latter, the difference was not significant, and neither was the fact that they made more mistakes than individuals with MCI. Overall UX results were positive: 62.5% expressed enjoyment and 80% liked it, although HE showed it more than individuals with cognitive impairment.

DISCUSSION

This systematic review presents current measures and characteristics of usability and UX in the field of CS, CT and CR technologies for older adults with MCI or dementia. This is relevant because of the importance of developing cognitive intervention systems in a digital age where technology is required to cater for the needs and particularities of this population group. A total of 10 studies were selected: five aimed at CS and five at CT. Most of them used a serious game format (*n* = 6), while the others consisted of cognitive exercises. The prevalence of the serious game format is consistent with other studies that support it as an increasingly popular alternative for the treatment of cognitive impairment because of its contribution to user motivation (Johnson et al., 2016; Manera et al., 2017). In addition, most were fundamentally computer-based programs (*n* = 6), which is also consistent with other studies where this hardware is found to facilitate older adults' interaction with technology (Góngora Alonso et al., 2019).

Given the ongoing debate on the relationship between usability and UX as broad terms that can overlap, this review took the position of considering UX (which focuses on the subjective area) as an extension of usability (which also evaluates objective items) (Tractinsky, 2018; Sauer et al., 2020). This allowed a consistent categorization in the different studies found where each had its own position. Both usability and UX were measured in 6 of the studies, while the other four focused on UX.

Effectiveness and efficiency appeared in the studies among the measurement of objective aspects of usability. Effectiveness consisted of counting the number of tasks that were completed by the participants (*n* = 4) and the number of mistakes (*n* = 2). According to Georgsson and Staggers (2016), these are the most commonly used effectiveness measures to provide information on how easy or difficult it was for subjects to solve them and of the obstacles that hindered their progress. However, apart from knowing whether the individual managed to complete the task, the resources he/she used are also important (International Organization for Standardization [ISO], 2019b), which is where efficiency comes into play. In the studies found, efficiency involved the time spent by participants on completing the tasks (*n* = 4), the number of unnecessary actions (*n* = 1) and moderator assistance (*n* = 3). These measures are consistent with other investigations (Landman et al., 2014; Bevan and Carter, 2016) where time spent on task completion is commonly used (Georgsson and Staggers, 2016).

Regarding UX, which allows the measurement of subjective aspects of usability, almost all the studies found used questionnaires and scales (*n* = 8). According to Albert and Tullis (2013), these self-reporting data collection tools provide the most relevant information about users' perceptions: if they report positive feelings or reactions about a technology, then they are likely to use it or reuse it. Some of the scales and questionnaires in the review were already standardized (e.g., TAM, PANAS, UEQ). Carvajal et al. (2011) emphasizes the use of standardized tools as a means of ensuring measuring quality, since they are valid, reliable, precise and feasible. The standardized and non-standardized questionnaires/scales found were not only about satisfaction, but encompassed other dimensions such as acceptability, which according to Borsci et al. (2020) is related, as well as other elements that are considered to be part of UX such as motivation, affectivity, perceptions and sustainability (Kramer, 2012; Lallemand et al., 2015).

The other tools found to measure UX consisted of observing participants' behavior while they interacted with the cognitive intervention technologies and conducting interviews. According to Hartson (2019), both are necessary, because they are a way of gathering information about what subjects express in their verbal and non-verbal behavior, as well as what they report. In addition, other measures of UX found were time spent and number of tasks that participants performed freely at home as often as they wanted, alongside attendance rates when tasks were performed at a center. These indicators of how often a program is used are linked to UX and are indicative of whether or not the technology system will be successfully implemented (Hong et al., 2014; Partala and Saari, 2015).

On the other hand, the study by Haesner et al. (2015) was different from the others in this review, because these authors only presented evidence of already existing technology and CT program exercises to gather information and develop their own software in the future. Although it could be argued that preferences and attitudes not linked to a current experience are not considered UX (Albert and Tullis, 2013), such criticism does not apply in this case, since UX can involve indirect interaction, which can trigger a certain behavior, and because of the effect of observing and thinking about the system, product or service (Albert and Tullis, 2013; Hartson, 2019).

Furthermore, because effectiveness and efficiency focus on objective aspects of usability while UX focuses on subjective aspects such as satisfaction, it is important to be aware of the differences and similarities in the studies' measurement results. According to Pluye et al. (2009), although quantitative and qualitative data may seem divergent, they actually have great potential to improve assessment and understanding of the topic in question.

In the studies of CS and CT technologies found (González-Palau et al., 2013; Ben-Sadoun et al., 2016; Garcia-Sanjuan et al., 2017; Tziraki et al., 2017), usability measures were consistent in that the performance of older adults with dementia or MCI was poorer (they completed fewer tasks, took longer to complete them or needed more help) as compared to that of healthy elderly people, which was also observed in other studies on their general functioning (de Frias et al., 2009). If both population groups are compared, usability results may appear negative for individuals with cognitive impairment; however, if attention is paid to the latter's performance, it can be observed that, despite their difficulties, they were able to complete a considerable number of tasks, reduce their errors and time spent on task completion, and also lengthen their period of interaction with the program. These results can also be seen in the studies found that only included individuals with cognitive impairment in their measurements (Boulay et al., 2011; Manera et al., 2015), and are in line with Holthe et al. (2018), who stress that technology programs with adequate usability allow people with lower cognitive capacity to achieve goals because they are user-friendly.

It is also essential to know how older adults with MCI or dementia regard their experience with the relevant technological intervention, given that it will help to improve its usability and success (Foster, 2014; Holthe et al., 2018). Regarding the measurements of UX reported in the review, in some studies people with cognitive impairment perceived difficulties in using the technological tool without help or in using certain icons and devices (González-Abraldes et al., 2010; González-Palau et al., 2013; Ben-Sadoun et al., 2016). These subjective data results are related to the objective performance data described above. However, these difficulties did not prevent them from having a positive experience, and, according to most of the studies they reported feelings of satisfaction, fun, engagement, interest, motivation, acceptability, a desire to continue using it as often as they wished, and even an increase over time in their feeling of self-efficacy (González-Abraldes et al., 2010; Boulay et al., 2011; González-Palau et al., 2013; Haesner et al., 2015; Manera et al., 2015; Ben-Sadoun et al., 2016; Djabelkhir et al., 2017; Garcia-Sanjuan et al., 2017; Kyriazakos et al., 2017; Tziraki et al., 2017).

These positive results are further supported by the low number of dropouts reported in the studies, most of which were due to medical problems associated with old age and aspects that were beyond the subjects' control. Torous et al. (2020) argue that UX and dropouts are strongly related, and that the degree of dropouts depends on how the technology was introduced. In this regard, most of the studies in the review included a period for older adults to become familiar with the cognitive intervention tool. On the other hand, half of the technological tools contained other functions besides CT, which could have influenced the results of the usability and UX measurements obtained. In fact, Contreras-Somoza et al. (2020) indicate that complementing cognitive intervention systems with social or emotional functions could improve adherence.

Finally, it is important to consider this review's limitations. First, most of the studies were conducted in Europe and most of the participants were women. As is known, sex and social background influence a person's characteristics (McCarrey et al., 2016). Second, no studies were found on usability or UX of CR technology, perhaps because CR focuses on improving functionality in activities of daily living, i.e., it is not restricted to cognitive tasks (Oltra-Cucarella et al., 2018). Third, some studies had few participants with dementia or MCI, although they equally provide relevant data in a field where few investigations were found. However, studies on participatory design or user-centered design could provide more data, even if they do not focus specifically on usability and UX evaluation. Computer sciences and engineering publications could also provide data in this area, although these sciences do not usually approach it from a clinical perspective. Fourth, not all studies provided detailed information about their software and hardware, as did other studies (Irazoki et al., 2020); nevertheless, for the purposes of this review they gave an overview of the technology used. Fifth, another limitation is not having assessed the risk of bias and the quality of the studies; however, only articles published in scientific journals were used. Finally, comparing instruments that measure usability and UX was challenging, because there is no consensus on these broad terms (Sauer et al., 2020) and there are also few studies involving older people with dementia or MCI, which may be due to a certain skepticism about the level of feedback they can provide and doubts about the appropriateness of testing prototypes on them, since possible mistakes can make them feel confused and disappointed with new technologies (Boman et al., 2014; Holthe et al., 2018).

CONCLUSION

This systematic review identified 10 studies that measured usability and UX in cognitive intervention technologies for older people with dementia or MCI. The studies showed lack of scientific consensus on the relationship between usability and UX, most of them using measures indiscriminately. This review's approach to UX (which focuses on subjective data) as an extension of usability (which also evaluates objective data) made it possible to consistently categorize the tools used to measure these parameters.

The objective measurement of usability, efficiency and effectiveness data led to the conclusion that older adults with cognitive impairment can complete a considerable number of tasks, even though they require more time and help in technological cognitive interventions. Likewise, questionnaires and scales were the most widely used tools to measure the subjective data of satisfaction and its related dimensions, the results showing that they regarded it as a positive experience, despite certain difficulties involving elements of the interface or the devices.

Measuring usability and UX in cognitive intervention technologies for older adults with MCI or dementia provides an integrated view that can contribute toward their proper development, since it is not only important to know if the technology is easy to use to achieve the therapeutic goals, but also whether the user perceives it as pleasant. To take these measurements it is essential to involve the target population: older people with cognitive impairment, who can give valuable feedback, despite their difficulties.

For future work, more research is needed to include this population group in usability and UX studies, as well as standardized tools and consensus on the relationship of these terms, which are crucial to guarantee the future effectiveness and success of technological interventions in the field of CS, CT, and CR. In this sense, it would also be interesting to compare the usability and UX results with effectiveness results. Finally, it is also necessary that studies give more information about the software and hardware features in order to have a more enriching view of usability and UX measures.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

L-CS and MF-M conceived the presented systematic review. LC-S, EI, and AD-B performed the data collection and were supervised by JT-G. LC-S drafted the manuscript with feedback of JT-G and IT-D. MP-B and EP-V provided the further critical feedback. MF-M, JT-G, and LC-S revised the last version of the manuscript. All the authors contributed to the manuscript and approved the submitted version.

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Framework for the Classification of Emotions in People With Visual Disabilities Through Brain Signals

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Nowadays, the recognition of emotions in people with sensory disabilities still represents a challenge due to the difficulty of generalizing and modeling the set of brain signals. In recent years, the technology that has been used to study a person's behavior and emotions based on brain signals is the brain–computer interface (BCI). Although previous works have already proposed the classification of emotions in people with sensory disabilities using machine learning techniques, a model of recognition of emotions in people with visual disabilities has not yet been evaluated. Consequently, in this work, the authors present a twofold framework focused on people with visual disabilities. Firstly, auditory stimuli have been used, and a component of acquisition and extraction of brain signals has been defined. Secondly, analysis techniques for the modeling of emotions have been developed, and machine learning models for the classification of emotions have been defined. Based on the results, the algorithm with the best performance in the validation is random forest (RF), with an accuracy of 85 and 88% in the classification for negative and positive emotions, respectively. According to the results, the framework is able to classify positive and negative emotions, but the experimentation performed also shows that the framework performance depends on the number of features in the dataset and the quality of the Electroencephalogram (EEG) signals is a determining factor.

Keywords: emotion classification algorithm, brain–computer interface, machine learning, visual disabilities, affective computing

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INTRODUCTION

The recognition of human emotions was proposed long ago as a way for the development of current computing, with the aim of designing machines that recognize emotions to improve the interaction between humans and computer systems (Picard, 2003). Besides, it represents a challenge since this could mean that computers respond in real time and in a personalized way to the affective or emotional states of a person (Kumar et al., 2016).

Emotions in a person play an important role in non-verbal communication and are essential for understanding human behavior (Liu et al., 2011). Moreover, some research related to analyzing emotional behavior and automatic recognition of emotions using machine learning techniques have generated high expectations. First, emotions have been studied from behavioral signals, named emotional signals (Ekman and Friesen, 1969) and from the analysis of body posture and movement

(Ekman et al., 1991). On the other hand, various approaches and ways have been tested for the classification of emotions in people under different circumstances, like music (Vamvakousis and Ramirez, 2015), autism (El Kaliouby et al., 2006), the recognition of emotions using electrodermal activity sensors (Al Machot et al., 2019), or e-Healthcare applications (Ali et al., 2016).

Although the human emotional experience has a vital role in our lives, scientific knowledge about human emotions is still minimal (Soleymani et al., 2012). Consequently, emotions classification is a problem considered challenging since emotional states do not have precisely defined limits, and often, the perception between users differs. Therefore, research on the recognition and emotions classification is of importance in real-life applications (Anagnostopoulos et al., 2012; Zhang et al., 2020).

Through the recognition of speech and the processing of facial gestures, it has been possible to classify a person's emotions, and commonly these approaches have given good results. However, it has been detected that people can manipulate these methods. Therefore, to achieve objectivity in the technique, the source of the emotion must not be easily manipulated (Ackermann et al., 2016). Consequently, a new reliable and objective approach is required to avoid these cases.

In recent years, through the brain–computer interface (BCI), the behavior and emotions of a person have been studied (Nijboer et al., 2008; Chaudhary et al., 2016; Pattnaik and Sarraf, 2018). These studies indicate that BCI technology offers an additional benefit as it is a method that cannot easily be manipulated by the person. Therefore, it is possible to obtain valid and accurate results by analyzing brain signals obtained using a BCI (Patil and Behele, 2018).

People with any sensory disability often do not have access to current technology. For this reason, it is necessary to develop new ways of communication and interaction between the human and the computer to give support to these people considering their disability and the degree it affects them. Therefore, the effective adaptation of a brain–machine interface to the recognition of the user's emotional state can be beneficial to society (Picard, 2010).

Commonly, people with total or partial visual disability have difficulties completing their daily tasks (Leung et al., 2020). This is associated with dependence when carrying out daily activities, even in some cases with decreased physical activity (Rubin et al., 2001). Frequently, people with visual disabilities need to use support tools that allow them to interact with the environment around them, so they must alter their behavior according to their needs. Therefore, changing how people with visual disabilities communicate, intervene, and express themselves in their environment through the recognition of their emotions would improve their quality of life. Besides, this would positively impact their daily lives since it would put them on an equal footing in current technology access and use.

In various studies related to the classification of emotions through biological signals such as brain signals, music has been used as a source to induce human emotions. Besides, music is considered capable of evoking a series of emotions and affect people's mood (Koelsch, 2010). However, music's influence on emotions is often unknown due to individual preference and appreciation for music (Naser and Saha, 2021). The action of listening to music and psychological processes such as perception, attention, learning, and memory are involved. Therefore, music has been considered a useful tool to help study the human brain's functions (Koelsch, 2012). Additionally, music can provoke strong emotional responses in listeners (Nineuil et al., 2020). Moreover, it has been shown that music is used for understanding human emotions and their underlying brain mechanisms (Banerjee et al., 2016). For these reasons, music is considered adequate to induce and study various human emotions, including positive and negative (Peretz et al., 1998). Taking into account various psychological aspects and the effects of music on emotions, music has been studied in the regulation of moods in people (Van Der Zwaag et al., 2013), the effects of music on memory (Irish et al., 2006), recognition of brain patterns while listening to music (Sakharov et al., 2005), etc.

Previously, this paper's authors analyzed the research that proposes the classification of emotions in people with visual disabilities (López-Hernández et al., 2019). The results showed that new approaches that specifically consider people with visual disabilities and the study of their emotions are still required. Based on these results, the design of a system that classifies the affective states of people with visual disabilities was proposed by identifying a person's emotional responses when they are auditory stimulated.

For the reasons mentioned above, this research's main motivation is to provide an integrated framework for acquiring brain signals through a BCI, characterizing brain activity models, and defining machine learning models for the automatic classification of emotions, focused on people with visual disabilities.

This study expects to obtain new evidence on the application of BCIs, affective computing, and machine learning, oriented toward the development of communication and interaction alternatives between systems and people with visual disabilities.

Likewise, the challenges associated with this research are the analysis and evaluation of emotional behavior as well as the perception of the responses to an auditory stimulus of people with visual disabilities.

RELATED WORK

Next, a review of related works on applying a BCI for the recognition and classification of people's emotions using machine learning algorithms is presented.

An EEG signal-based system for automatic recognition of emotions was proposed to examine different methods of extracting EEG features, channel locations, and frequency bands (Ackermann et al., 2016). Machine learning algorithms such as support vector machines (SVMs), random forests (RFs), and decision trees (DTs) were evaluated with pre-processed data for the analysis of emotions, based on physiological data provided during the training and testing tasks. In their results and experimental findings, the authors report that the RF algorithm behaves better in recognition of emotions from signals coming from the EEG. Likewise, they mention that although it is possible to recognize human emotions from other sources, the most reliable way is through EEG signals due to this approach's objectivity.

Another study proposes the identification of four emotions through the analysis of EEG and the exploration of machine learning algorithms such as Multiclass SVM for the emotion classification task (Patil and Behele, 2018). The results indicate that the model obtains a 91.96% precision in the classification of emotions. Likewise, it is mentioned that an EEG is a more reliable data source for the study of emotions since the subject cannot alter the data.

An approach to the acquisition and processing of the EEG signals obtained using the Emotiv Epoc+ device and the evaluation of a neural network model for the classification of emotional states of people without disabilities reports results of 85.94, 79.69, and 78.13% for valence, excitement, and dominance, respectively (Sánchez-Reolid et al., 2018).

A model for identifying human emotions using EEG signals and Multi-Feature Input Deep Forest Model has been used as an alternative to classifying five emotions, neutral, angry, sad, happy, and pleasant (Fang et al., 2021). In this study, EEG signals from a public dataset for emotion analysis (DEAP) are used. Data processing involves dividing the EGG signals into several frequency bands, processing the power spectral density, the differential entropy of each frequency band, and the original signal as features of the model. Results show that the MFDF model achieves 19.53% more precision with the compared algorithms (RF, SVM, and KNN).

The detection of emotions from EEG signals is also studied by Ramirez and Vamvakousis (2012). The paper describes an automatic approach to emotion detection based on brain activity using the Emotiv Epoc+ headset. In this study, a group of men and women were stimulated auditorily with 12 sounds from the IADS database. During the extraction of features, alpha waves (8–12 Hz) and beta waves (12–30 Hz) were considered, using a bandpass filter and the Fourier analysis of frequency. Linear Declining Analysis (LDA) and SVM algorithms were evaluated for the two-class classification task. Finally, the results indicated that the best classification results for excitation and valence were 83.35 and 86.33%.

A new normalization method of features named stratified normalization is studied to classify emotions from EEG signals (Fdez et al., 2021). In this research, the SEED dataset is used, and the data on the effects of three independent variables (labeling method, normalization method, and feature extraction method) are recorded. This method proposes an alternative for the normalization of features to improve the precision of the recognition of emotions between people. The results indicate 91.6% in the classification of two categories (positive and negative) and 79.6% in the classification of three categories (positive, negative, and neutral).

Other research shows the analysis and evaluation of machine learning, SVM, and K-nearest neighbors (KNN) methods to classify a person's emotions while observing a visual stimulus (Mehmood and Lee, 2015). In this research, five people (without disabilities) participated in the experiment, and the EEG data were recorded through the Emotiv Epoc+ headset. The processing of the EEG signals was through the EEGLAB toolbox applying the Independent Component Analysis (ICA) technique. The best result of the application of the automatic learning methods for the classification of emotions was 61% accuracy for KNN, as opposed to SVM, which obtained 38.9% accuracy.

K-nearest neighbors algorithm and its functioning to classify emotions are described by Kaundanya et al. (2015). This proposal is a method for EEG signal acquisition tasks, pre-processing, feature extraction, and emotion classification. Several subjects were stimulated for the emotions of sadness–happiness, and the data acquisition was performed with the ADInstruments device. The recorded EEG signals were processed by applying a bandpass filter (3–35 Hz) to remove the signals' noise. The results indicated that the KNN algorithm is viable for the classification task.

Decision tree classifiers for EEG signals have been used in different research works. A fast and accurate DT structure-based classification method is used for classifying EEG data with computer cursor up/down/right/left movement images (Aydemir and Kayikcioglu, 2014). The detect epileptic seizure in EEG signals uses a hybrid system based on DT classifier and fast Fourier transform (FFT) (Polat and Güneş, 2007). DT and a BCI have also been used to assist patients who are nearly or entirely "locked-in," i.e., cognitively intact but unable to move or communicate (Kennedy and Adams, 2003).

In summary, several approaches have been proposed to classify emotions, from voice recognition or facial expressions to BCI, to extract brain signals (EEG). Although these methods have been tested in different settings and their results are correct, the literature mentions that the most reliable method is the use of brain signals (EEG) due to its objectivity in reading the data. Additionally, the classification of emotions for the development of new systems that respond to the emotional states of a person has been analyzed in different research works. In addition, machine learning models, previously labeled datasets and different scenarios have been explored, and the results demonstrate the viability of the proposals. However, the authors consider that new scenarios must be evaluated, considering the classification of affective states in people with disabilities.

The remainder of this article is organized as follows: In section "Related Work," the related works are discussed, and section "Materials and Methods" presents the methods and materials used in this research. In section "Proposed Framework," the proposed framework is described, highlighting its principal features. Section "Results" shows the results obtained from the experimentation after the implementation of the proposed model. Possible causes of the results are discussed in section "Discussion." Finally, section "Conclusion" presents the conclusions and future works related to the implementation of systems capable of recognizing and responding in real time to the emotions of a person with disabilities.

MATERIALS AND METHODS

This section describes the tools and methods used during the experimental phase of this research.

Headset Emotiv Epoc+

Emotiv Epoc+ is a high-resolution portable EEG device, which is used to record brain signals. This device has 14 electrodes for reading brain signals and two CML/DRL reference electrodes. It is designed to operate quickly during the tasks of acquisition and processing of brain signals (Emotiv Epoc, 2019). The configuration of the device Emotiv Epoc+, for the acquisition of the EEG signals, is supported by the sensors: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4. **Figure 1** shows the electrode locations for Emotiv Epoc+.

Participants

The present study was developed in collaboration with the ONCE social group from Madrid, Spain. This group involves the National Organization of the Spanish Blind (ONCE) and other related entities. ONCE supports people with needs derived from blindness or a severe visual impairment by providing of specialized Social Services.

This study involved seven participants, five men and two women, from whom the ONCE social group invited four people to participate in the study. The age of the participants is between 40 and 55 years old. Previously, all participants reported having normal hearing, and before the experiment, they gave their consent in a confidentiality document to process personal data and participate in the study. Likewise, they were informed of the procedure and of their right to suspend the study. Considering the participants, the experiment was carried out following the principles of the Declaration of Helsinki.

Stimuli

For the experimentation of this study, two classical music audios with different musical styles were selected, the first being joy–happiness and the second being fear–suspense. From these, 40 stimuli (audios) with 5 s each have been generated and selected. The purpose of using stimuli of different musical styles is to induce different affective states (emotions) in the participants.

PROPOSED FRAMEWORK

The related work has exposed different research works for the identification of a person's emotional responses when they are auditory stimulated. As it has been stated, despite the number of works in this area, future research is needed for developing high-performance BCI systems to allow people with needs to perform activities of daily living (Yuan and He, 2014).

Furthermore, due to the advancement of computational tools, the task of recognition and classification of human emotions based on machine learning models has generated interest (Asghar et al., 2019). For this reason, in this research, different machine learning models are evaluated looking for the one with the best performance in this problem.

This manuscript presents a new framework focused on people with visual disabilities, taking into account those findings. The framework is composed of different components and stages:

(A) Data acquisition: EEG signals data acquisition by a BCI interface and brain activity models characterization.
(B) Pre-processing: Analysis of brain activity models and EEG data signals for feeding the training and test process of the machine learning models.
(C) Machine Learning: Definition and evaluation of different machine learning models.
(D) Classification: Automatic classification of basic emotions (positive or negative).

The different components and stages of the framework are shown in **Figure 2** and detailed in the following subsections.

Data Acquisition

The first step of the proposed framework is data acquisition and collection. During the presentation of a stimulus, the Emotiv Epoc+ device is used to read and record real-time people's brain activity. These sensors are placed on the participants as shown in **Figure 1**, following the guidelines of the international 10–20 standard for electrode positioning (Sharbrough et al., 1991).

Experiments

Before starting the experimentation stage, the participant is informed of the data recording procedure and the process to evaluate each stimulus. Subsequently, the participant performs a test with the Emotiv Epoc+ headband to ensure the correct reading of the data; in addition, volume tests with the audio device were carried out to validate that the participant is comfortable.

During each test, the task of inducing different affective states or emotions in the participants was presented using auditory stimulation. Each participant listens to 40 previously selected auditory stimuli, divided into four groups of 10 stimuli, where each stimulus is presented for 5 s. Between each stimulus, the participant has 3 s to rate the stimulus heard and 5 s of silence to evoke a neutral emotional state in the participant. The experimentation process is divided into four stages that are described below.

Experiment 1

In this test, 10 trials' data are recorded presenting 10 stimuli (in that order): five of Joy–Happiness and five of Fear–Suspense. Likewise, the participant will rate each stimulus as positive (pleasant) or negative (unpleasant) according to their musical preferences.

Experiment 2

During this test, 10 trials are carried out from presenting 10 stimuli (in random order): five of joy–happiness and five of fear–suspense. In this test, the participant rates each stimulus according to their musical preferences, positive (pleasant), or negative (unpleasant), respectively.

Experiment 2

For this test, data from 10 trials are saved by an orderly presentation of five joy–happiness stimuli and five fear–suspense stimuli. Each participant rates each stimulus according to their musical preferences (positive or negative).

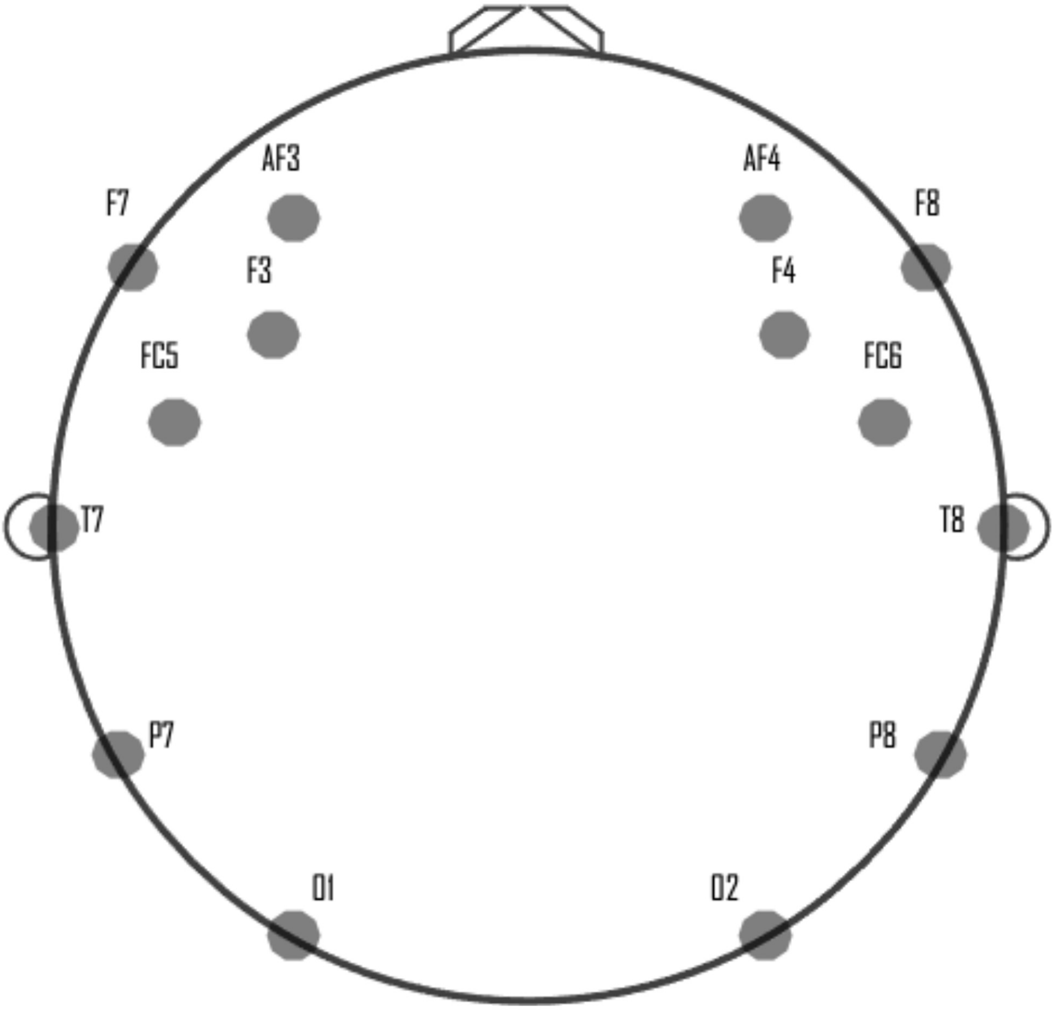

FIGURE 1 | Location of the electrodes in Emotiv Epoc+ headset.

Experiment 4
In this last test, a random order is considered for recording the data of 10 trials using five stimuli of joy–happiness and five of fear–suspense, respectively. Each stimulus is rated positive or negative, depending on each participant.

Finally, the data obtained from the signal's EEG are digitized into a file for each user. The file contains all the information related to the experiment: type of stimulus, the time interval the stimulus was presented, the wave magnitude for each electrode, and the participant's evaluation for each stimulus.

Pre-processing

This component of the framework processes the source data of the EEG signals of each participant obtained in the data acquisition stage. A component of the framework extracts the signal from each sensor, applies FFT, and filters the signal using a filter band pass between 0.5 and 30 Hz. The result of this task is the conversion of the data into the signal frequencies, delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–15 Hz), beta (15–30 Hz), and an average wave magnitude of each electrode, reducing the amount of data generated and therefore improving its understanding.

Machine Learning

The machine learning component of the framework includes eight machine learning classifiers: RF, logistic regression (LR), multilayer perceptron (MLP), KNN, Linear Discriminant Analysis (LDA), Naive Bayes (NB), DT, and neural networks (NNs) where different experiments are configured, altering the main parameter for each algorithm.

The KNN method is a popular classification method in data mining and statistics because of its simple implementation and significant classification performance. KNN classifier is a type of instance-based learning or non-generalizing learning: it does not attempt to construct a general internal model but simply stores instances of the training data. Classification is computed from a simple majority vote of the nearest neighbors of each point: a query point is assigned to the data class, which has the most representatives within the nearest

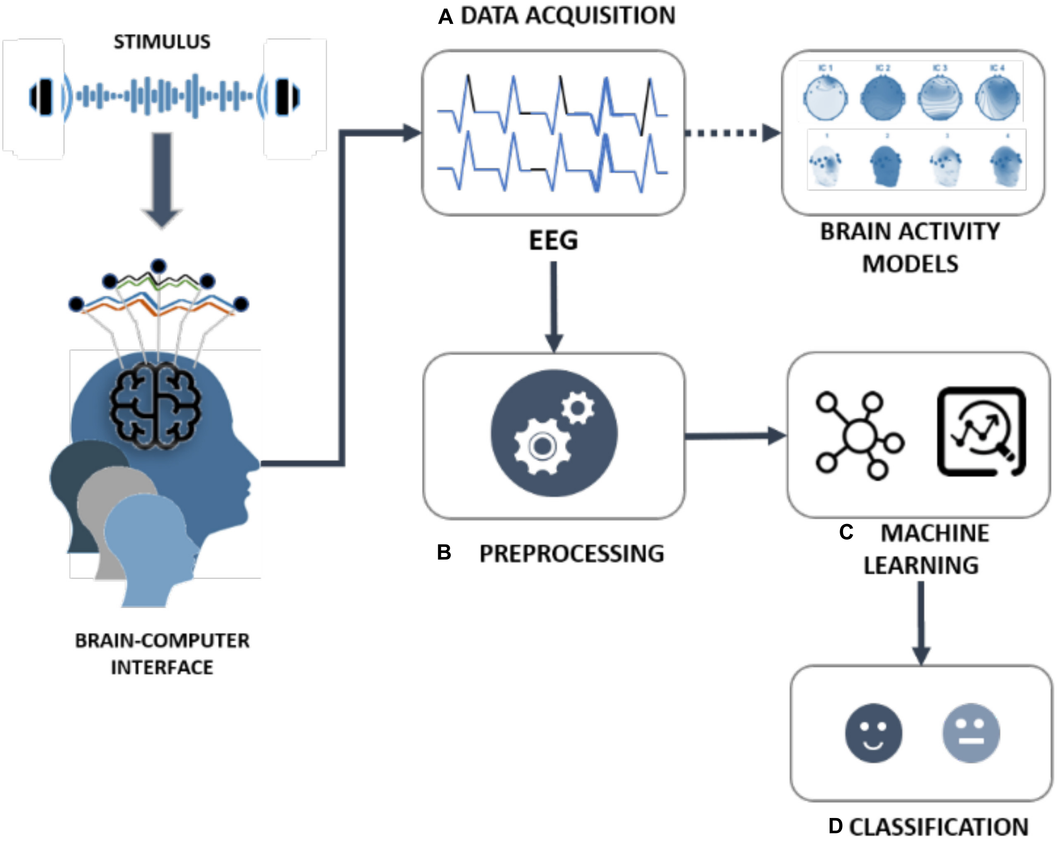

FIGURE 2 | Framework for the classification of emotions in people with visual disability.

neighbors of the point. However, it is impractical for traditional KNN methods to assign a fixed *k* value (even though set by experts) to all test samples (Zhang et al., 2017, 2018). Considering this, for the KNN classifier, the number of neighbors (n_neighbors) parameter is modified in the experimentation (moving from 1 to 20).

Random forest classifier is an ensemble classifier that produces multiple DTs, using a randomly selected subset of training samples and variables. Over the last two decades, the use of the RF classifier has received increasing attention due to the excellent classification results obtained and the speed of processing (Belgiu and Drăgu, 2016). RF algorithm is a meta estimator that fits a number of DT classifiers on various subsamples of the dataset and uses averaging to improve the predictive accuracy and control over-fitting. The subsample size is always the same as the original input sample size, but the samples are drawn with replacement in this case. The number of trees (NT) in the RF algorithm for supervised learning has to be set by the user. It is unclear whether the NT parameter should be set to the largest computationally manageable value or whether a smaller NT parameter may be enough or, in some cases, even better (Cutler et al., 2012; Probst and Boulesteix, 2018). RF is an algorithm that has been shown to have excellent performance for classification tasks. It uses a set of trees (n_estimators), which are based on the technique of sampling the data (Vaid et al., 2015). Taking this into account, for the RF classifier, the NT parameter (n_estimators) is modified in the experimentation (moving from 1 to 25).

Decision trees are a non-parametric supervised learning method used for classification and regression. The goal is to create a model that predicts the value of a target variable by learning simple decision rules inferred from the data features. Many systems have been developed for constructing DTs from collections of examples (Quinlan, 1987). The study for the number of features to consider when looking for the best split has been under research for many years (Kotsiantis, 2013; Fratello and Tagliaferri, 2018). Taking this into account, for the DT classifier, the number of features (max_features) for the best split is modified in the experimentation (moving from 1 to 14).

Linear Declining Analysis algorithm is a classifier that works with a linear decision limit. However, it is also considered a technique for feature extraction and dimensionality reduction. LDA projects the data in a vector space with a covariance matrix and an average vector of lower dimensions. Finally, the samples are classified according to the closest average vector (Torkkola, 2001; Ye et al., 2005). Furthermore, LDA has been used to reduce the number of dimensions in datasets, while trying to retain as much information as possible.

Logistic regression is a statistical method that examines the relationship between a dependent variable (target) and a set of independent variables (input), which is applied in regression problems, binary classification, and multiclassification. The LR algorithm technique is based on finding a prediction function and a loss function and identifying the parameters that minimize the loss function. In LR classification problems, you first create a cost function and then apply an iterative optimization process to identify the optimal model parameters (Tsangaratos and Ilia, 2016; Fan et al., 2020).

Naive Bayes classifier is a probabilistic algorithm known for being simple and efficient in classification tasks. From a set of training data, it estimates a joint probability between the features (X) and the targets (Y) (Tsangaratos and Ilia, 2016). NB learns the parameters separately for each attribute, which simplifies learning, even in large datasets (Mccallum and Nigam, 1998).

Multilayer perceptron is a type of NN frequently used in pattern recognition problems. Due to its ease of implementation and adaptability to small datasets (Subasi, 2007). The MLP implementation consists of three sequential layers: input (s), hidden (s), and output (s). The hidden layer processes and serves as an intermediary between the input and the output layer (Orhan et al., 2011).

A NN is a model that has been studied in supervised learning approaches. These models are composed of a large number of interconnected neurons, on which parallel calculations are performed to process data and obtain certain knowledge. The learning of a NN is based on rules that simulate biological learning mechanisms. For classification tasks, NN models are important for their ability to adapt and fit the data (Subasi, 2007; Naraei et al., 2017).

Taking this into account, **Table 1** shows the configuration of each algorithm and the parameters that have been modified during experimentation.

Classification

At this stage and taking into account the main insights obtained from the related work, machine learning classifiers are trained, evaluated, and validated through cross-validation and different precision metrics. **Figure 3** describes the workflow adopted to validate the results of the classification models using cross-validation and to obtain a comparison of the best results in the model's evaluation process.

All the data recorded from the trials that have been collected during the experimentation stage have been included in two different approaches, looking for the machine learning model with the best fit for the recognition and classification of emotions. The evaluations of users include negative samples (stimuli that the user qualified as unpleasant), neutral samples (periods when the user did not hear any stimuli), and positive samples (stimuli rated as pleasant by the user). Approach A includes negative (unpleasant) and neutral cases. Instead, approach B contains neutral and positive cases. The purpose of generating these approaches is to identify and recognize the difference between cases with different emotional state using machine learning models.

The percentage of samples for training and testing, the dimensionality of the feature vector, and the number of classes to evaluate the machine learning models' performance are presented in **Table 2**. The features are extracted from each

TABLE 1 | Classifiers configuration.

Algorithm	*Parameter*	*Value*	*Comment*
K-nearest neighbors (KNN)	Algorithm	"Auto"	KNN will attempt to decide the most appropriate algorithm based on the values passed to fit method: Ball tree, K-d tree or brute-force search
	Leaf_size	10 to 30	Leaf size passed to BallTree or KDTree algorithms
	Metric		"Minkowski"
	n_neighbors	From 1 to 20	Number of neighbors to use by default for queries
	P	2	Power parameter for the Minkowski metric. When $p = 2$, metric is Euclidean_distance
Random forest (RF)	Max_depth	None	The maximum depth of the tree
	Max_features	"Auto"	The number of features to consider when looking for the best split
	Max_leaf_nodes	Unlimited	Grow trees in best-first fashion. Best nodes are defined as relative reduction in impurity
	Min_impurity_split	$1e^{-7}$	Threshold for early stopping in tree growth.
	n_estimators	From 1 to 1000	The number of trees in the forest
Decision tree (DT)	Max_features	From 1 to 56	The number of features to consider when looking for the best split
	Max_depth	None	The maximum depth of the tree. If none, then nodes are expanded until all leaves are pure or until all leaves contain less than min_samples_split samples
	Min_samples_split	From 2 to 5	The minimum number of samples required to split an internal node
	Splitter	best	It defines the strategy to choose the split at each node
Linear Discriminant Analysis (LDA)	Solver	Svd, lsqr, and eigen	Solver that will use the algorithm
	Tol	0.0001, 0.001, and 0.01	Threshold for Solver Range Estimation (SVD)
	n_components	None	Number of components, for dimensionality reduction
	Store_covariance	False	Allows to calculate the class covariance matrix

(Continued)

TABLE 1 | Continued

Algorithm	*Parameter*	*Value*	*Comment*
Logistic regression (LR)	Max_iter	From 100 to 2,000	Maximum number of iterations taken for the solvers to converge
	Solver	Liblinear, lbfgs	Algorithm to use in the optimization problem.
	Multi_class	Ovr, auto	"ovr," for a binary problem
	Tol	1e-4, 1e-3, and 1e-2	Tolerance for stopping criteria
	Penalty	L1 and L2	Used to specify the norm used in the penalization
Naive Bayes (NB)	Priors		Prior probabilities of the classes
	Var_smoothing	1e-9, 1e-7, and 1e-5	Portion of the largest variance of all features that is added to variances for calculation stability
Multilayer perceptron (MLP)	Hidden_layer_sizes	From 28 to 56	The *i*th element represents the number of neurons in the ith hidden layer
	Max_iter	5,000	Maximum number of iterations
	Early_stopping	True	Whether to use early stopping to terminate training when validation score is not improving
	Activation	Relu	Activation function for the hidden layer
	Alpha	0.0001 and 0.001	L2 penalty (regularization term) parameter
Neural network (NN)	Input_dim	From 28 to 56	Number of neurons in the input layer
	Kernel_initializer	Uniform	Initializers define the way to set the initial random weights of layers
	Activation	Relu and tanh	Activation function for the hidden layer
	Loss	Binary_crossentropy	The purpose of loss functions is to compute the quantity that a model should seek to minimize during training
	Optimizer	Adam	Adam optimization is a stochastic gradient descent method that is based on adaptive estimation of first-order and second-order moments

sensor's EEG signal spectrum as a potential feature to feed the machine learning model.

The number of features of each dataset depends on the type of waves included. Approaches A1 and B1 use 56 features for the binary classification of "unpleasant – neutral" and "neutral – pleasant," respectively, extracted from 14 sensors (56 = 14 * 4 {delta, theta, alpha, and beta}). Instead, approaches A2 and B2 employ 28 features for binary classification of "unpleasant – neutral" and "neutral – pleasant," respectively, obtained from 14 sensors (28 = 14 * 2 {alpha and beta}). In A2 and B2 approaches, it has been chosen to evaluate the alpha and beta frequencies since it is known from the literature that these frequencies reflect active mental states. Therefore, it is proposed to evaluate the importance of this type of frequencies in emotion classification tasks.

During classification tasks, first, the precision of each machine learning algorithm is validated using cross-validation (10 folds). Subsequently, each algorithm is evaluated by training a new model and with a set of samples reserved for its validation. The percentages of samples assigned in each step of the process have been described in **Table 2**. The results of the accuracy, precision, recall, and F1 score metrics will indicate the ability of the model to generalize new cases. Additionally, it is essential to validate that the model does not present a classification bias toward one of the problem classes.

RESULTS

In this section, the results of the proposed framework are presented. First, the percentage of samples evaluated as negative or positive per participant is reported. Later, machine learning algorithms for classifying affective states in people with visual disabilities are compared. Finally, each algorithm's performance is analyzed, and precision analysis of the proposed models is presented.

Pre-processing: Dataset Analysis

First, an analysis of each experiment's responses reveals the percentage of samples that have been evaluated negatively or positively by all participants. **Table 3** reports these results, ID Participant, Stimuli evaluated, % of negative samples, and % of positive samples associated with the evaluation by all participants.

Once the EEG signals have been extracted and the average wave values processed from the 14 electrodes of the Emotiv Epoc+ headband, data analysis for inspecting, cleaning, and transforming data to highlight useful information has been performed. For visualizing this process, two boxplot diagrams have been defined. The usefulness of the boxplot diagram is that it offers, by simple visual inspection, a rough idea of the central tendency (through the median), dispersion (through the interquartile) of the symmetry of the distribution (through the symmetry of the graph), and possible outliers in each classifier. The rectangular part of the plot extends from the lower quartile to the upper quartile, covering the center half of each sample. The center lines within each box show the location of the sample medians. The whiskers extend from the box to the minimum and maximum values in each sample, except for any outside or far outside points, which will be plotted separately (Gonzalez-Carrasco et al., 2014; Molnar, 2019).

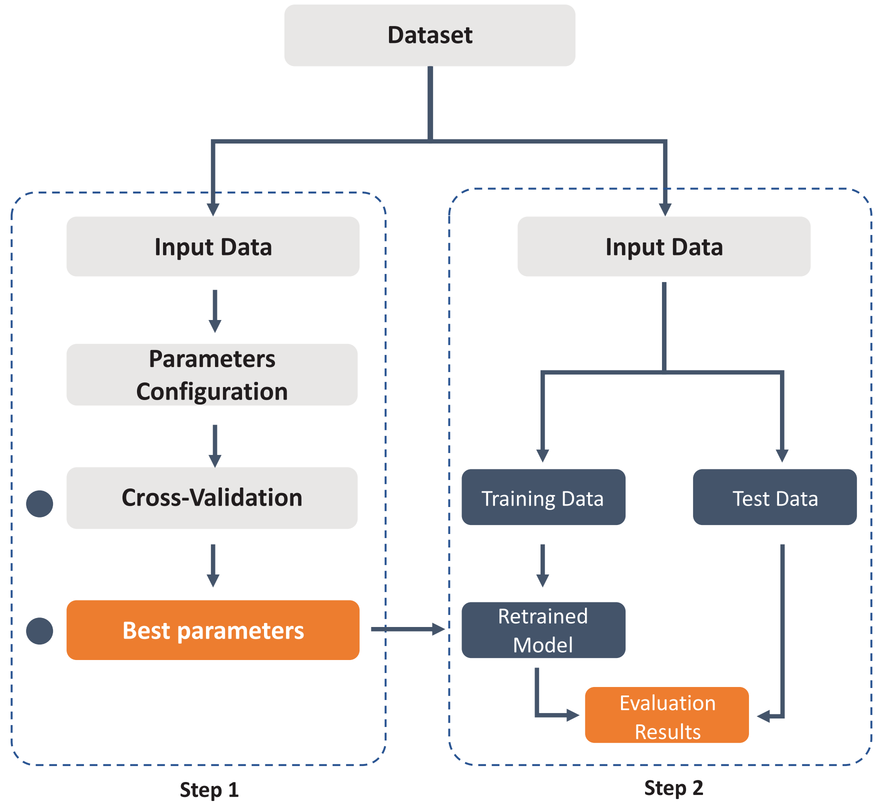

FIGURE 3 | Workflow for cross-validation in model training and evaluation.

TABLE 2 | Dataset specification.

Dataset (Approach)	*Number of samples*			*Number of features (Features = sensors * waves)*	*Class*
	Cross-validation	*Training*	*Test*		
A1	100%	85%	15%	56 features = 14 sensors * 4 waves {delta, theta, alpha, and beta}	Unpleasant (-1) Neutral (0)
A2	100%	85%	15%	28 features = 14 sensors * 2 waves {alpha and beta}	Unpleasant (-1) Neutral (0)
B1	100%	85%	15%	56 features = 14 sensors * 4 waves {delta, theta, alpha, and beta}	Neutral (0) Pleasant (1)
B2	100%	85%	15%	28 features = 14 sensors * 2 waves {alpha and beta}	Neutral (0) Pleasant (1)

The detection of these outliers is crucial for understanding possible causes and implications of their presence (Cousineau and Chartier, 2010; Leys et al., 2013). Moreover, the importance of outliers has been studied in different domains and problems (Felt et al., 2017; Iwata et al., 2018; Peiffer and Armytage, 2019).

Figure 4 depicts the variability of the distribution of brain signal values in positive and negative emotions for the 14 electrodes of the BCI. Based on the visual analysis of the dataset, there are some outliers for the electrodes in the distribution of the values (median around 4200 μV). In the same way, the behavior of the signals is quite similar for positive and negative emotions. For this reason, it is essential to mention that the existence of outliers could determine the reaction and behavior of the brain to a given stimulus. Therefore, for the experimentation of this research, these outliers have been taken into account.

Machine Learning

As mentioned above, the goal of the framework is to predict the basic emotions, positive or negative, of the participants.

TABLE 3 | Percentages of samples negatives and positives evaluated by each participant.

ID participant	*Number of Stimuli evaluated*	*Negatives (%)*	*Positives (%)*
1	40	25.0%	75.0%
2	40	50.0%	50.0%
3	40	42.5%	57.5%
4	40	40.0%	60.0%
5	40	50.0%	50.0%
6	40	50.0%	50.0%
7	40	50.0%	50.0%

For this reason, at the machine learning stage, several machine learning algorithms and two approaches were evaluated to obtain the best performance. This section shows the process of evaluation and validation performed to determine the contribution of the research.

Classification

Approach A

Firstly, the models' performance for approaches A1 and A2 with 56 and 28 features, respectively, is presented in **Figure 5**. The configuration to evaluate the performance contemplates cross-validation with 10 folds for all models. Subsequently, the comparison of the performance of each model for approaches A1 and A2 is presented in **Table 4**. The first part describes each model's results with the precision achieved during the cross-validation, the average, standard deviation, and the precision minimum and maximum. Next, the evaluation of the models is detailed; this includes the accuracy result for training and test tasks and the metrics obtained in precision, recall, and F1 score.

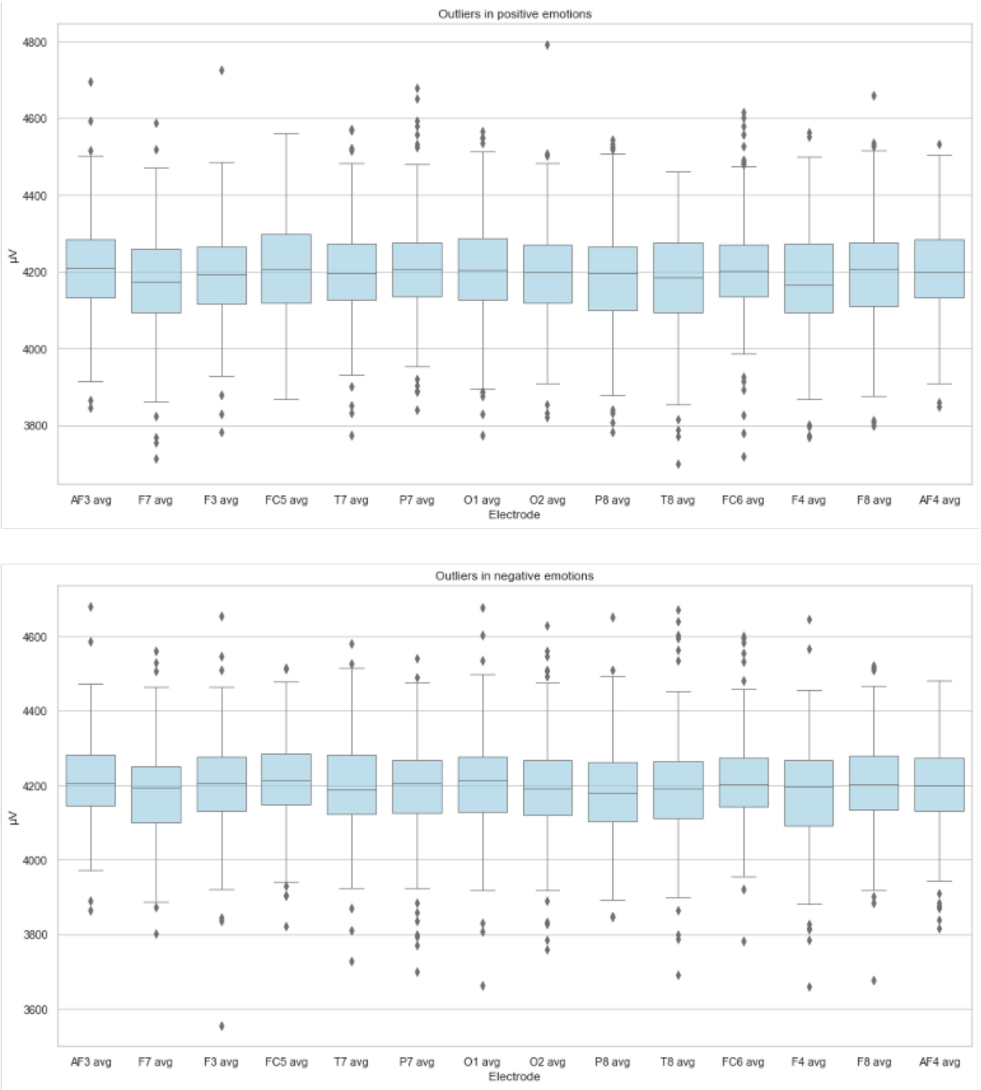

FIGURE 4 | Variability of data and typical values in positive and negative emotions.

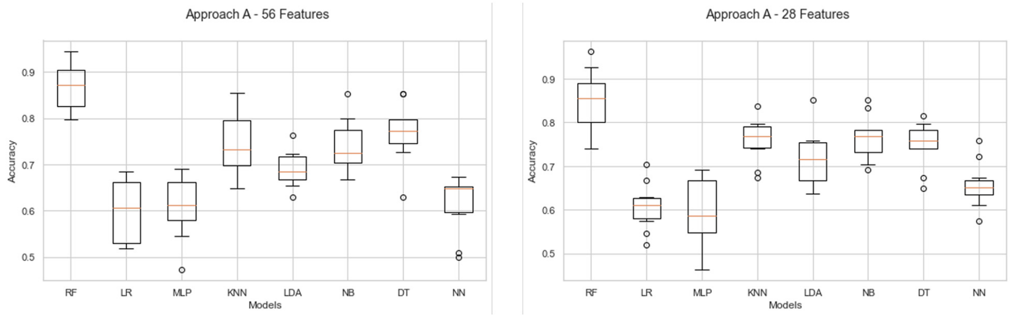

FIGURE 5 | Behavior of classifiers in approach A1 and A2 with 56 and 28 features.

TABLE 4 | Performance of classifiers for training and validation tasks in approach A.

			Approach A															
			A1 (56 features)								**A2 (28 features)**							
Dataset			***Cross-validation (10 folds)***															
Cross-validation (100%)	**Run**		**RF**	**LR**	**MLP**	**KNN**	**LDA**	**NB**	**DT**	**NN**	**RF**	**LR**	**MLP**	**KNN**	**LDA**	**NB**	**DT**	**NN**
	1		0.87	0.56	0.69	0.80	0.76	0.80	0.78	0.67	0.82	0.60	0.60	0.84	0.73	0.69	0.78	0.67
	2		0.89	0.58	0.47	0.69	0.65	0.76	0.73	0.51	0.87	0.62	0.69	0.67	0.64	0.78	0.67	0.65
	3		0.82	0.67	0.55	0.85	0.67	0.75	0.76	0.65	0.84	0.55	0.55	0.75	0.67	0.78	0.78	0.65
	4		0.94	0.69	0.59	0.72	0.63	0.85	0.74	0.50	0.93	0.61	0.61	0.78	0.74	0.83	0.65	0.76
	5		0.80	0.63	0.57	0.65	0.67	0.67	0.80	0.65	0.89	0.63	0.56	0.80	0.70	0.78	0.74	0.65
	6		0.93	0.69	0.67	0.83	0.72	0.70	0.85	0.65	0.74	0.52	0.69	0.69	0.76	0.70	0.76	0.72
	7		0.91	0.52	0.61	0.72	0.69	0.78	0.63	0.67	0.80	0.70	0.46	0.74	0.85	0.72	0.81	0.65
	8		0.87	0.52	0.61	0.78	0.72	0.70	0.85	0.65	0.96	0.61	0.52	0.80	0.67	0.76	0.74	0.63
	9		0.80	0.52	0.65	0.74	0.69	0.70	0.76	0.61	0.89	0.67	0.69	0.76	0.76	0.85	0.80	0.61
	10		0.85	0.63	0.67	0.69	0.70	0.70	0.80	0.59	0.76	0.57	0.57	0.78	0.65	0.76	0.76	0.57
	Avg		***0.87***	***0.60***	***0.61***	***0.75***	***0.69***	***0.74***	***0.77***	***0.62***	***0.85***	***0.61***	***0.59***	***0.76***	***0.72***	***0.77***	***0.75***	***0.66***
	Std		***0.05***	***0.07***	***0.07***	***0.07***	***0.04***	***0.06***	***0.06***	***0.06***	***0.07***	***0.05***	***0.08***	***0.05***	***0.07***	***0.05***	***0.05***	***0.05***
	Min		***0.80***	***0.52***	***0.47***	***0.65***	***0.63***	***0.67***	***0.63***	***0.50***	***0.74***	***0.52***	***0.46***	***0.67***	***0.64***	***0.69***	***0.65***	***0.57***
	Max		***0.94***	***0.69***	***0.69***	***0.85***	***0.76***	***0.85***	***0.85***	***0.67***	***0.96***	***0.70***	***0.69***	***0.84***	***0.85***	***0.85***	***0.81***	***0.76***
			Models evaluation															
Training 85%	**Acc**		**1.0**	**0.70**	**0.61**	**0.88**	**0.77**	**0.74**	**1.0**	**0.75**	**1.0**	**0.68**	**0.65**	**0.87**	**0.78**	**0.77**	**1.0**	**0.69**
Validation 15%	**Acc**		**0.83**	**0.56**	**0.55**	**0.70**	**0.72**	**0.70**	**0.72**	**0.63**	**0.85**	**0.51**	**0.61**	**0.67**	**0.78**	**0.77**	**0.74**	**0.60**
	P	−1	0.63	0.21	0.36	0.45	0.48	0.45	0.48	0.38	0.77	0.30	0.29	0.54	0.79	0.71	0.62	0.36
		0	0.94	0.71	0.90	0.86	0.84	0.84	0.84	0.80	0.90	0.62	0.64	0.73	0.78	0.79	0.83	0.65
	R	−1	0.86	0.23	0.86	0.68	0.59	0.64	0.59	0.55	0.83	0.28	0.07	0.48	0.52	0.59	0.72	0.17
		0	0.82	0.68	0.43	0.70	0.77	0.72	0.77	0.67	0.87	0.64	0.90	0.77	0.92	0.87	0.75	0.83
	F1	−1	**0.73**	**0.22**	**0.51**	**0.55**	**0.53**	**0.53**	**0.53**	**0.44**	**0.80**	**0.29**	**0.11**	**0.51**	**0.62**	**0.64**	**0.67**	**0.23**
		0	**0.87**	**0.69**	**0.58**	**0.77**	**0.80**	**0.77**	**0.80**	**0.73**	**0.88**	**0.63**	**0.75**	**0.75**	**0.84**	**0.83**	**0.79**	**0.73**

Acc, accuracy; P, precision; R, recall; and F1, F1 score.
Bold and Italic values represent the highlight relevant values.

In the results for approach A1 with 56 features, it is observed that RF is the model that best adapts to the problem of recognition of Negative and Neutral emotions. RF achieves a mean accuracy of 87%. Moreover, the performance of the KNN, NB, and DT models is very similar, reaching between 74 and 77%. Otherwise, the remaining LR, MLP, LDA, and NN models' average performance is less than 70% mean accuracy. The evaluation of approach A1 with 56 features shows that the best model is RF with an average precision of 87% and a minimum accuracy of 80%, and a maximum of 94%. KNN behavior indicates an average of 75%, besides a minimum and maximum accuracy of 65 and 85%, respectively. On the other hand, NB averages 74% accuracy, with 67% as the minimum level and 85% as the maximum level. Meanwhile, the DT model achieves

TABLE 5 | Performance of classifiers for training and validation tasks in approach B.

		Approach B															
		B1 (56 features)								**B2 (28 features)**							
Dataset		***Cross-validation (10 folds)***															
Cross-validation (100%)	**Run**	**RF**	**LR**	**MLP**	**KNN**	**LDA**	**NB**	**DT**	**NN**	**RF**	**LR**	**MLP**	**KNN**	**LDA**	**NB**	**DT**	**NN**
	c	0.90	0.56	0.44	0.74	0.70	0.62	0.80	0.59	0.89	0.52	0.61	0.74	0.66	0.70	0.70	0.51
	2	0.90	0.57	0.46	0.70	0.72	0.79	0.66	0.62	0.89	0.56	0.54	0.66	0.67	0.74	0.82	0.62
	3	0.82	0.61	0.46	0.84	0.67	0.69	0.77	0.59	0.84	0.54	0.56	0.61	0.66	0.74	0.75	0.46
	4	0.84	0.66	0.48	0.79	0.74	0.64	0.80	0.52	0.92	0.57	0.56	0.75	0.69	0.70	0.70	0.54
	5	0.93	0.61	0.52	0.72	0.56	0.67	0.74	0.62	0.84	0.64	0.46	0.74	0.67	0.64	0.77	0.56
	6	0.85	0.59	0.52	0.74	0.79	0.75	0.79	0.70	0.89	0.46	0.62	0.72	0.67	0.67	0.80	0.54
	7	0.84	0.57	0.59	0.69	0.59	0.75	0.77	0.56	0.90	0.59	0.54	0.79	0.72	0.75	0.77	0.59
	8	0.85	0.57	0.56	0.79	0.57	0.72	0.75	0.51	0.92	0.57	0.62	0.75	0.62	0.69	0.80	0.61
	9	0.80	0.53	0.55	0.77	0.67	0.67	0.82	0.45	0.83	0.48	0.53	0.63	0.67	0.77	0.83	0.58
	10	0.85	0.62	0.58	0.67	0.58	0.67	0.78	0.58	0.85	0.55	0.55	0.70	0.65	0.83	0.73	0.50
	Avg	**0.86**	**0.59**	**0.52**	**0.74**	**0.66**	**0.70**	**0.77**	**0.58**	**0.87**	**0.55**	**0.56**	**0.71**	**0.67**	**0.72**	**0.77**	**0.55**
	Std	**0.04**	**0.03**	**0.05**	**0.05**	**0.08**	**0.05**	**0.05**	**0.07**	**0.03**	**0.05**	**0.05**	**0.06**	**0.03**	**0.05**	**0.05**	**0.05**
	Min	**0.80**	**0.53**	**0.44**	**0.67**	**0.56**	**0.62**	**0.66**	**0.45**	**0.83**	**0.46**	**0.46**	**0.61**	**0.62**	**0.64**	**0.70**	**0.46**
	Max	**0.93**	**0.66**	**0.59**	**0.84**	**0.79**	**0.79**	**0.82**	**0.70**	**0.92**	**0.64**	**0.62**	**0.79**	**0.72**	**0.83**	**0.83**	**0.62**
		Models evaluation															
Training 85%	**Acc**	**1.0**	**0.67**	**0.55**	**0.86**	**0.69**	**0.70**	**1.0**	**0.75**	**1.0**	**0.61**	**0.58**	**0.81**	**0.69**	**0.74**	**1.0**	**0.62**
Test 15%	**Acc**	**0.88**	**0.62**	**0.52**	**0.79**	**0.71**	**0.77**	**0.79**	**0.52**	**0.88**	**0.60**	**0.57**	**0.74**	**0.66**	**0.73**	**0.80**	**0.60**
	P -1	0.91	0.70	0.59	0.80	0.74	0.79	0.82	0.62	0.94	0.64	0.58	0.75	0.68	0.73	0.89	0.60
	0	0.84	0.51	0.35	0.77	0.65	0.74	0.74	0.41	0.81	0.52	0.25	0.72	0.63	0.72	0.72	0.57
	R -1	0.89	0.66	0.70	0.88	0.80	0.86	0.84	0.54	0.85	0.72	0.94	0.83	0.81	0.85	0.76	0.94
	0	0.86	0.56	0.25	0.67	0.56	0.64	0.72	0.50	0.92	0.42	0.03	0.61	0.45	0.55	0.87	0.11
	F1 -1	**0.90**	**0.68**	**0.64**	**0.84**	**0.77**	**0.82**	**0.83**	**0.58**	**0.89**	**0.68**	**0.72**	**0.79**	**0.74**	**0.79**	**0.82**	**0.73**
	0	**0.85**	**0.53**	**0.29**	**0.72**	**0.60**	**0.69**	**0.73**	**0.45**	**0.86**	**0.46**	**0.05**	**0.66**	**0.52**	**0.63**	**0.79**	**0.18**

Acc, accuracy; P, precision; R, recall; and F1, F1 score.
Bold and Italic values represent the highlight relevant values.

an average accuracy of 77%, with a minimum performance of 63% and a maximum of 85%. The average performance of the LR, MLP, LDA, and NN models is less than 70%, with minimal accuracy ranging from 44% up to a maximum accuracy of 76%.

Finally, the results of the validation of each model are shown. These indicate that RF achieves the best result for the classification of new cases; it obtains 83% accuracy. Additionally, the F1 score metric reports 73% for negative cases and 87% for neutral cases.

The performance of the models of approach A2 with 28 features (alpha and beta frequencies) is shown in the right part of **Figure 5**. The results again indicate that RF with 85% mean accuracy is the model with better levels. On the other hand, KNN, LDA, NB, and DT reach a mean accuracy between 70 and 80%. These models' minimum values are between 64 and 69% and maximum values are from 81 to 85%. Finally, for LR, MLP, and NN models, the results indicate the lower performance with values less than 70% mean accuracy.

Likewise, in **Table 4**, the evaluation results of approach A2 with the alpha and beta frequencies are detailed. The results show that RF achieves the best mean result with 85% accuracy, with a minimum of 74% and a maximum of 96%. The results of the KNN model indicate a mean accuracy of 76% and a minimum and maximum of 67 and 84%, respectively. Instead, NB achieves a mean of 77%, a minimum of 69%, and a maximum of 85% accuracy. On the other hand, DT reports a mean of 75% accuracy and 69 and 85% as minimum and maximum, respectively. The LDA model achieves a mean of 72%, with a minimum of 64% and a maximum of 85%. The lowest performance models are LR, MLP, and NN; they show minimums of 46% to 57%, mean between 59 and 66%, and maximums of 69 up to 76% accuracy.

Finally, the models' validation data with approach A2 with 28 features are presented in the lower part of **Table 4**. The data show that RF obtains the best result with 85% accuracy in the classification of new cases. Furthermore, this result is validated with the F1 Score metric, which shows 80% for negative classes and 88% for neutral classes.

Based on the results, it is observed that RF is the model that best adapts to the classification of new cases, considering the two scenarios proposed for approaches A1 and A2. Besides, the data show that RF is capable of classifying similarly for cases that are negative and neutral.

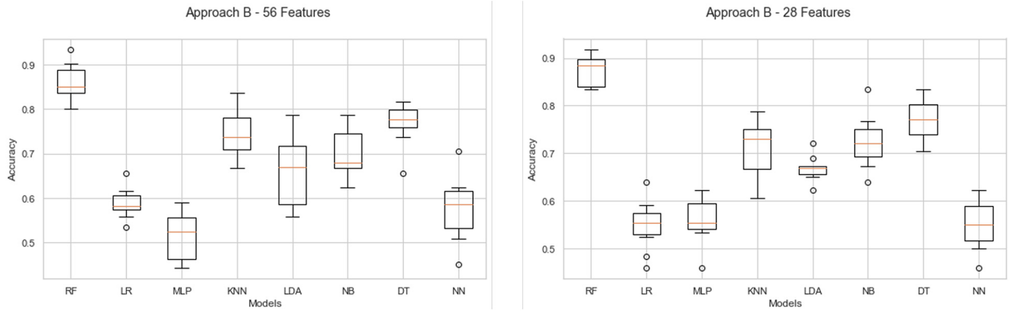

FIGURE 6 | Behavior of classifiers in approach B1 and B2 with 56 and 28 features.

Approach B

Initially, **Figure 6** details the different models' behavior evaluated for approaches B1 and B2 with 56 and 28 features, respectively. Next, the statistics of the behavior of the models on approach B are presented in **Table 5**.

Firstly, in the results of approach B1 with 56 features, it is observed that RF is the best model, achieving a mean precision of 86%. The models that reach similar values of 70% are KNN (74%), NB (70%), and DT (77%). In contrast, LR, MLP, LDA, and NN show a mean performance below 67% accuracy. The data RF shows a mean performance of 86% accuracy, and a minimum and maximum of 80 and 93%, respectively. On the other hand, KNN results indicate a maximum accuracy of 84%, a mean of 74%, and a minimum of 67%. NB model shows a mean accuracy of 70%, and minimum and maximum values of 62 and 79%. DT results indicate a mean accuracy of 77%, as well as a minimum and maximum of 66 and 82%, respectively. Finally, LR, MLP, LDA, and NN models show a mean accuracy of 66%, minimums from 45 to 56%, and maximums from 59 to 79%.

On the other hand, the models' behavior for approach B2 with 28 features is represented in the right part of **Figure 6**. First, it is observed that RF obtains a mean accuracy of 87%. On the other hand, the KNN, NB, and DT models achieve a mean accuracy of more than 70%. Lastly, the LR, MLP, LDA, and NN models report results below 68%.

The performance statistics of approach B2 with 28 features show RF as the best model, which obtains a mean accuracy of 87%; maximum and minimum correspond to 93 and 83%, respectively. The KNN model achieves a mean accuracy of 71%, a minimum value of 65%, and a maximum of 79%. On the other hand, although NB and DT obtain a superior performance of 74% mean accuracy, it is below the RF model. The data minimum and maximum of NB are 64 and 83% accuracy. Instead, DT achieves a minimum value of 70% and a maximum value of 83%. The lowest results belong to LR, MLP, LDA, and NN models; they obtain a mean accuracy of less than 68%. The minimum percentages of these models range from 46 to 62% and the maximums range from 62 to 72%.

Finally, **Table 5** presents the results of the validation of each model. The data indicate that RF is the model with the best result; it obtains 88% in the generalization of new cases, and F1 Score validation metric indicates 89% for neutral classes and 86% for positive classes.

According to the results for approaches B1 and B2, RF obtains the best performance in classifying neutral and positive cases. Besides, the data indicate that RF shows balanced performance in the classification of the proposed cases.

In order to demonstrate the best performance of the evaluated models, the average classification precision achieved in the cross-validation task and the result in the test task of each model are presented in the **Figure 7**. RF stands out for its uniform performance in the four evaluated approaches. Approach A1-56 obtains the best performance with 87% and 83% in the cross-validation and evaluation of the model, respectively. In comparison, approach A2-28 achieves the same result, 85% in both tasks. For approaches B1-56 and B2-28, RF achieves the best results. In B1-56, RF achieves 86% during cross-validation and 88% in model testing. In B2-28, RF obtains 87% and 88% accuracy in cross-validation and model evaluation, respectively.

The importance of the features of the A2 approach (28 features) and the B2 approach (28 features) is shown in **Figure 8** [Tree SHAP technique (Lundberg et al., 2020)]. Feature relevance is calculated as the decrease in node impurity weighted by the probability of reaching that node. The node probability can be calculated by the number of samples that reach the node, divided by the total number of samples. In both cases, the higher the value, the more important the feature. Looking at the feature sensibility analysis, the relevant features are similar for both techniques. Therefore, future work should include significant features as a small set of electrodes (F3, T7, T8, F7, AF4, etc.) for trying to achieve similar performance with less complexity.

To evaluate the relevance of each participant's dataset on the best model obtained, these are evaluated considering the results of the classification stage. Based on the data, RF is the model that is considered appropriate to evaluate all scenarios with the data per user. It is important to note that during data evaluation of each participant, a similar process is followed for the evaluation of each proposed approach, which consists of selecting the negative and neutral or neutral and positive samples, corresponding to approaches A1–A2 and B1–B2, respectively. The results per participant and the performance of the data on each model are presented in **Table 6**. It is identified that the performance of the data of participants 1, 2, 3, and 4 are

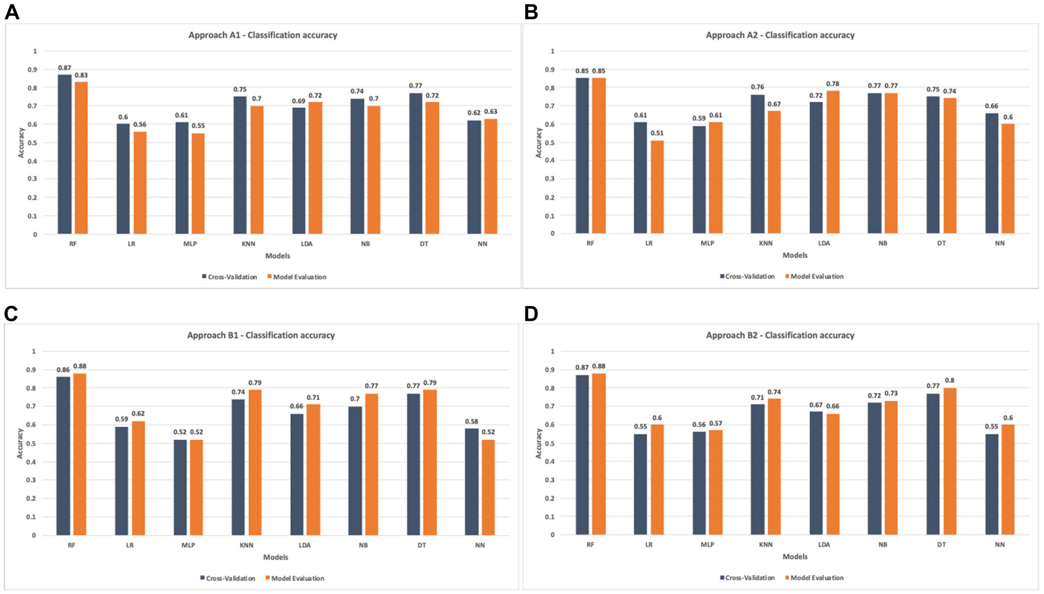

FIGURE 7 | Accuracy comparison in cross-validation and models evaluation. **(A)** Classification accuracy in approach A-1. **(B)** Classification accuracy in approach A-2. **(C)** Classification accuracy in approach B-1. **(D)** Classification accuracy in approach B-2.

similar, and they obtain accuracy results superior to the rest of the participants. Furthermore, it is possible to visualize that subjects 5, 6, and 7 obtain lower percentages of precision than the rest of the participants.

On the other hand, it is observed that the A2 and B2 models that include 28 features with the alpha and beta frequencies obtain slightly higher results compared to the models with 56 features that include the alpha, beta, theta, and delta frequencies.

Finally, **Table 7** includes an accuracy comparison among relevant related research and the approach proposed by the authors (at the bottom of the table).

DISCUSSION

This section discusses the main insights and breakthroughs regarding the results obtained with the framework proposed in this work.

Firstly, this study presents a new scenario for the recognition and classification of emotions in people with visual disabilities, a group of people not previously evaluated. The work defines and implements a framework through a non-invasive BCI (Emotiv Epoc+) with a set of auditory stimuli. From the records obtained, two datasets were formed with the stimuli classified as negatives-neutrals and neutrals-positives. Subsequently, the model's RF, LR, MLP, KNN, LDA, NB, DT, and NN were configured and evaluated to identify the model with the best performance in recognition and classification tasks emotions from EEG data.

The results show that in the individual evaluation of the stimuli, participants 1, 3, and 4 evaluated more than 50% of the stimuli positively. Instead, participants 2, 5, 6, and 7 had a balanced evaluation toward stimuli. On the other hand, it is possible to observe brain signal variability concerning stimuli considered positively and negatively (see **Figure 4**). Although the behavior shows similar values of 4,200 μV, outliers were recorded in the data. That could indicate a different reaction of the participants to the presented stimuli. It is important to note that the entire data have been considered during the machine learning tasks. That is, the outliers have not been omitted. Additionally, the data show that RF is the model with the best performance during classification tasks. In evaluating results, the RF model in the A1-56 and A2-28 approaches to negative emotions achieved a classification accuracy of 83% and 85%, respectively. In turn, with the positive emotions of approaches B1-56 and B2-28, he obtained an accuracy of 88% in both cases. The best results obtained from the RF model in approaches A2-28 and B2-28 with negative and positive emotions and analysis of the features' importance allowed us to recognize that the beta frequencies related to the frontotemporal areas of the brain are important in the decision making of the models. On the other hand, the results show that the algorithms LR, MLP, KNN, LDA, NB, DT, and NN obtain a lower performance compared to RF (see **Figure 7**). Although, in the validation of the models, it is observed that DT and KNN obtain acceptable results for the classification of positive emotions, this result is not consistent with the identification of negative emotions. Therefore, these models tend to classify toward one type of emotions.

The analysis of the participants' brain signals' dataset allows identifying the variability in each subject's data. This characteristic is relevant because it is considered relative to the perception of each subject toward each stimulus. This agrees with what is stated by Anagnostopoulos et al. (2012), which mentions that people's emotional perception commonly differs. The evaluation of the different machine learning models and, according to the results obtained from the RF algorithm, their

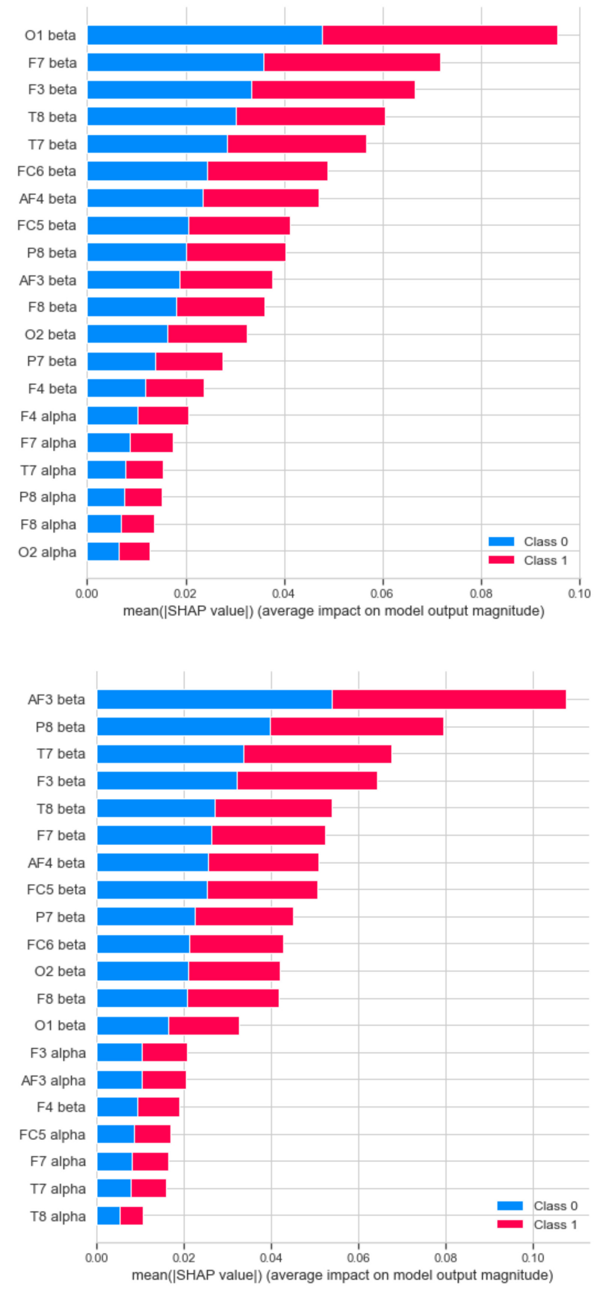

FIGURE 8 | Feature sensibility analysis by SHAP technique. RF best result in approach A2 (upper) and B2 (lower).

performance coincides with the findings reported in Ackermann et al. (2016). It is stated that RF is a robust algorithm in the processing and recognition of patterns from EEG signals. The test's precision indicates that RF is an algorithm useful for classifying emotions using EEG signals. Moreover, in the validation of the RF model, it achieves the best results with an accuracy of 85% for negative emotions and 88% for positive emotions. Therefore, the RF classifier shows that it learns in both classes.

TABLE 6 | Relevance analysis of data by participant.

Approach/Participant	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*
A1 (56 features)	1.00	0.99	0.99	0.99	0.45	0.45	0.45
A2 (28 features)	1.00	1.00	0.98	0.98	0.52	0.5	0.45
B1 (56 features)	1.00	0.99	0.99	0.98	0.45	0.5	0.5
B2 (28 features)	0.99	1.00	0.98	1.00	0.55	0.5	0.57
Avg	**0.99**	**0.99**	**0.98**	**0.98**	**0.49**	**0.48**	**0.49**

TABLE 7 | Comparison of results with other related approaches.

Classifier	Accuracy (%)	Comment
SVM (Patil and Behele, 2018)	91.96	Multiclass SVM is used for the multiple classification of four different emotions
SVM (Ramirez and Vamvakousis, 2012)	86.33	Machine learning techniques work well and are generally able to distinguish patterns to classify a person's emotional states
SVM (Ackermann et al., 2016)	52	SVM is a robust algorithm when it has few EEG signal characteristics, and it also has the ability to classify a person's emotions
MLP (Sánchez-Reolid et al., 2018)	96	It is mentioned that an ANN based on a multilayer perceptron (PMC) is a competent approach to classify emotions
KNN (Mehmood and Lee, 2015)	61	Indicates that the KNN algorithm for the classification of emotions will have better results than SVM
KNN (Kaundanya et al., 2015)	100	It is identified that the smaller the number of neighbors, the results obtained in the identification of emotions are better
RF	85 Negatives 88 Positives	In this research, RF is a useful algorithm for the classification of emotions, from alpha and beta brain signals
DT	74 Negatives 80 Positives	In this research, DT is an algorithm that has a non-uniform behavior for the classification of negative and positive emotions

Considering the types of frequencies, delta, theta, alpha, and beta, different machine learning models have been trained and evaluated to determine their ability to recognize and classify different affective states of a group of people with visual disabilities. The data show that models that consider alpha and beta frequencies perform slightly better than models that consider all frequencies. The results show that models that consider alpha and beta frequencies perform slightly better than models that consider all frequencies. These results coincide with Ramirez and Vamvakousis (2012), who mention that the most important frequencies are alpha waves (8–12 Hz), which predominate in mental states of relaxation, and beta waves (12–30 Hz), which are active during states with intense mental activity. Similarly, the results show that the frontotemporal brain areas associated with the beta frequency show the greatest contribution to the performance of the models (see **Figure 8**). Finally, the model's performance proposed in this research reaches values comparable to other research (Fdez et al., 2021) to classify emotions into two categories (negative and positive).

Due to the limitations of this study in processing brain activity from EGG data, it is important to consider different signal acquisition and processing aspects. The first factor needs to check all the sensors; this avoids errors in the recorded data. On the other hand, signal processing includes considering aspects such as noise generation. Previous tests are necessary to minimize noise generation, ensuring that the participant feels comfortable with the device; this avoids unexpected data generated by involuntary movements.

Finally, one way to respond to the study limitations is to increase the participant population in the experimentation stage. This would result in a greater number of evaluations toward the stimuli. Another criterion is to expand the number of stimuli and experimental sessions to obtain a large amount of information related to people's emotional perception of different auditory stimuli. In turn, this would allow extending the analysis of the behavior of brain signals and their response to specific stimulus.

As future work, the authors propose to extend the framework with more techniques such as recurrent neural networks (RNN), convolutional neural networks (CNN), or long short-term memory (LSTM). Those techniques could be compared with the current ones for obtaining a more in-depth study of brain waves and emotions in people with visual disability. Additionally, it is proposed to explore the brain regions' behavior using 2D and 3D maps of the participants' brain activity. This process will allow recognizing the brain areas that reflect high or low activity during the stimulation process. Future research can also consider incorporating data from other sources; i.e., the framework will have more than one entry at the same time. Adding data from a new source, other than EEG brain signals, will provide more knowledge for the classification of a person's affective state and could improve the accuracy of the model. Also, as exposed in the section "Discussion," a reduced dataset can be tested, taking into account the relevant features of the sensitivity analysis. Besides, as stated in the related work, many of the models proposed for the classification of emotions have not been evaluated in real time. Therefore, the authors take into account the assumptions made by Lotte et al. (2018) and propose as future research to adapt and evaluate the framework as a BCI for real-time emotion recognition.

It is remarkable that, although the participants of this research have visual disabilities (population not previously tested), the authors' proposal reached similar levels of accuracy compared to other research for the classification of people's emotions.

CONCLUSION

It should be taken into account that emotions play an essential role in many aspects of our daily lives, including decision making, perception, learning, rational thinking, and actions. Likewise, it should be considered that the study of emotion recognition is indispensable (Pham and Tran, 2012).

In this work, the authors have explored and analyzed a previously unreported scenario, the classification of emotions in people with visual disabilities. The most important aspects of the framework are as follows: (i) It is a twofold framework. The first is mainly focused on data acquisition (signal extraction) with a BCI device using auditory stimuli. The second is concerned with analysis techniques for the modeling of emotions and machine learning models to classify emotions. (ii) The framework can be expanded with more machine learning algorithms, and therefore it increases the flexibility. (iii) Experimentation is focused on people with visual disabilities. Experimentation results show that 28 feature approaches, including alpha and beta frequencies, performed best for emotion recognition and classification. According to these models' performance, the achieved accuracy is 85 and 88% in the classification of negative and positive emotions, respectively. Therefore, it is considered that feature selection plays a key role in classification performance. Also, an analysis of features illustrates that the brain's frontotemporal areas linked to beta frequency have the most significant contribution to the proposed models' performance. Finally, it has been proposed to continue research based on brain signals and to incorporate new sources of information from people with disabilities, to develop new ways of communication and technological interaction that will allow them to integrate into today's society.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because data protection. Requests to access the datasets should be directed to corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the Local Legislation and Institutional Requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JL-H, IG-C, and JL-C: writing—original draft preparation. JL-H, IG-C, JL-C, and BR-M: writing—review and editing. IG-C and BR-M: supervision and funding acquisition. All authors contributed to the article and approved the submitted version.

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Using Technology to Identify Children With Autism Through Motor Abnormalities

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Autism is a neurodevelopmental disorder typically assessed and diagnosed through observational analysis of behavior. Assessment exclusively based on behavioral observation sessions requires a lot of time for the diagnosis. In recent years, there is a growing need to make assessment processes more motivating and capable to provide objective measures of the disorder. New evidence showed that motor abnormalities may underpin the disorder and provide a computational marker to enhance assessment and diagnostic processes. Thus, a measure of motor patterns could provide a means to assess young children with autism and a new starting point for rehabilitation treatments. In this study, we propose to use a software tool that through a smart tablet device and touch screen sensor technologies could be able to capture detailed information about children's motor patterns. We compared movement trajectories of autistic children and typically developing children, with the aim to identify autism motor signatures analyzing their coordinates of movements. We used a smart tablet device to record coordinates of dragging movements carried out by 60 children (30 autistic children and 30 typically developing children) during a cognitive task. Machine learning analysis of children's motor patterns identified autism with 93% accuracy, demonstrating that autism can be computationally identified. The analysis of the features that most affect the prediction reveals and describes the differences between the groups, confirming that motor abnormalities are a core feature of autism.

Keywords: autism spectrum disorder, sensory-motor impairment, motion analysis, machine learning, classification, assessment technologies

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INTRODUCTION

Autism spectrum disorder (ASD) is a neurodevelopmental disorder notoriously characterized by communication impairment, a lack of social interaction, and the presence of restricted, repetitive, and stereotyped behaviors. Clinically, autism includes a very variable repertoire of symptoms and manifestations. The different target behaviors occur for each child with different degrees of severity. The etiology of the disorder is still unknown, and it can involve both genetic and environmental factors. Because of these variabilities, many specialists are assuming that autism can be classified into different types, each of which may have different etiology and response to treatment. Recent studies have defined ASD as the most frequently observed neurodevelopmental disorder with an incidence estimate of 60–70/10,000 (Fombonne, 2009). The scientific community is currently moving in the direction of deepening the etiopathogenesis of the disorder and increasingly refine the techniques of diagnosis and assessment (Bertoglio and Hendren, 2009; Fombonne, 2009; Lenoir et al., 2009). Assuming that the disorder could be influenced by both genetic and environmental factors (Hallmayer et al., 2011; Sandin et al., 2014), intervention on this second aspect becomes a core topic for clinicians. An effective environmental intervention is possible through early and targeted therapeutic treatments. For these reasons, an early diagnosis becomes a fundamental step to set up a more effective therapeutic intervention (Howlin et al., 2009; Bradshaw et al., 2015). The diagnosis of autism is recommended from 3 years of age by the Roehr (2013), and this is due to the most widely used diagnostic tools and the only ones to be validated that are based on observational analysis of the specific behaviors considered the core symptoms of the disorder according to the Diagnostic and Statistical Manual of Mental Disorders (5th ed.). These symptoms mainly concern the communication area, social interaction, and the presence of ritualistic, repetitive, and stereotyped behaviors. Heretofore, the diagnostic tools relied on the interpretative skills of clinicians during the administration of paper and pencil tests and the support of parents and caregivers who provided salient information through structured interviews. All these methods take a long time without being able to deliver an objective and shareable result. One of the main gaps in the diagnosis of autism is related to the lack of a quantitative evaluation of the disorder; in fact, although the variability within the disorder is known, there is still no valid method to recognize and categorize these differences. These limits increase the time to diagnosis due to the uncertainty in the clinical diagnostic fit. In recent years, the literature on ASD has been focusing on identifying the links between the core symptoms at a high level and the corresponding impairment at a lower level. In the perspective of embodied cognition, these behavioral anomalies or, more generally, these high-level cognitive dysfunctions cease to be considered the central focus of the syndrome and begin to be analyzed as mere manifestations of underlying physiological dysfunctions and neural abnormalities. It would mean that ASD individuals cope with dysfunctions present at much lower levels, not only at the level of the central nervous system but also at the one of the peripheral nervous system and autonomic nervous system (Torres et al., 2013).

Kanner (1943) was the first to identify the disruption of normal movement patterns as a cardinal feature of ASD. Leary and Hill (1996) were among the first to identify a link between motor disorder and autistic symptoms, focusing on the effects of motor abnormalities on language, emotional expressions, and social interaction. This new point of view was followed by consideration of an "enactive mind" approach (Klin et al., 2003), according to which "… social cognitive processes emerge only from recurrent sensorimotor patterns that allow action to be perceptually guided."

In 2014, Friston recognized the presence of anomalies in the predictive coding systems associated with ASD. This anomaly originates from perceptual systems and from an impairment of the integration of sensory information that would lead to maladaptive motor acts. In this scenario, it is difficult to identify and topographically define the resulting motor anomaly. In the last years, several studies aimed to identify the specific characteristics of motor abnormalities in autism.

Frequently, ASD is associated with greater clumsiness, motor coordination abnormalities, postural instability, and abnormalities in the kinematics of purposeful movements, such as grasping, reaching, or writing (Bauman, 1992; Ghaziuddin et al., 1994; Molloy et al., 2003; Dowd et al., 2012; Sacrey et al., 2014; Stoit et al., 2013; Kushki et al., 2011). Many studies identify movement abnormalities during prospective, goal-directed motor control (Trevarthen and Delafield-Butt, 2013) and an ineffective prospective organization during a series or chains of movements (Fabbri-Destro et al., 2009).

An interesting interpretative proposal was given by Sinha et al. (2014), and the authors focused on the predictive abilities of individuals with autism, to explain their abnormal behaviors, "…if our predictive abilities were somehow to be compromised, then even mundane occurrences in the environment might appear magical… A magical world suggests lack of control and impairs one's ability to take preparatory actions. It can result in outcomes such as those that constitute the autism phenotypes." In fact, predictive ability appears to be the main compromised component in autism. An impaired prediction leads to an impaired online object's position estimation as well as a weak anticipation of the others' actions. The perceptual awareness of others' motor intentions conveyed in body movement or eye gaze is notoriously disrupted in autism (Pierno et al., 2006; Cattaneo et al., 2007). According to this approach, the stereotypical movements themselves would be configured as the expression of a prediction problem. Individuals with autism, through the repetitiveness of their stereotypes, would be able to have the sensation of controlling the surrounding environment (Sinha et al., 2014).

Thus, if motor abnormalities in ASD are derived from a predictive and perceptual problem, it is possible that its effects are observable from the first months of life. Several studies in which home videos were used to observe children before the age of two and then diagnosed as autism have found motor differences compared with typically developing children (Adrien et al., 1993; Teitelbaum et al., 1998; Baranek, 1999). This would mean that motor deficits could be present even before communication or social interaction problems, suggesting that motor impairment could actually be the precursors of the main symptoms of ASD (Leary and Hill, 1996; Nayate et al., 2005). During a critical developmental step, an ineffective perception of the external environment and an ineffective spatial interaction can certainly affect the interaction with the physical and social world, leading to the typical manifestations of autism. These findings highlight the need for further studies of motor difficulties as distinctive for ASD.

However, the literature still reports controversial results due to the weak methodological strategy and to the high variability of the autistic symptomatology. Although it is common to recognize the presence of motor impairment through interviews with parents, it is not easy to recognize these problems in childhood. For this reason, there is a growing need for an objective system to recognize autistic motor signatures from their early evidence. In recent years, several studies focused on using machine learning systems to recognize autism motor patterns.

In the present study, we try to determine whether a simple dragging movement on a tablet screen could be useful to accurately classify children with ASD. We developed a supervised machine learning system to discriminate children with ASD from typically developing children by means of kinematics analysis.

Taking advantage of a type of technology widely used in daily life and integrating it with classic diagnostic and assessment tools, we tried to enhance the assessment processes in autism. We aimed to make these processes more detailed and capable of providing an objective measure of the disorder. At the same time, we made the assessment sessions more motivating for the users and easy to administer for clinicians (Milano et al., 2017; Simeoli et al., 2019a).

RELATED WORKS

In the last 20 years, authors have raised the problem of being able to categorize and recognize motor abnormalities in autism, taking advantage of new technologies and new methods of artificial learning. In particular, they focused on the recognition and anticipation of stereotypical motor movements (SMM) (Westeyn et al., 2005; Albinali et al., 2009, 2012; Min and Tewfik, 2010; Goodwin et al., 2011, 2014; Goncalves et al., 2012; Rodrigues et al., 2013; Großekathöfer et al., 2017; Milano et al., 2019). Using a variety of different features and semi-supervised classification approaches (orthogonal matching pursuit, linear predictive coding, all-pole autoregressive model, higher order statistics, ordinary least squares, and K-VSD algorithm), recognition rates of 86/95% for SMM and no-SMM have been documented. Such studies have had a great impact on rehabilitation and intervention in autism.

An important goal to reach is still related to the diagnostic and assessment processes. In fact, many attempts have been made to make predictions by recognizing and categorizing the typical motor patterns of ASD. The recent identification of motor disorders in young children who develop ASD represents a new goal for the development of early assessment tools (Trevarthen and Delafield-Butt, 2013; Licari et al., 2020). Crippa et al. (2015) used a supervised machine learning method to determine whether a simple upper-limb movement could be useful to recognize autism. They compared typically developing children and autistic children by means of kinematic analysis, reaching a maximum classification accuracy of 96.7%. Torres and Jose (2012) proposed to use a sophisticated measurement tool and statistical metric to classify and diagnose individuals with ASD (Torres and Jose, 2012).

Some other researchers have tried to delve into the topic by analyzing the coordinates of movement during the performance of simple tasks that required drag movements on the screen of a tablet. Anzulewicz et al. (2016) used an iPad gameplay and 262 features of movements, derived from touch screen and inertial sensors, and they showed that children with autism could be identified with up to 93% accuracy. Differences between children with ASD and typically developing children have emerged in terms of linearity, speed, and pattern of interaction (Simeoli et al., 2019b, 2020). Also, a greater engagement in carrying out cognitive tasks using digital tools has emerged, especially for individuals with severe autism (Simeoli et al., 2019a). Thus, it would appear that measures of motor patterns could provide a means to assess young children for autism.

Since several interactions of motion variables could, actually, affect the presumed typical autistic motor pattern, we cannot assume that there must necessarily be movement variables typical of autism and different in typically developing individuals. Thus, in this context, using classical statistical analysis can often be a stretch. For this reason, the aforementioned studies and the present one choose a predictive method rather than exploratory to address this issue (Yarkoni and Westfall, 2017).

In this study, we developed a software tool that, through a smart tablet device with touch screen sensor technologies, records kinematics movement while students are engaged to perform cognitive tasks. We extracted 12 features of movement, analyzed by a supervised machine learning method to obtain an automatic classification system, able to differentiate typical patterns of movements and autistic ones. This study aims (i) to describe motor information data that could differentiate children with autism from typically developing children and (ii) to develop a computational model that could recognize these motor patterns within ASD and typically developing children, in order to enhance autism assessment processes.

MATERIALS AND METHODS

Participants

The study was attended by 60 children aged between 5 and 10 years, divided into two groups: 30 children with an average age of 7 years, standard deviation 1.4, clinically diagnosed with ASD according to the Diagnostic and Statistical Manual of Mental Disorders (5th ed.); and 30 children, aged 6 years and 8 months, standard deviation 1, with typical development (TD). The original version of the Leiter-3 International Performance Scale was used to assess the IQ for both groups. The IQ score for the TD group ranged between 74 and 110, and the ASD group covered a range from 59 to 109. Six children in the ASD group had a mild mental retardation with an IQ score ranging between 59 and 70 (World Health Organisation [WHO], 2016). No moderate, severe, or profound mental retardation was detected.

All participants had normal vision and no sensory or motor deficit. Any child whose clinician or teacher was uncertain about the child's diagnosis or health was excluded.

The ASD participants were recruited from the Neapolisanit S.R.L. Rehabilitation Center. Inclusion criteria were as follows: a diagnosis of autism according to both DSM-V clinical criteria and to the Autism Diagnostic Observation Schedule (ADOS-2) (Lord et al., 2012), age range between 5 and 10 years, and no existing comorbidities. The TD participants were recruited from a primary school. Exclusion criteria were suspected signs of autistic spectrum disorders, developmental abnormalities, and current or past history of psychiatric or neurological disorders.

All the participants belonging to the ASD group were diagnosed with ASD by qualified doctors and professionals in the sector. They have no affiliation with our laboratory or our research. Children with ASD follow psychomotor and speech therapy treatment at the Neapolisanit S.R.L. Center. No specific comorbidity was reported.

Prior to the study, children's parents gave written informed consent for their children's participation in the study. The experimental protocols employed were approved by the Federico II University of Naples Ethical Committee of Psychology Research.

Materials

The movement detection software was developed in Unity and C#. The study was performed on Android tablet 6.0, size ($H \times W \times D$) 241.9 × 149.5 × 8.5 mm, screen size 9.6 inches with a resolution of 1,280 × 800 (WXGA) and a refresh rate of 60 Hz. The tasks were presented to the children within a bespoke app organized in a sequence of scenes which play tasks of the cognitive battery of the Leiter-3 test (Roid et al., 2013; **Figure 1**), a totally nonverbal test of intelligence and cognitive abilities, widely used in ASD individuals. The software plays exactly the same tasks of the Leiter-3, presented in the same order, and the administration of the digital version followed the same rules of the original test. Participants were required to perform the tasks according to their cognitive abilities. The examiner switched from a subtest to another, according to the instruction procedure of the original version of the test, after the error threshold was reached.

Scenes are composed of a maximum of five moving cards and eight fixed images (the placeholders). Moving cards are placed at the bottom of the screen and they can be dragged across the screen; placeholders are placed at the top. The placeholders are programmed to catch the moving cards dragged nearby. For each task, placeholders and moving cards range from a minimum of two to a maximum of eight and can include distractors.

The battery is composed of five different subtests related to five different cognitive domains. Each subtest is composed of 10 or more items. Tasks are divided in five cognitive categories as follows: (a) figure-ground (FG) tasks require to identify parts of figures within a complex stimulus. The user must identify the correct areas, within a complex picture, where to place the moving cards representing parts of the picture above. The placeholders are positioned within the target image and are invisible to the user who must match identical figures within the complex background; (b) figure completion (FC) demands the ability to recognize an entire object from all its roles randomly arranged on the scene; (c) classification analogies (CA) requires classification of objects or geometric figures in which participants have to complete a sequence of geometric shapes and matrices with increasing levels of complexity; (d) sequential order (SO) requires to place figures according to a logical, SO; and (e) visual patterns (VP) requires discrimination and matching of pictures. All the subtests, except FG, are arranged in the same way. The users have to drag the moving cards at the bottom into delimited placeholders positioned at the top of the screen.

Tasks are presented following an increasing level of complexity and are characterized by a progressive increase of distracting stimuli and details of the images. The ascending level of complexity requires increasing levels of attention and decision-making.

Since all participants correctly performed at least the first five items of each subtest, only the trajectories derived from these items were analyzed.

Experimental Protocol

During the study, participants sat in front of a table 65–70 cm high according to the age of the child. The experimenter sat at the opposite side of the table. Children performed the task on the Android tablet placed on the table in front of the child within 20 cm of the edge of the table. At the beginning of each subtest, the examiner provided the instructions to carry out each task, according to the instruction procedures of the original version of the test. The experimental task consisted of dragging images on the tablet screen from a point to another, according to the cognitive demand of each specific task (**Figure 2**). After the instructions, the examiner left the child free to perform the task without any further aid. The instruction phase included a series of guides that encouraged attention to the main cognitive target, using pointing and specific gestures, without any vocal aid. If needed, the examiner can demonstrate how to carry out the task by moving the cards himself. This is allowed only for the first item of the first subtest (FG1). Coordinates extracted from this item have not been considered for the analysis.

Switching between tasks was automatic when the child completed the task. The task was considered complete when each of the moving images was placed into one of the placeholders at the top, regardless of the performance result. In case the child did not place all the moving cards above the placeholders, the examiner switched to the next by double clicking an invisible button placed at the upper corners of the screen.

Data Acquisition and Analysis

Features Extraction

The software recorded information about the position over time of each stimulus displayed on the screen during each task and, at the same time, information about the participant's finger position. Touch data were collected runtime at a rate of 40 Hz. That is, the software recorded 40 pair coordinates (x, y) of movement per second. Information about which task was performed was always associated with the touch data. The recorded space-time touch data were analyzed as trajectories of movement. We considered as "finite" trajectories all the coordinates resulting from the dragging movement from the first tap on the screen until the finger was lifted from the screen at the end of the dragging movement. For each "finite" trajectory, we obtained the value of the features in **Table 1**. For the analysis, we used the average value merged per task.

Seventeen variables were extracted from the analysis of these trajectories: 12 features refer to characteristics of the trajectories (**Table 1**), and five additional variables are related to the task during which those features have been recorded, in order to provide implicit information about the difficulty level of the task performed. The features allowed us to obtain a comprehensive computational description of a child's motion patterns during the interaction with the device.

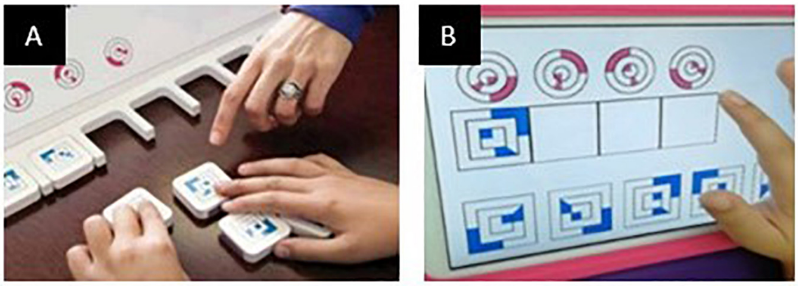


FIGURE 1 | Panel **(A)** depicts the Leiter-3 test in its original version; on the right, panel **(B)** is an example of a test scene in its digital version.

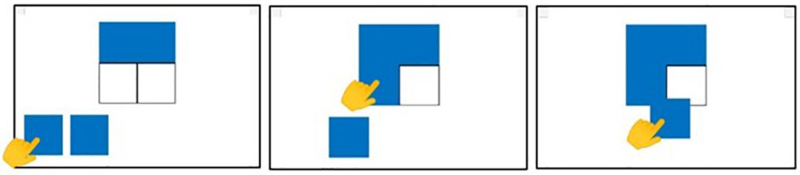


FIGURE 2 | An example of dragging movement during the performance of a CA task. The users are required to drag the moving cards from the bottom to the corresponding placeholders at the top of the screen, according to the task demand.

TABLE 1 | Features obtained from the RStudio traj package analysis.

Feature name	Description
MeanSpeed	Average speed values per task
MaxSpeed	Average value of the maximum speed peaks reached during the performance of a task
MinSpeed	Average value of the minimum speed peaks reached during the performance of a task
sdSpeed	Standard deviation of the speed values collected during the task
MeanAcceleration	Average acceleration values per task
MaxAcceleration	Average value of the maximum acceleration peaks reached during the performance of a task
MinAcceleration	Average value of the minimum acceleration peaks reached during the performance of a task
sdAcceleration	Standard deviation of the mean acceleration values collected during the task
STH	The Straightness index as ratio between the distance of the starting and ending points of a trajectory and its length
DC	Directional change is the change in direction over time
sdDC	Standard deviation of directional change value obtained during the task
MeanLength	The average amount of finite trajectories conducted during each task

STH is a number ranging from 0 to 1, where 1 indicates a straight line. STH is an index of linearity. DC is defined for each pair of steps so that a trajectory may be characterized by the mean (DC) and standard deviation (sdDC) of all directional changes. DC may be used as an index of nonlinearity, and sdDC as a measure of irregularity.

Features were computed from the consecutive sets of raw coordinates using RStudio software and the *traj* package (Leffondree et al., 2004; Sylvestre et al., 2006). Motion data for each task were aggregated and divided into finite trajectories based on the start and stop of each particular movement. The analysis was conducted, and features were extracted for each of these trajectories. All these data were then aggregated in order to find the average values for each task. The final dataset consisted of the mean value for all the features (**Table 1**) divided per task (five difficulty levels).

Two types of information were obtained: (i) kinematics information, e.g., speed or acceleration, and (ii) touch-based functions, e.g., the number of trajectories drawn during the task and the average length.

These compiled datasets were entirely used as input for an artificial neural network (ANN) (see below). The dataset included information about the tasks, as per Leiter-3 structure, in order to classify the motion pattern according to the cognitive demand required during the movement. Five different cognitive domains within the Leiter-3 scale were identified and analyzed.

Classification Methods

The ANN was used to recognize the autism motor signatures, since the capacity of ANNs to process complex and nonlinear relationships between variables is well known (Hornik et al., 1989; Chen et al., 1990). Seventeen features were obtained, as explained above. The set of data was composed of the average values of each feature, divided into tasks. Data were labeled accordingly to the

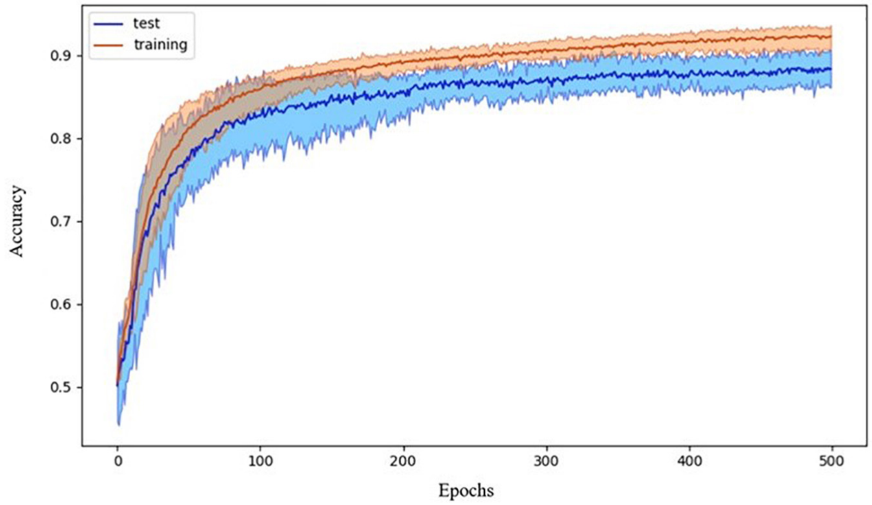


FIGURE 3 | Accuracy during the training process. Data refer to the average accuracy of all the models of the 10-fold CV with five repetitions. Mean and 90% bootstrapped confidence intervals of the mean (shadow area) across all the replications.

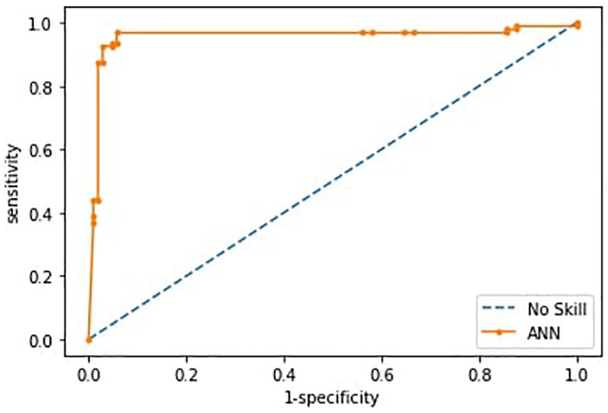


FIGURE 4 | Receiver operating characteristics curves (ROC) of the ANN model. The curve is derived from the sensitivity and specificity index, the rate of correctly classified samples in the positive and negative classes.

child's diagnostic group (ASD or TD). Data were standardized, before being assigned to the ANN.

The ANN used for the ASD/TD classification was a feedforward multilayer perceptron, composed of an input layer of 17 neurons, an output layer of two neurons, and a hidden layer whose number of neurons has been selected through grid search optimization with cross-validation, in a descending search starting from 10 hidden neurons, as we tried to keep to the model as simple as possible in order to reduce overfitting. Indeed, it is a well-known result of ANN, the fact that simple models, i.e., with few hidden units, are less prone to overfitting (Musavi et al., 1994).

The tangent hyperbolic (*Tanh*) activation function was used for the five neurons in the hidden layer. *Tanh* is widely used for the hidden layers of an ANN. Its values are between -1 and 1, and the average turns out to be 0 or very close to it; in this way, it helps to center the data by bringing the average close to 0. For the output layer, a normalized exponential function (*Softmax*) was used. The *Softmax* function will output a probability of class membership for each class label and attempt to best approximate the expected target for a given input. Adaptive moment estimation (*Adam*) learning algorithm was used to update the iterative network weights based on the training data (Kingma and Ba, 2015), and for the training, we used a sparse categorical cross-entropy loss function to calculate the model error.

To evaluate our approach and select the best architecture, we use a 10-fold cross-validation with five repetitions: Using the 10-fold cross validation scheme, the dataset was randomly divided into 10 equal subsets. At each run, nine subsets were used to construct the model, while the remaining subset was used for prediction. The average accuracy for the 10-fold was recorded as the final measurement.

To eliminate the statistical variations due to the random weight initialization, we repeated the resampling procedure five times and recorded the average classification errors.

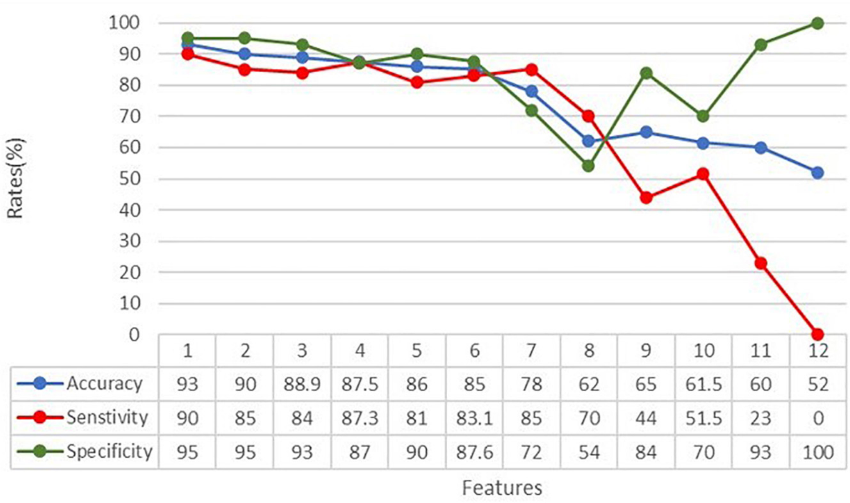
The dataset was composed of a total of 1,500 samples, coming from 60 subjects doing 25 tasks divided into five subtasks, and the dataset is randomized between subjects and tasks. Each sample was composed of 12 motor-based features and five task features, by which the current task was equal to one and the others equal to zero. The target was a simple two class one-hot encoded dataset where ASD subjects were assigned to (1,0) and TD to (0,1).

Data regarding the motor features were standardized. The general method of calculation is to determine the mean distribution and standard deviations for each feature. Next, we subtract the mean from each feature. Then, we divide the obtained values of each feature by its standard deviation.

Then, the 10-fold cross-validations with five repetitions are applied to a 500-epoch lasting training process, and for each fold, we take the 10% of the samples for testing and the remaining 90% for training, regardless of the number of ASD or TD subjects in the test or training set.

The purpose was to generate a model able to learn from the selected characteristics how to discriminate individuals belonging to two different groups and correctly classify, through these characteristics, new unlabeled individuals.

Moreover, in order to understand how the kinematic and touch features provided as input for the ANN contributed to the classification, a form of sensitivity analysis is applied to the model, where the accuracy, sensitivity, and specificity of the model are calculated over the whole number of features ranging from 1 to 12 (subtest features were always provided to the ANN) in an iterative way. In particular, we have iteratively applied the method called *Improved stepwise selection 1*, as presented in Olden et al. (2004). It assesses the change in the accuracy, sensitivity, and specificity of a trained ANN by sequentially removing input neurons from the neural network. The resulting changes for



	1	2	3	4	5	6	7	8	9	10	11	12
Accuracy	93	90	88.9	87.5	86	85	78	62	65	61.5	60	52
Senstivity	90	85	84	87.3	81	83.1	85	70	44	51.5	23	0
Specificity	95	95	93	87	90	87.6	72	54	84	70	93	100

FIGURE 5 | Classification accuracy, specificity, and sensitivity rates in relation to the number of features analyzed by the ANN. Features have been withdrawn as follows: (1) sdAcc, (2) STH, (3) sdSpeed, (4) sdDC, (5) MaxSpeed, (6) DC, (7) MeanRow, (8) MinSpeed, (9) MeanSpeed, (10) MinAcc, (11) MaxAcc, and (12) MeanAcc.

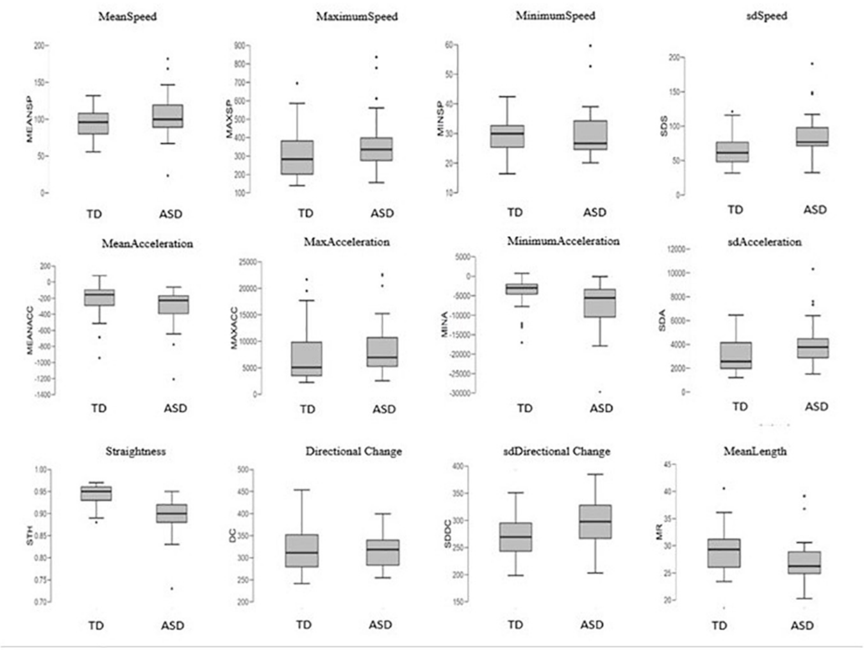


FIGURE 6 | Boxplots of the 12 kinematics features extracted from coordinates of movement and compared between the groups. Features definition in **Table 1**.

each variable removal illustrate the relative importance of the predictor variables (see Gevrey et al., 2003). In our modification, starting from the entire set of 12 input variables, we selectively remove one single input neuron and record the change in accuracy, sensitivity, and specificity after the removal of every input variable, one at a time. That is, we test all possible 12 variables. Once the variable with the lesser impact on the overall performance of the ANN is identified, it is permanently removed. The same process is applied to all remaining input variables, until the process exhausts the number of input variables of the model. In this way, it is possible to measure the relative importance of independent variables for the final categorization performance of the one neural network found as the best predicting model.

RESULTS

The grid search with 10-fold cross-validation, applied to set the most effective number of hidden neurons for the ANN, indicated comparable accuracies for models from 10 to 5 hidden neurons. Learning rate was set to 0.01 and synaptic weights were initialized following the so-called *Xavier initialization* (Glorot and Bengio, 2010). The accuracy started to degrade with fewer than five hidden neurons. To keep the model simple, we have chosen the ANN with the smaller layer of hidden units that showed the best accuracy as the final model, that is, the ANN with five hidden units.

The chosen ANN was able to successfully classify participants by diagnosis. The 10-fold cross-validation showed an accuracy of 88 ± 3%. Data showing the accuracy versus the epoch for the 10 cross-validation models are reported in **Figure 3**.

Having checked that no overfitting is present in every fold, for the successive analysis, we used the best trained model across the 10-fold, as reported in Riccio et al. (2020). Such ANN correctly differentiated individuals within ASD and TD groups with an accuracy of 0.93 (sensitivity 0.87, specificity 0.98). The ROC curve is shown in **Figure 4**.

In order to understand how the input variables contributed to the classification, the accuracy, sensitivity, and specificity rates were calculated over the 12 input variables representing the kinematic and touch measures, as specified above. The subtest features were always provided to the ANN. **Figure 5** shows the dependence of the metrics on the number of considered features. From the graph and the accompanying table, we can see that accuracy, specificity, and sensitivity rates reached their maximum when considering all the extracted features. Moreover, according to the iterative assessment described above, the metrics degrade slowly until the seventh variable is removed (78% accuracy). After that, the accuracy falls sharply until 52% of accuracy is reached.

According to their progressively greater impact on the overall classification performance, input variables have been withdrawn as follows: (1) sdAcc, (2) STH, (3) sdSpeed, (4) sdDC, (5) MaxSpeed, (6) DC, (7) MeanRow, (8) MinSpeed, (9) MeanSpeed, (10) MinAcc, (11) MaxAcc, and (12) MeanAcc. It means, for example, that variables number 1, 2, or 3 have less impact on the classification than variables number 10, 11, or 12, indicating that variables related to speed and acceleration of the finger seems more important than other measures, such as the straightness (STH) and the coherence (DC) of the entire trajectory.

DISCUSSION

Autism is primarily assessed by relying on qualitative judgments by expert clinicians and through semi-structured interviews conducted by parents and caregivers. Given this gold standard, in recent years, the use of a pattern recognition method has obtained great attention as a suitable tool to define objective, quantitative measures of the disorder.

The purpose of the present work was to use kinematic features of simple dragging movements as predictors to discriminate children with ASD from typically developing children. Our results suggested that motor patterns related to autism can be identified by machine learning method. Our analysis showed that 17 features were sufficient to classify autism with an accuracy rate of 93%, sensitivity of 87%, and specificity of 98%.

The study shows that autism can be identified by the interaction of a few specific movement features and their characteristics. We cannot assume that these features are statistically different between groups, but we can suppose that the dynamic interaction of these features can be categorizable.

In order to understand how these features appear between groups, we observed them in detail (**Figure 6**). Results revealed that autism motor patterns are characterized by low linearity of movements. As shown in **Figure 6**, the ASD group reached a low level of STH and high level of DC. This means that their trajectories were not straight and characterized by many changes of direction. Furthermore, the average length of their trajectories (MeanLength) was lower than that of the TD group, indicating more fragmented movements. Velocity index revealed a wide range of values associated with speed and acceleration of ASD children's movements. In fact, they showed big values of MeanSpeed and MaximumSpeed, but low values of MinimumSpeed. Likewise, mean gesture acceleration also covered a wide range for the ASD group, with great MaximumAcceleration value and low MinimumAcceleration. These results explain the higher standard deviation values (sdSpeed; sdAcceleration) shown for both speed and acceleration in the ASD group (**Figure 6**).

Our results are consistent with the findings of Anzulewicz et al. (2016), since they found that ASD children displayed greater force of impact and different patterns of force than their typically developing peers. The authors explain these characteristics as likely due to maintaining great velocity at contact with consequent increased impact force. These findings are in line with the notion that prospective guidance of goal-directed movement is disrupted in ASD, and this disruption could likely determine over- and undercompensations during the movement, e.g., during the movement to reach the tablet as shown by Anzulewicz et al. (2016) and during the dragging movement across the screen as shown in our study. Other features contributed to describe this phenomenon as, e.g., for the results related to DC, STH, and MeanLength of trajectories. In fact, our results indicated that autism finite trajectories were basically very short, as shown in **Figure 6** for the MeanLength feature. In addition, our autistic trajectories were characterized by a low straightness and linearity and a great irregularity, as indicated by the values of STH, DC, and its SD, respectively (**Figure 6**). All these characteristics could be linked to the compensations mechanism described above.

Our results could be considered in line with the previous findings about optical motion tracking experiments of goal-directed tasks. Considering the motion structure described above, it could suggest that individuals with autism make greater moment-by-moment adjustments of their progressive movements compared with the neurotypical group (Cook et al., 2013; Torres et al., 2013; Whyatt and Craig, 2013). Whyatt and Craig (2013) demonstrated that ASD children, during their movements, made multiple corrective movements, reaching greater velocity at the end of their motion. Our study confirms these findings reporting a general greater velocity and acceleration for children with autism, but also describing the movement as more fragmented and less straight. The higher rate of change of direction could be a representative index of the aforementioned overcorrection of movements.

These results support the idea of the presence of a fundamental deficit in the prospective control of movement (Klin et al., 2003; Fabbri-Destro et al., 2009; Trevarthen and Delafield-Butt, 2013; Lawson et al., 2014). This deficit would manifest itself with the interruption of the anticipatory, or feedforward mechanism (Mari et al., 2003; Papadopoulos et al., 2012) or feedback re-afferences (Torres et al., 2013), during the goal-directed actions. Deficits in perception of others' intentions and on fluid selective attention on the adequate stimuli to program a consistent movement with the external environment are notoriously damaged in autism (Pierno et al., 2006; Cattaneo et al., 2007). All these findings support the idea of a deficit in sensorimotor timing integration that affects the perception–action process and the ability to understand the social environment. If the proprioceptive feedback that allows online movement guidance is interrupted, movement control errors can be generated, resulting in abnormal motor signature that we are proposing to use as markers for children with ASD.

About index and markers for identifying autism, many studies have focused on discovery biomarkers of the disorder, but the heterogeneity and the complex etiology of autism have always made this process very tough. For this reason, studies of recent years and our study are focusing on identifying computational biobehavioral markers of the disorder. However, the analysis of these markers requires further study to avoid potential attribution errors. In fact, the motor signature identified may overlap with other disorders, such as attention deficit disorder, motor coordination disturbance, or general intellectual disabilities. Further studies are needed to elucidate this aspect.

The present study is a theoretical demonstration of the development of accessible and attractive assessment tools that can integrate new important information to the ordinary assessment process for autism.

Despite our promising results, some methodological limitations are evident. One of the limitations is certainly related to the small sample size, and a replication on a larger sample is needed to validate this method on a new not trained dataset. Further studies are necessary to test whether the algorithm used could remain predictive also for a greater sample or if it requires to be retrained.

Furthermore, we were not able to exclude intelligence as confounders. Even if we tested children's IQ through the test tasks themselves, we did not use IQ as an independent feature for the analysis. However, most of the ASD children who participated were classified as high functioning and only six of the participants with ASD had a mild mental retardation with an IQ between 59 and 70. In order to reduce the cognitive interference, we selected for the analysis the features extracted from tasks correctly performed by all participants.

Our study involved children with different types of autism (from high to low functioning) since the hypothesis was that autism, regardless of type, could affect the classification.

Previous studies assumed the presence of a sensory integration dysfunction (SID) to explain motor abnormalities in autism (Klin et al., 2003; Mari et al., 2003; Fabbri-Destro et al., 2009; Papadopoulos et al., 2012; Torres et al., 2013; Trevarthen and Delafield-Butt, 2013; Lawson et al., 2014). SID is not currently recognized as a distinct medical diagnosis, but it is usually found in development conditions, particularly in autism. Other conditions could be affected by SID as for example ADHD. Thus, in addition to an IQ control, future extensions of this work should include other neurodevelopmental disabilities in order to verify the specificity of these motor signatures for ASD.

CONCLUSION

In conclusion, this study represents a proof of concept that kinematic analysis of a simple dragging movement can be useful to discriminate individuals with autism and differentiate them from their typically developing peers. The predictive power of our algorithm might support clinical assessment processes and encourage a computer-aided diagnosis perspective.

Our future aim is to recognize these autistic signatures in younger children and, thus, facilitate the diagnostic processes.

However, we can affirm that the automatic learning of autistic motor patterns, through kinematic analysis, during tablet cognitive assessment, can be considered a promising new method for autism detection and that it could enable the use of biobehavioral markers for the assessment of the disorder. Through this study, we also suggest how technologies, integrated with classic diagnostic and clinical tools, can be wisely used to support the clinic and intervention in the field of ASD, facilitating and refining the research, diagnosis, and assessment processes.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethical Committee of Psychological Research of the Department of Humanities of University of Naples Federico II. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

RS contributed to the conception and design of the study, developed the software and carried out the experimental sessions, contributed to the data analysis, and drafted the manuscript. NM contributed to the data analysis developing the machine learning model. AR provided substantial contributions to the acquisition of data and coordinating the experimental work. DM supervised the work, contributed to the conception and design of the study, and coordinated the data analysis and software development process. All authors read and approved the final manuscript.

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BRIEF RESEARCH REPORT
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Psychometric Properties of the Spanish Version of Psychosocial Impact of Assistive Devices Scale in a Large Sample of People With Neuromuscular, Neurological, or Hearing Disabilities

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Assistive technology (AT) is any device, software, or equipment designed for and used by individuals with disabilities to engage in everyday activities and achieve independence. However, the usefulness of those technology-based or supported treatments is a complex issue that has led to the development of various conceptual models for assistive technology outcomes research and practice as well as different assessment tools that help to explore the effect of technology on people's lives. One of those instruments is the Psychosocial Impact of Assistive Device Scale (PIADS), a 26-item questionnaire that measures the psychosocial impact of interventions, using assistive devices in three quality-of-life domains: competence, adaptability, and self-esteem. PIADS scale has been translated and adapted to several languages, and it has been successfully used to measure AT outcomes in different disability profiles to predict abandonment or even as a relevant determinant of future adoption of eHealth. Quinteiro (2010) adapted PIADS to Spanish for the first time, although no studies have yet been published to systematically study its psychometric properties. Therefore, the purpose of this study was to evaluate measurement properties of the Spanish version of PIADS scale by means of a dataset obtained from its application to a large sample ($n = 417$) of people with neuromuscular, neurological, or hearing disabilities that used different assistive devices. The results will provide valuable indicators about the measurement quality of the Spanish PIADS scale and will help to promote the use of reliable and valid AT outcome assessment tools for research and clinical purposes.

Keywords: assistive technology, psychosocial impact, neurological disabilities, neuromuscular disorders, hearing disabilities, psychometric properties, outcome assesment

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INTRODUCTION

According to ISO:9999:2016 and UNE-ISO 9999:2017, assistive technology (AT) is "any product (including devices, equipment, instruments, and software), especially manufactured or commercially available, used by or for persons with disabilities to facilitate participation; protect, support, train, measure or substitute body functions and/or structures and activities; and prevent impairments, activity limitations, or participation restrictions." Examples of assistive devices and technologies include a variety of products as wheelchairs, prostheses, hearing aids, visual aids, communication systems, low-tech devices, and specialized software and hardware that increase mobility, hearing, vision, cognition, or communication skills, among others. Assistive devices and technologies have the primary purpose of maintaining or improving the functioning and independence of a person and, therefore, are tools that promote participation and increase the health and well-being of individual users and their families. They can also help prevent impairments and secondary health conditions. But the benefits of the use of assistive technologies are also clear in the socioeconomic field where they can serve to reduce costs in the health system or to stimulate economic growth (World Health Organization, 2018).

The Convention on the Rights of Persons with Disabilities (The United Nations, 2006) recognizes access to assistive technology as a human right and has called for international cooperation to improve access (Article 32). However, the Global Cooperation on Assistive Technology (GATE) describes that today, only 5–15% of the population that need an assistive technology have access to it, with the problem being much more serious in low- and middle-income countries (World Health Organization, 2020).

Poor availability and access to support products are complex issues determined by multiple factors. For example, Tangcharoensathien et al. (2018) consider that limited access to assistive technologies in low- and middle-income countries is determined by a variety of key factors as lack of awareness among potential beneficiaries, products designed without consideration of user preferences, economic difficulties, shortages of trained personnel, or lack of quality evidence on the effectiveness of assistive technologies. As stated by the WHO (World Health Organization, 2018), the challenges to improve access to assistive technologies are varied and involve government, professional, and industrial sectors. Thus, research and development must be improved, especially in low-income countries, and low-cost solutions must be promoted. Standards and norms must also be created to ensure the effectiveness and safety of assistive devices as well as to improve manufacturing and distribution processes.

Another major challenge is to improve services for the provision of assistive technologies. Standards must be developed to ensure quality decision-making regarding the provision of products, including assessment procedures, prescription, adjustment, user training, follow-up, maintenance, and repair. In this context, it is of great importance to have adequate models, and the corresponding assessment tools that help to make decisions and evaluate outcomes in interventions with assistive devices. A review of such models is beyond the scope of this paper [see, for example, Lenker and Paquet (2003), Bernd et al. (2009), Alves et al. (2016), Federici and Scherer (2018)]. But the literature in recent years has showed some assessment instruments that have proved to be particularly useful, as it is the case of the Psychosocial Impact of Assistive Devices Scale (PIADS; Jutai and Day, 2002; Day and Jutai, 2003).

The PIADS scale was designed to measure the user's perception of the impact of assistive technology on his/her functional independence, well-being, and quality of life with 26 self-rated items grouped into three perspectives. Twelve items measure the feelings of competence and efficacy associated with the use of a product (competence); six items are related to the willingness to try out new things and to take risks (adaptability); and eight items measure feelings of emotional health and happiness (self-esteem). The PIADS scale has been translated to 19 languages, and it has been used in more than 120 scientific works to evaluate results derived from interventions with a huge variety of products and assistive technologies as well as a wide range of user profiles (Jutai, 2019). It also has proved to have good reliability and content validity, excellent internal consistency, and structural, cross-cultural, and criterion validity (de Lima Barroso et al., 2018), and seems to be powerful enough to predict assistive technology abandonment and retention (Day et al., 2001, 2002).

Two Spanish PIADS versions are available: one for Puerto Rican-Spanish (Orellano and Jutai, 2013; Orellano-Colón et al., 2016) and the other for Spain-Spanish (Quinteiro, 2010). To our knowledge, no studies have yet been published to systematically explore the psychometric properties of the Spain-Spanish PIADS version. Bearing in mind that construct validity and reliability are critical aspects in order to ensure a good adaptation of an assessment instrument, this work aims to study the psychometric properties of the Spanish-PIADS from its application to a large sample of people with neuromuscular, neurological, or hearing disabilities, using a variety of assistive devices. More specifically, the objectives of the research were to analyze the internal consistency and the factorial structure (confirmatory factor analysis) of the Spanish-PIADS.

METHODS

Sample

The sample was composed of 417 adults who had been administered the Spanish version of the PIADS scale in other independent studies (Pousada et al., 2015; Jiménez-Arberas et al., 2019; Jiménez-Arberas and Díez, 2021). In all cases, a convenience sampling was used, and the scale had been applied as a way of assessing the perceived psychosocial impact related to the use of the person's main assistive technology. **Table 1** shows the main sample characteristics as a function of the type of disability.

Measures

The Spanish version of the PIADS scale adapted by Quinteiro (2010) was used in this study. The adaptation followed the instructions provided by the authors of the original instrument and roughly consisted of translating and adapting to Spanish the original questionnaire, the glossary of terms, the spreadsheet of the results, and the guidelines for application. Subsequently, a

TABLE 1 | Socio-demographic characteristics of the sample by the type of disability.

	All sample	Acquired brain injury	Hearing loss	Neurodegenerative diseases	Neuromuscular disorders	Other diagnoses
Sex (*N*)						
Female	231	23	175	6	22	5
Male	186	27	113	14	38	4
Age (years)						
Mean (*SD*)	55.2 (23)	59 (15.2)	56.6 (24.9)	55.5 (13.6)	43.8 (16.1)	72.4 (20.4)
Assistivetechnology (*N*)						
Behind The Ear (BTE) hearing aid	90		90			
Cochlear implant	30		30			
Completely In the Canal (CIC) hearing aid	36		36			
Deep insertion hearing aid	5		5			
Hearing glasses	2		2			
Instant voice and text messaging app (Oovoo)	17		17			
Software Skype	15		15			
Video Relay Service (Svisual)	66		66			
External Ear Sound Amplifier	1		1			
Powered Wheelchair	54	14		8	32	
Manual Wheelchair	41	7		7	25	2
Mobile Phone	26		26			
Quad Cane Walking Stick	1					1
Trekking cane	8	8				
Walker	8	2		2	1	3
Crutch	16	9		2	2	3
Foot-Up	1			1		

backward translation into English was carried out, which was reviewed and approved by the authors of the original scale.

Procedure

The application of the PIADS scale was carried out through different methods, including interviews by experienced occupational therapists (85.9%), questionnaires sent by post/e-mail (5%), and a self-administered webform version of the scale (9.1%).

The administration procedure of the PIADS scale consisted of showing a list of words or short phrases describing how the use of an assistive device may affect a person (e.g., willingness to take chances, independence, or self-confidence). For each word/short sentence, the participants rated the extent to which they were affected, using a seven-point Likert scale, ranging from −3 (maximum negative impact) to +3 (maximum positive impact) with a 0 midpoint, indicating no impact or no perceived change as a result of using the assistive device. Following scale completion instructions, if the participant asked for a definition for a PIADS item, the experimenter gave the explanation for the item taken from the PIADS glossary.

Analysis

Analyses were performed with JAMOVI (The jamovi project, 2020) and R software (v.4.0.2) (R Core Team, 2020) by using, mainly, lavaan (v. 0.6-7) (Roseel, 2012), semTools (v.5.4) (Jorgensen et al., 2021), psych (v. 2.0.12) (Revelle, 2020), boot (v. 1.3-25) (Davison and Hinkley, 1997; Canty and Ripley, 2020), and EFA tools (v..3.0) (Steiner and Grieder, 2020) packages.

Confirmatory factor analysis (CFA) was performed, using the MLMV estimator, and the following several indices and cutoffs criteria were used to analyze the goodness of the data fit by the different models: comparative fit index ($CFI \geq 0.90$) as incremental fit indices, and standardized root mean square residual ($SRMR < 0.08$) and root mean squared error of approximation ($RMSEA < 0.05$) as baseline fit indices. Two information criteria (the AIC and the BIC) were also computed.

RESULTS

Psychosocial Impact by Subscale and Disability Groups

Descriptive results showed (**Table 2**) that the psychosocial impact of assistive devices perceived by the participants was mainly positive, with positive mean scores for the three subscales. A mixed analysis of variance (ANOVA) with one within-subjects factor with three levels (psychosocial impact, PIADS: competence, adaptability, and self-esteem) and one between-subjects factor (disability group: hearing, neuromuscular, or neurological disability) showed a significant main effect of psychosocial impact [$F_{(1.80,745.5)} = 68.70; p < 0.001; \eta^2\text{-}p = 0.14$] as well as a significant interaction psychosocial impact x disability [$F_{(3.60,745.5)} = 9.49; p < 0.001; \eta^2\text{-}p = 0.04$]. *Post-hoc* (Bonferroni

TABLE 2 | Mean, standard deviations, minimum, maximum scores in each subscale of the Spanish (Spain) Psychosocial Impact of Assistive Device Scale by the disability group.

PIADS subscale	Mean	*SD*	Min	Max
All sample ($n = 417$)				
Competence	1.13	1.03	−2.08	3.00
Adaptability	1.32	1.11	−2.17	3.00
Self-steem	0.98	1.11	−2.75	3.00
Hearing disabilities ($n = 288$)				
Competence	1.24	0.99	−1.66	3.00
Adaptability	1.38	1.08	−2.17	3.00
Self-steem	1.16	1.21	−2.00	3.00
Neuromuscular disorders (+ 5 from other diagnoses: 2 Spinal cord injury, 2 Spina Bifida, 1 Sudeck Syndrome) ($n = 65$)				
Competence	1.00	0.84	−1.00	2.92
Adaptability	1.21	1.04	−0.83	3.00
Self-steem	0.68	0.78	−1.00	2.25
Neurological disabilities (acquired brain injury, neurodegenerative diseases, + 4 from other diagnoses -cerebral palsy-) ($n = 64$)				
Competence	0.77	1.28	−2.08	2.75
Adaptability	1.18	1.29	−2.00	3.00
Self-steem	0.43	1.13	−2.75	2.25

corrected) comparisons showed significant greater scores for competence than for adaptability [$t_{(828)} = -5.97$; $p < 0.001$; $d = -0.31$, 95% CI (−0.41, −0.21)] and self-esteem [$t_{(828)} = 5.75$; $p < 0.001$; $d = 0.24$, 95% CI (0.14, 0.34)], and also greater adaptability than self-esteem [$t_{(828)} = 11.72$; $p < 0.001$; $d = 0.43$, 95% CI (0.32, 0.53)] for the whole sample. For competence or adaptability, no differences were observed as a function of disability group, but, in the case of self-esteem, significant greater scores were found for the group of hearing disabilities in comparison to neuromuscular [$t_{(546)} = 3.25$; $p < 0.001$; $d = 0.45$, 95% CI (0.18, 0.72)] or neurological groups [$t_{(546)} = 4.93$; $p < 0.001$; $d = 0.65$, 95% CI (0.37, 0.92)].

Validity Evidence Based on Internal Structure

To our knowledge, no published studies have assessed the factorial structure of PIADS against the proposed three-factor model that has been extensively used to interpret PIADS scale applications. In this study, we used confirmatory factor analysis (CFA) models to compare the proposed original factorial structure solution (three correlated factors: competence, adaptability, and self-esteem), with different competing models that could also explain the PIADS factorial structure: a single-factor model for testing the key assumption of unidimensionality; a three-uncorrelated-factor model with the same structure as the original (competence, adaptability, and self-esteem); a higher-order model, which incorporates a superordinate global psychosocial impact factor mediated by a series of subordinates factors (competence, adaptability, and self-esteem); and a bifactor model, including a general factor that loads directly onto all items and three grouping factors (competence, adaptability, and self-esteem), which load onto specific items for those subscales for testing orthogonality of the factors with a general factor.

As reported in **Table 3**, model χ^2, which assesses the overall fit and the discrepancy between the sample and fitted covariance matrices, resulted in rejecting the null hypothesis of the perfect model fit for all models. However, due to its sensitivity to sample size, χ^2/df ratio was also considered. The ratios were <3 for all models, except for model C.

In relation to the models that included all the items of the original scale (models A–E), the measures of the model fit showed the best results for the three-correlated-factor model (model A) and the single-factor model (model B), with measures denoting almost acceptable (CFI very close to 0.90), acceptable (SRMR $<$ 0.08) and a good fit (RMSEA ≤ 0.05).

The standardized factor loadings for the most commonly PIADS factor model (three correlated factors) showed values ranging from 0.62 to 0.83 for 23 items. But, for three items, the loadings were especially low (items 5, 10, and 21, with loadings of 0.11, 0.23, and 0.16, respectively). We also explored the local misfit with a residual variance–covariance matrix, and those three items exhibited very high positive residual covariances. The affected items belonged to the competence (item 5, confusion) and self-esteem (item 10, frustration; and 21, embarrassment) factors. Precisely, those items are the only ones in the PIADS scale that are reversed (higher positive scores denoting worse impact). We decided to create two new models (single-factor and three correlated factors), deleting those items (Models F and G in **Table 3**; see also **Figure 1**). This time, all the measures showed a good fit to both the single-factor and the three-correlated-factor models (CFI $\geq$ 0.90; SRMR $<$ 0.05; RMSEA $< = 0.05$), denoting a potential problem with the differential response format of these three items. The average variance extracted (AVE) for the F model showed values $>$0.5 for all PIADS subscales (competence $= 0.55$; adaptability $= 0.54$; self-esteem $= 0.60$), denoting acceptable convergent validity.

Internal Consistency

When considering the original complete scale, model comparisons revealed the superiority of the original three-correlated-factor solution. Consequently, this factorial solution was chosen to perform reliability analysis. The reliability of each of the three factors was determined, using ordinal McDonald's omega and Cronbach's alpha (Elosua and Zumbo, 2008; Peters, 2014). Also, nonparametric confidence intervals (CI) were estimated with a bootstrap procedure, using the adjusted bootstrap percentile (BCa) method. As shown in **Table 4**, both Cronbach's Alpha and McDonald's Omega showed excellent internal consistency for the whole scale and the competence subscale, and good for adaptability and self-esteem subscales. When those indexes were also calculated for the model with no reversed items, an increment in both Cronbach's alpha and McDonald's omega was verified for the competence ($\alpha = 0.93$; $\omega = 0.93$) and self-esteem ($\alpha = 0.90$; $\omega = 0.90$) factors.

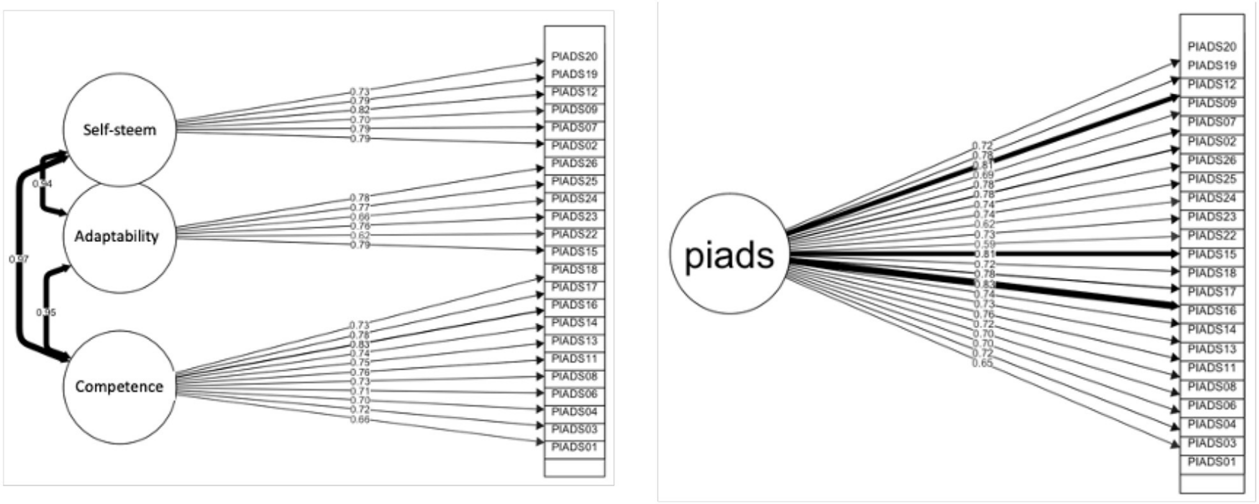
TABLE 3 | Confirmatory factor analysis (CFA) model fit summary.

	χ2 (df)	χ2/df	RMSEA	CFI	SRMR	AIC	BIC
Model A	585.991 (296)***	1.98	0.048	0.882	0.057	33,405.955	33,732.635
Model B	605.116 (299)***	2.02	0.050	0.876	0.058	33,451.851	33,766.431
Model C	1033.716 (299)***	3.46	0.077	0.701	0.361	34,602.415	34,916.995
Model D	592.026 (298)***	1.99	0.048	0.880	0.061	33,411.335	33,729.948
Model E	689.111 (297)***	2.32	0.056	0.841	0.185	33,707.867	34,030.513
Model F	438.302 (227)***	1.93	0.047	0.909	0.045	28,280.971	28,571.354
Model G	456.093 (230)***	1.99	0.049	0.903	0.046	28,324.100	28,602.383

****p* < 0.001.*

(A) The original model, three correlated factors (competence, adaptability, and self-esteem); (B) the single-factor model; (C) the three-uncorrelated-factor model (competence, adaptability, and self-esteem); (D) the higher-order model; (E) the bifactor model; (F) three correlated factors with no reversed items; (G) the single-factor model with no reversed items.

AIC, Akike information criteria; BIC, Bayesian information criteria; CFI, comparative fit index; RMSEA, root mean square error of approximation; SRMR, standardized root mean square residual.



Model F (three correlated factors with no reversed items)

Model G (single-factor model with no reversed items)

FIGURE 1 | Confirmatory Factor Analysis (CFA) of PIADS Scale with no reversed items. Fit indexes (see **Table 3**) showed the best results for this two models.

TABLE 4 | Ordinal Cronbach's alpha and McDonald's omega (with bootstrap confidence intervals) scores in each subscale of the Spanish (Spain) Psychosocial Impact of Assistive Device Scale.

PIADS subscale	Crobach's α (95% CI)	McDonald's ω (95% CI)
Competence	0.93 (0.92–0.94)	0.94 (0.93–0.94)
Adaptability	0.90 (0.89–0.92)	0.90 (0.89–0.92)
Self-steem	0.87 (0.85–0.89)	0.88 (0.87–0.90)
Global Score	0.96(0.96–0.97)	0.97(0.96–0.97)

DISCUSSION

The present research aimed to obtain psychometric evidence for the use of the PIADS scale in Spain. The need for standardized methods for the follow-up of individual interventions with AT, especially through outcome measures that show good metric properties, motivated the exploration of the factorial structure and internal consistency of the Spanish PIADS scale based on data from its application to a large sample of participants, using different assistive devices.

First, because the study of dimensionality considerations is very important when reporting scores in order to assess more specifically the psychosocial impact of using assistive technologies, we were interested in analyzing in detail the structural validity of the Spanish PIADS. Previously, other studies reported evidence for construct validity by way of exploratory factorial analysis, mainly using Principal Component Analysis. For example, Jutai and Day (2002) found a solution of three factors, accounting for 61.1% of the total variance. But this is the first time that Confirmatory Factor Analysis has been used to test both the validity and the reliability of the PIADS scale. Specifically, we have compared the factorial structure of the original PIADS scale (three correlated factors) with other possible alternative structures. The results have shown acceptable fit measures for both a single factor and three correlated factors, although slightly favoring the latter but showed worst results for other common factorial structures as the higher-order model or the bifactor model.

Second, reliability analysis based on the three-factor structure showed that PIADS has a very good internal consistency, confirming the results of many other studies adapting PIADS to other languages (e.g., Chae and Jo, 2014; Tofani et al., 2020), although showing worst results for the self-esteem subscale as has also been verified in other adaptation studies (e.g., Demers et al., 2002; Hsieh and Lenker, 2006).

Third, the detailed exploration of the item loadings showed some problems with the items that are reversed in the PIADS scale. When fitting both single-factor and three-correlated-factor models with those items deleted, all model fit measures, as well as internal consistency measures, increased. Reversed items are common means of controlling for the effects of acquiescence, but, usually, in the context of balanced scales, where half of the items measure the construct in one direction and, the other half, in the opposite direction. In the PIADS scale, only three items (out of 26) are reversed, and this could favor the negative effects of having reversed items. There is evidence that the use of reversed items may have positive effects (e.g., increase validity by providing a more complete representation of an underlying construct or promoting more careful reading of the items). But it also could have negative effects, as the reduction of internal consistency and affectation to the factorial structure of measures, being common to observe a poor fit to the expected model (Vigil-Colet et al., 2020). Although there is no agreement in the literature regarding the use of reversed items, in the case of the PIADS scale, our results could suggest to change the direction of the reversed items or, alternatively, to include more reversed items to maintain the equivalent proportion of positive and negative items in each subscale.

Fourth, the analysis of differences in the PIADS scores has shown a general positive psychosocial impact associated with the use of different assistive technologies in a heterogeneous sample of participants with disabilities. Specifically, the impact has been greater for aspects related to perceived functional capability, independence, and performance (i.e., competence) in comparison to other aspects like the inclination or motivation to participate socially and take risks (i.e., adaptability) or the perceived self-confidence, self-esteem, and emotional well-being (i.e., self-esteem). The scores on the self-esteem dimension were the lowest, in line with the results of other recent studies (e.g., Devitt et al., 2004; Orellano-Colón et al., 2016; Pousada et al., 2021). Likewise, significant differences were verified in the dimension of self-esteem as a function of a disability group, finding better values for the participants with hearing impairment compared with the participants with neurological or neuromuscular disabilities.

In addition to all these results, other studies with the Spanish PIADS version (Jiménez-Arberas and Díez, 2021) have demonstrated the predictive validity of the Spanish version of the PIADS scale on the abandonment and retention of assistive technologies (e.g., a correlation of −0.54 to −0.61 with abandonment), as well as a moderate but reliable correlation with the history of positive experiences with technology as measured by the Matching Person and Technology instrument (Scherer, 2002).

This study has some limitations, in particular the use of samples of the participants chosen by convenience sampling procedures and, also, the small sample size of some disability groups and the limited disability profiles considered. With random sampling and a higher and more balanced sample size across disability groups, age, and sex, it would be possible to study the PIADS subscale's measurement invariance, which plays a crucial role in the interpretation of test scores appropriately for individuals from different populations or cultures. It would also have been of interest to administer other measures to the entire sample (e.g., quality of life) in order to analyze the convergent validity of the PIADS, as well as following-up participants to determine the predictive validity of each factor on the possible future abandonment of the assistive devices. These limitations point to future research lines.

In summary, our results build on existing evidence of the good to excellent psychometric properties of the PIADS scale and corroborate the possibility of using it in subsequent studies as a valid and reliable outcomes measure of the psychosocial impact of assistive technology users. In addition, other recent results have also shown the compatibility of the PIADS language with models of human functioning frequently used in the rehabilitation field, such as the International Classification of Functioning, Disability and Health (ICF), which strengthens the potential implementation of PIADS in those contexts (Traversoni et al., 2018). Also, the three PIADS dimensions have proved their usefulness as relevant determinants of the adoption of eHealth solutions in the elderly (Axelsson and Wikman, 2016). All this evidence, undoubtedly, can contribute significantly to better inform the usefulness of the technology-based or supported interventions and thus to improve the quality of life of Spanish-speaking people with disabilities.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: The raw data supporting the conclusions of this article will be made available by the authors, on reasonable requests. Requests to access these datasets should be directed to Emiliano Díez, emid@usal.es.

ETHICS STATEMENT

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ED: conceptualization, methodology, formal analysis, data curation, writing the original draft, writing, reviewing, editing, and project administration. EJ-A: conceptualization, investigation, resources, data curation, writing, reviewing, and editing. TP: conceptualization, investigation, resources, data curation, writing, reviewing, and editing. All authors contributed to the article and approved the submitted version.

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SYSTEMATIC REVIEW
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Vocational Training in Virtual Environments for People With Neurodevelopmental Disorders: A Systematic Review

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People with neurodevelopmental disorders are often considered unsuitable or incapable of working in open employment. When employment is available, tasks are often limited, and opportunities for career development are restricted. Policy and funding constraints leave people with disabilities without an opportunity to develop skills due to the additional time and costs for employers. To overcome these barriers, virtual environments have been proposed as a safe and reliable solution for training. An important prerequisite for a wider uptake of training in virtual environments are demonstrations that the training leads to improved performance in the real world. This is particularly true for people with neurodevelopmental disorders, as transferring learnings from one context to another can be challenging. A systematic review was conducted to assess whether training in virtual environments can be used to improve real-world vocational skills in people with neurodevelopmental disorders. After a systematic search in six databases, eight out of the initially identified 1,806 articles met the inclusion criteria. The findings from these eight studies demonstrate that people with neurodevelopmental disorders can transfer vocational skills from virtual environments to real-world settings. With substantial technological improvements, a surge in accessibility, and improved affordability, there is a need to build upon the promising results identified in this review.

Keywords: neurodevelopmental disorder, intellectual disability, Autism, virtual environment, virtual reality, vocational training, work, transfer

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INTRODUCTION

Rates of people with neurodevelopmental disorders in competitive (i.e., open) employment are disproportionately low (Waghorn et al., 2012; Kinoshita et al., 2013; Modini et al., 2016b; Bush and Tasse, 2017). People with neurodevelopmental disorders such as Autism spectrum disorder and intellectual disability encounter considerable challenges in obtaining and sustaining work in open employment. Employment provides numerous benefits, including structure, a source of social support, opportunities to make decisions, income and greater independence (Modini et al., 2016b). Thus, despite frequent challenges such as stigmatising views and a low priority given by employers, it is evident that most still want to work (Kinoshita et al., 2013; Modini et al., 2016a). While open employment is the goal for many, the most common outcome is employment in sheltered workshops or unemployment (Lehman, 1995; Colella and Bruyère, 2011; Cimera et al., 2012; Winsor et al., 2018).

Sheltered employment is a program in which people with disabilities receive training to develop work-related skills and behaviours. The underlying premise is that individuals need preparation before entering open employment; a "train then place" model. The inherent value of sheltered workshops includes tailored support, longstanding social relationships and the opportunity to work. While sheltered workshops may be appropriate for many individuals, the tasks available are often limited, repetitive, and career development opportunities can be restricted. Cimera (2011) suggests only a few individuals transition out of sheltered workshops into open employment. Resource constraints and a lack of innovation are real problems faced by transition educators, making it difficult for people with disabilities to achieve their goals in open employment (Walker et al., 2019). Perhaps if sheltered workshops had access to more flexible, affordable and advanced training tools, they would achieve greater success in transitioning their clients into competitive positions.

Supported employment is an alternative approach where people with disabilities are placed in open employment, often without extensive preparation. The premise is that individuals are placed into competitive positions while receiving intensive on-the-job support; a "place then train" model. Supported employment is not dissimilar to *in-vivo* training, where learners are immediately engaged in a targeted activity in the same location where it is performed in real life. *In-vivo* is generally the preferred method of training as it exposes learners to the work setting and avoids the need to transfer learnings from artificial environments, like in computer-based training. Ideally, people with neurodevelopmental disorders would participate in supported employment all the time, although there are some drawbacks (Choi et al., 2012; Panerai et al., 2018; Lindsay and Lamptey, 2019).

The effectiveness of supported employment is well-established, but challenges remain, which prevent its wide-spread implementation (Marino and Dixon, 2014; Chen et al., 2015). One drawback is concerns surrounding its cost-effectiveness. As trained staff and focused interventions are required, it can become a time and resource-intensive process (Rogers, 2000; Parsons and Cobb, 2011; Marino and Dixon, 2014). Salkever (2013) reviewed the most common supported employment practise (Individual Placement and Support) and found its wide-spread expansion did not support long-term financial gain for employers. In essence, ongoing assistance effectively helps people with disabilities in competitive positions but it is not cost-effective to maintain (Vornholt et al., 2018). Educators and researchers have considered virtual environments to be a cost-effective method to help people in learning environments (Cromby et al., 1996; Bozgeyikli et al., 2014; Smith et al., 2020).

Virtual environments have appealed to educators as a way to bring the real world into the classroom (van Vonderen, 2004; Newbutt et al., 2016b). Immersive and interactive virtual environments may benefit people with disabilities via simulation of training which permits practising as if in real life. Real-world scenarios can be created to provide safe, repeatable and targeted training that focuses on improving the social and practical skills needed in the real world. Various environments and scenarios can be simulated to create realistic interactions for users to practise specific skills and develop confidence before attempting tasks in real-world settings, such as in open employment. Generally, people with intellectual disabilities and Autism spectrum disorder have limited opportunities for skill development in the real world due to concerns surrounding safety and ability (Dempsey and Ford, 2009). Certain life skills make sense for training to occur *in-vivo*; where one will perform the task in real life. Though, for training work-related tasks such as job interviews and the use of hazardous equipment, perhaps there is merit to training in virtual environments (Volkmar et al., 2014).

Virtual environments can be manipulated in ways that take advantage of the learning styles of people with neurodevelopmental disorders (Kandalaft et al., 2013; Knight et al., 2013; Newbutt, 2013; Newbutt et al., 2016a). Features can be enhanced or diminished, objects can be isolated, highlighted or removed, and relationships and associations can be emphasised. The environment can be controlled and manipulated in unique ways that make it particularly interesting for educators (van Vonderen, 2004). Tailored prompts and corrective feedback can be seamlessly integrated into training to reinforce teachings (Kandalaft et al., 2013; Knight et al., 2013; Newbutt, 2013; Newbutt et al., 2016b). Furthermore, visual and auditory cues have been used to help initiate responses and memorise steps in a procedure (Lancioni et al., 1999; Riffel et al., 2005; Mechling, 2007; Sauer et al., 2010; Bailey et al., 2011).

There is encouraging evidence that virtual environments can be used to improve life skills and social skills in people with neurodevelopmental disorders (Standen and Brown, 2005; Ramdoss et al., 2011, 2012). The two most common forms of training using virtual environments for people with disabilities are video-based and computer-based interventions. Video-based interventions involve the learner observing a target skill via video, and then opportunities are provided for the person to imitate the behaviours shown (Ramdoss et al., 2012). There is encouraging evidence to support both video-based interventions (Norman et al., 2001; Rehfeldt et al., 2003; Sturmey, 2003; Mechling et al., 2005; Sigafoos et al., 2005; Rayner et al., 2009; Mechling and O'Brien, 2010; Munandar et al., 2020) and computer-based interventions (Davies et al., 2003; Hutcherson et al., 2004; Hansen and Morgan, 2008; Ayres et al., 2009). However, unlike video-based interventions, computer-based interventions allow the learner to interact via external hardware (e.g., touch screen, keyboard, mouse, joystick) (Mechling and Gast, 2003; Ramdoss et al., 2012). Some view this interaction with the learner as a way of actively involving the participant, which may be beneficial for learning outcomes (Mechling et al., 2005).

The purpose of training in virtual environments is to develop valuable and functional skills to apply in the real world, such as obtaining and sustaining employment. Though, a significant challenge for people with neurodevelopmental disorders that is widely reported in the literature is difficulties in generalising learned skills from one environment to another (Hwang and Hughes, 2000; Rogers, 2000; Parsons and Mitchell, 2002; Westwood, 2009; Ramdoss et al., 2012; Knight et al., 2013). People with neurodevelopmental disorders tend to have difficulty applying learned behaviours in new tasks or contexts, such as in spontaneous situations. Thus, it is unclear how well the skills learned in virtual environments can be applied to real-world settings.

An essential prerequisite for a wider uptake of training in virtual environments are demonstrations that the training leads to improved performance in the real world. That is, the trained skills transfer to the real-world setting. In this paper, *transfer* has been defined as the process by which skills, abilities and knowledge developed through training are applied in a real-world situation or task (Baldwin and Ford, 1988). It is insufficient to assess the effectiveness of virtual environments by only quantifying the extent of improvement in training. This is because the results can almost always be expected to be positive, mainly due to practise effects (Michalski et al., 2019). Measures of real-world performance are therefore needed to determine the added value of training.

The potential benefit of training in virtual environments is clear, but its effectiveness in this population is less certain. Thus, it is necessary to assess virtual environments' effectiveness to improve work-related skills by reviewing articles that measure real-world transfer. This review's primary aim is to synthesise the evidence of virtual environments as a tool to train vocational skills in people with neurodevelopmental disorders.

METHOD

Search Strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) were followed throughout the review process (Liberati et al., 2009). The review was not pre-registered. A systematic literature search was performed on August 29, 2019. The search was updated on February 8, 2021. The following databases were used: PsycINFO, Ovid Nursing Database, Ovid MEDLINE, Ovid Emcare, and Embase. Psychology, medical and health databases were accessed to cover the scope of this current review. In addition, IEEE Xplore was searched on May 3, 2021. For all mentioned databases, the following search was conducted: [("virtual reality" OR "virtual environment*" OR "augmented reality" OR "mixed reality") AND (vocation* OR job OR work OR employment OR workplace OR profession* OR occupation) AND (disab* OR mental health OR "intellectual disability" OR "developmental disability" OR "learning disability" OR "brain injury" OR Autism OR retardation OR stroke OR schizophrenia OR bipolar OR depress* OR ADHD OR dyslexia)].

Inclusion Criteria

Peer-reviewed articles and conference papers published in English were included if they met the inclusion criteria while reviews and meta-analyses were not considered. Each article must have included (a) participants with a neurodevelopmental disorder; (b) a virtual environment; (c) vocational theme; and (d) real-world transfer. Our definition for each factor is detailed in turn.

a) The Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5) includes a category of conditions referred to as the "neurodevelopmental disorders." Studies with at least half of the participants diagnosed with a neurodevelopmental disorder were included.
b) To have been considered a virtual environment in this review it must have included the following components: (i) display or projection of an image; (ii) ability to interact in the environment; (iii) provision of sensory feedback (e.g., visual, auditory or haptic) (Gray, 2017; Michalski et al., 2019).
c) For this current review, a study was considered to have a vocational theme if the study outcome was work/job focused.
d) A study was considered to measure real-world transfer if real-world performance was measured pre- and post-training.

Article Selection

Four reviewers completed the article selection and screening process using Covidence systematic review management software (Covidence, 2020). Titles and abstracts were screened to identify studies that appeared eligible for inclusion. Full texts were sourced and read for articles that appeared eligible or for which eligibility could not be determined. During the full-text reading, articles were included if they met the inclusion criteria. At least two reviewers screened and read each full-text article. Articles were only included when both reviewers agreed. If a conflict arose in any stage during the article selection and screening process, the reviewers resolved the dispute via discussion until a consensus was reached. Reasons for all excluded articles during full-text screening are listed in **Figure 1**. Additionally, reference lists of included articles were scanned for additional articles.

Data Extraction

Data extracted from selected studies included information regarding sample, diagnoses, intervention, real-world performance and employment outcomes post-study. Only measures of real-world performance were extracted. Only data from participants with neurodevelopmental disorders were reported. Humm et al. (2014) was excluded as results from participants with Autism could not be separated from participants with other diagnoses.

Critical Appraisal

A critical appraisal for quasi-experimental studies was used to assess the methodological quality and risk of bias (Tufanaru et al., 2020). Items in the appraisal cover the presence or absence of basic elements of a study, including appropriate statistical analyses, a control group, reliability of measures and group similarity.

Two authors assessed each study. Both authors provided *yes, no, unclear* or *not applicable* responses to each of the nine items in the appraisal. Conflicts were resolved until a consensus was reached. The initial agreement was 90.5% before the two raters resolved conflicts.

Yes responses indicate a satisfactory level of quality was reached. All responses were tallied, and *yes* responses were reported as a percentage. Not *applicable* responses (8%) were not included in the analysis. Higher *yes* scores index greater methodological quality with the maximum being 100%. No studies were excluded based on the critical appraisal.

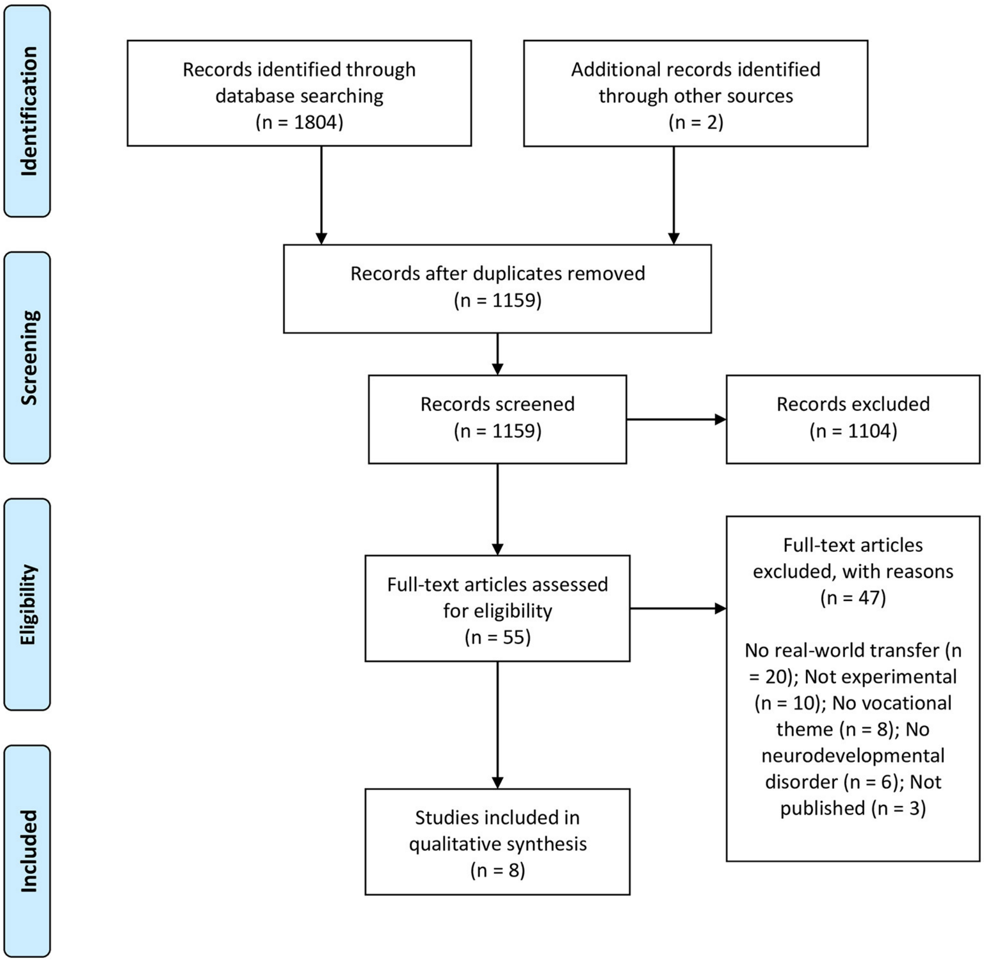

FIGURE 1 | The article selection and screening process using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram (Liberati et al., 2009).

RESULTS

Search Results

A total of 1,806 papers were identified through database searching and a snowballing strategy designed to identify additional articles. These publications were imported into EndNote where 647 duplicates were removed. Titles and abstracts were screened for the remaining 1,159 papers. Fifty-five articles appeared eligible for inclusion and were selected for full-text review. Forty-seven articles were excluded with the reasons outlined in **Figure 1**. Eight studies were included in this systematic review.

Critical Appraisal

The methodological quality of the included studies varied considerably (37.5–100%), with a mean satisfactory level of 82% across the eight studies.

Description of Studies

Of the eight articles, two reported multiple assessments resulting in a total of 10 real-world performance assessments. Studies compared training in virtual environments to different control groups: no training (four assessments), real-world training (one assessment), and workbook training (one assessment). Four assessments included pre-post measurements without a control group. Five assessments included participants with intellectual disabilities, three assessments included participants with Autism spectrum disorder, and two assessments included a mixed sample of participants with intellectual disability and Autism spectrum disorder.

Five studies used virtual reality job-interview training programs. These programs require users to engage in conversations with a virtual training agent. While each program is unique, they were similar in that discussion topics varied between sessions, users had freedom in their responses, and the virtual trainers displayed numerous emotions and feedback based on the user's response. Brooks et al. (2002) trained participants to prepare simple meals and identify hazards in a computer-based simulation of a virtual kitchen. Chang et al. (2013) trained meal preparation on a real table with the assistance of a flat-screen display used to provide cues and instructions. Mendozzi et al. (2000) trained simple warehouse tasks, including selecting objects by clicking on them with a mouse and moving them to another location. Mendozzi et al. (2000) also trained workshop skills which included the assembly of a torch, where a flat-screen display was used to provide textual hints to help participants follow the procedure.

Main Findings

Training in virtual environments significantly improved real-world performance from pre-test to post-test in nine out of 10 real-world assessments. All assessments with no-training controls (four) found training in virtual environments to be significantly more effective than no training. All assessments with real-world training controls (two) found no significant differences in comparison to training in virtual environments. One out of two assessments with a workbook training control found training in virtual environments to be significantly more effective, the other found no significant difference. See **Table 1** for a summary of the results.

DISCUSSION

This systematic review demonstrates that people with neurodevelopmental disorders can improve vocational skills via training in virtual environments. In nine out of 10 performance assessments, training in virtual environments lead to a significant improvement from pre-test to post-test in real-world settings. Importantly, the findings show that virtual training is more effective than no training. Four assessments with no-training controls found training in virtual environments to be significantly more effective. All available evidence suggests that training in virtual environments can enhance real-world performance in comparison to no training. These findings demonstrate the potential of virtual environments as a complementary tool for training.

No-training controls are essential for determining the added benefit of training but tell us little about its usefulness in comparison to other forms of training. One out of four assessments with an active control group found training in virtual environments to be significantly more effective. It is important to note that non-significant differences were found in the remaining three assessments. Overall, these findings are quite encouraging and suggest that training in virtual environments may be comparable to the outcomes of real-world training.

The findings from this review particularly highlight the effectiveness of conversational virtual human agents to develop job-interview skills. All studies assessing job interview skills found role-play performance improved after training in virtual environments. By practising speech and having the chance to go over their responses, users were able to improve content and delivery skills (Strickland et al., 2013; Walker et al., 2019). Strickland and colleagues (Strickland et al., 2013) found that participants were better able to improve content skills (i.e., verbal skills) in comparison to than delivery skills (i.e., non-verbal skills). However, the studies included were not designed to improve these delivery skills, perhaps due to the limitations in technology at the time. Modern technology may be better equipped to target non-verbal skills in training. For example, posture can be assessed via body sensors, facial expressions can be examined via video recordings, and eye contact can be measured via eye-tracking (Rogers et al., 2018). Thus, while virtual environments in this review were not accommodating for non-verbal skills, future training simulations could target these skills.

Assessments of real-world performance may identify whether participants improved their skills, but this provides no insight to participants' future employment prospects. One of the included studies (Smith et al., 2014) provided follow-up information regarding participants success in finding a job at a 6-month follow up (Smith et al., 2015b). Interestingly, the participants that trained in virtual environments were more likely to be competitively employed in comparison to participants that received no training (Smith et al., 2015b). Similar trends in employment have been found at five and 6-month follow-ups among other clinical populations (e.g., Autism spectrum disorder, bipolar disorder, major depressive disorder, post-traumatic stress disorder, and schizophrenia) (Humm et al., 2014; Smith et al., 2015a,c; Smith et al., 2017). The evidence that training in virtual environments leads to real opportunities is promising, though more studies providing follow-up data are needed to support this finding.

A job interview is a confronting experience and a critical part of obtaining a job in open employment, thus it is essential to teach people the skills needed for an interview. While this is an important step, employers look for individuals which have the necessary skills required for the job (Hall and Wilton, 2011). Three studies investigated skill transfer in applied tasks and found positive results. Mendozzi et al. (2000) assessed skill transfer from virtual environments in an item retrieval and assembly task. Furthermore, Brooks et al. (2002) evaluated the efficacy of using a virtual kitchen for vocational training in food preparation and hazard awareness training scenarios. Finally, Chang et al. (2013) assessed food preparation skills in participants with cognitive impairments. In taking the next steps, more researchers should continue to target skills that people will need on the job. Having an ability to practise skills in safe and repeatable settings may benefit certain training aspects, including procedural learning and adaptation to different work settings.

Training in virtual environments puts the learner in control of the learning situation but having an instructor present might be ideal for providing support in the learning process. In a study by Walker and colleagues (Walker et al., 2016), training job-interview skills in virtual environments was combined with immediate face-to-face coaching. Coaching included a reflection on the participant's training performance and strategies on how to improve future responses. This was designed to promote the generalisation of skills in real-world settings. Ideally, learners' practise with the support of a therapist or caregiver all the time; however, we know one-on-one training is expensive and time-consuming. Perhaps an integration of training in virtual environments with the guidance of an instructor is a practical yet effective approach. If training in virtual environments is to be adopted by organisations, understanding how training should be structured is essential. Information on the dose and frequency of training is therefore critical, yet only a few

TABLE 1 | Summary of included articles.

Study			**Brooks et al. (2002)**	**Burke et al. (2018)**	**Burke et al. (2021)**	**Chang et al. (2013)**	**Mendozzi et al. (2000)**	**Smith et al. (2014)**	**Strickland et al. (2013)**	**Walker et al. (2016)**
Sample	VE group	*n*	24	32 (M25, F7)	150 (M110, F40)	3 (M2, F1)	20 (M14, F6)	16 (M12, F4)	M11	5 (M1, F4)
		Age mean (*SD*)	15–43 (range)	23 (3.12)	21.7 (3.2)	22 (2.6)	25.8 (4.2)	24.9 (6.7)	18.21 (1.03)	20 (1.22)
	Control (specify)	Condition	1) No training 2) Real-world training 3) Workbook	-	-	-	-	No training	No training	-
		n	24	-	-	-	-	10 (M8, F2)	M11	-
		Age mean (*SD*)	15–43 (range)	-	-	-	-	23.2 (3.0)	17.66 (1.27)	-
Diagnoses per study sample*	Intellectual disability		100%	34%	40%	100%	100%	-	-	100%
	Autism spectrum disorder		-	69%	65%	-	-	100%	100%	-
Intervention	Content/Theme		a) Food b) Hazard awareness	Interview	Interview	Food	a) Warehouse b) Workshop	Interview	Interview	Interview
	Display		Flat screen	Flat screen	Flat screen	Flat screen	Flat screen	Flat screen	Flat screen	Flat screen
	Program		Custom program	Virtual interactive training agent	Virtual interactive training agent	ARCoach	Custom program	PeopleSIM$^{\text{TM}}$ technology	VenuGen4	TLE TeachLivE$^{\text{TM}}$
	User interaction		Computer-based	Video-based	Video-based	Physical	Computer-based	Computer-based	Video-based	Video-based
	Average time in minutes		-	-	-	-	5,760	532.5 (SD 92.6)	-	-
	Dropouts		-	-	-	-	0%	-	-	-
Real-world performance	Assessment		a) Food preparation b) Hazard identification	Role-play interview	Role-play interview	Food preparation	a) Item retrieval b) Assembly task	Role-play interview	Role-play interview	Role-play interview
	Outcome		Positive	Positive	Positive	Positive	Mixed	Positive	Positive	Positive
	Did VE training significantly improve real-world performance as compared to the no-training control?		a) Yes b) Yes	-	-	-	-	Yes	Yes	-
	Did VE training significantly improve real-world performance as compared to other controls (specified)?		2a) n.s. 2b) n.s. 3a) Yes 3b) n.s.	-	-	-	-	-	-	-
	Did VE training significantly improve real-world performance from pre-test to post-test (within-subjects)?		a) Yes b) Yes	Yes	Yes	Yes	a) Yes b) No	Yes	Yes	Yes
Employment outcomes post-study			-	-	-	-	-	VE group sig. more likely to receive a job at 6 months (Smith et al., 2015b).	-	-

M, Male; F, Female; VE, virtual environment; sig., significant; n.s., a non-significant difference.
**Combined totals may exceed 100% as participants may have had multiple diagnoses.*

studies included in this review reported the amount of time spent training.

The available studies training vocational skills in virtual environments have found encouraging results despite using technology that would now be considered outdated. In the eight included studies, three were computer-based, using keyboard, mouse, and joystick interactions. While most studies found positive skill transfer with such interactions, Mendozzi et al. (2000) found mixed results. They found their participants improved in an item retrieval task but did not improve in an item assembly task. These mixed results could be attributed to the technology used. In the study, participants were able to benefit from training in a virtual environment in the item retrieval task, which, by nature, requires fewer complex interactions. However, in the item assembly task of a torch, the physical interactions in training would be considered unrealistic, as using a keyboard and mouse is quite different from assembling objects by hand. This study was published 20 years ago, and technologies are now available to provide more realistic interactions via hand tracking and haptic feedback. It stands to reason that a greater realism in the interactions would improve the learning of practical hands-on skills.

Virtual environments offering a low level of immersion were found to be useful in this review. All studies used flat screen displays in the form of televisions and desktop monitors. This technology would generally be considered to offer a low level of immersion in comparison to what is currently available on the market (e.g., wearable head-mounted displays). Encouragingly, studies in this review reported that sessions were well-attended. As no studies used highly immersive technology, it remains unclear how people with neurodevelopmental disorders may respond in more immersive experiences. Future studies that include immersive virtual environments should report participant dropout rates as this is one indicator of comfort and usability.

Before immersive virtual environments can be encouraged for training people with neurodevelopmental disorders, information regarding adverse effects is critical and must be carefully considered. Self-report measures provide insight on a human level (i.e., how the participant is thinking and feeling), though such findings must be interpreted with caution. There are issues around assessing cybersickness via self-report, and these issues may be confounded in this population. People with neurodevelopmental disorders generally have communication barriers and a tendency to positively self-report (Schwartz and Rabinovitz, 2003; Cummins, 2005). Careful investigation of these responses must be considered to ensure the safe use of virtual reality and reduce the risk of adverse symptoms.

CONCLUSION

This review demonstrates that training in virtual environments can be used to improve vocational skills in people with neurodevelopmental disorders. While these results are encouraging, they are only supported by a small evidence base and a very limited range of skills assessed. The authors note 20 articles did not meet the inclusion criteria due to lack of a real-world transfer assessment. There seems a real lack in the translation from prototype to real-world testing. Many studies included in this review used technologies that would be considered outdated today. With substantial technological improvements, a surge in accessibility, and improved affordability, there is a need to build upon the promising results identified in this review. Support organisations may benefit by using virtual environments to boost productivity in the tasks people with disabilities have been commonly assigned to. However, the real advantage is providing people with opportunities to fulfil their goals and ambitions through safe virtual tasks that simulate activities they are typically excluded from in real life.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

SM, CE, AS, and TL conception of the work, article selection, and screening. SM wrote the manuscript. All authors revised the work critically for intellectual content and have read and approved the manuscript.

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Nurturing Grandchildren With Down Syndrome: A Qualitative Study on Grandparents' Needs Using Digital Tools†

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Grandparents who have grandchildren with disabilities are an underrepresented group in existing research related to the field. This qualitative phenomenological study's general purpose is to analyze, from a personal perspective, the situations and needs of grandparents who have grandchildren with Down syndrome. The participants' ages range from 65 to 85, and the ages of their grandchildren with Down syndrome range from 3 to 21 years. All participants had one grandchild with a disability, except for two, who each had two. A sociodemographic questionnaire was administered, and individual interviews were conducted, using open questions, through phone and/or video calls. An analysis of the participants' speech was carried out, which implied the development of a system of meta-categories and categories. This analysis was developed manually, given the COVID-19 environment. The results indicate a substantial change from negative feelings caused by the knowledge of the diagnosis to feelings related to positive experiences expressed currently. The participants see themselves as a fundamental source of support (informal, instrumental, practical, social, emotional, and economic) for their families and, mainly, for their grandchildren with Down syndrome. A need for information and training was observed when the grandparents talked about first being informed of the diagnosis and their concerns about the future of these grandchildren and their siblings. They made social demands, such as greater government involvement or more significant opportunities to access resources and rights for their grandchildren. The results are discussed, as are possible future research directions.

Keywords: grandparents, Down syndrome, grandchildren, needs, family, qualitative investigation

INTRODUCTION

In recent years, social changes have transformed traditional family models (Muñoz et al., 2015). Today, grandparents play a different role than they did decades ago due to, among other reasons, difficulties reconciling work and family life, as well as an increasing tendency to have fewer grandchildren. In addition, they share more years of their lives with their grandchildren, creating

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†Following Royal Spanish Academy recommendations (RAE, 2014), throughout the text, the masculine will be used as unmarked or generic gender to facilitate readability. In any circumstances in which the context may induce doubt or require clarification or emphasis that the group comprises people of both genders, or of a specific one, the necessary splitting or specification will be made

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a relationship that can be viewed as bidirectional (Velasco et al., 2016). Currently, older adults can be grandparents for as much as a third of their lives (Drew et al., 1998). However, despite this important reality, research on grandparents' role is scarce. One reason is limited opportunities in the past to exercise their role in the face of shorter life expectancies and the fact that parenting was done mainly by parents. Early studies largely have not focused on grandparents' influence on grandchildren (Velasco et al., 2016). Moreover, family members' relationships have changed over the years. It has been observed that a social need exists to acknowledge grandparents' role, including a desire for more closeness on the part of children and grandchildren. The relationship between grandchildren and grandparents is viewed as a unique one (Woodbridge et al., 2011).

Grandparents and Disability

A potentially shocking moment in some grandparents' lives is the birth of a grandchild with a disability. It is very likely that most grandparents today have limited experience with people who have disabilities, as they largely had been stigmatized, invisible, and normally excluded from society while they were growing up. Social attitudes have changed and evolved, yet many grandparents still have not considered the possibility/experience of having/caring for a grandchild with a disability (Woodbridge et al., 2011). Therefore, grandparents are experiencing new demands from the family unit (Velasco et al., 2016) and perceive a change in ways of exercising and giving meaning to their role (Sullivan et al., 2012; Muñoz et al., 2015). Some, upon the shock of learning of their grandchildren's disability diagnosis, experience recurring feelings of guilt or a strong sense of responsibility (Lehmann et al., 2011). Because of this and other feelings, they often must reconstruct their idealized grandparental identity and, thus, readjust their expectations (Woodbridge et al., 2011). More specifically, they may give up personal life pursuits and even move to live closer to their grandchildren with a disability (Velasco et al., 2016). Such circumstances could cause grief or stress (Lee and Gardner, 2010), and possibly even double suffering created by the situation of their grandchild's diagnosis while experiencing their children's pain. Therefore, it is particularly important to prevent possible anxiety, anguish, and/or worries so that they do not lead to more serious consequences (Sevilla et al., 2019). Grandparents have few opportunities to learn about their grandchildren's disabilities except through hearing secondhand information from their adult children (Lee and Gardner, 2010). However, this has been changing: Today, grandparents receive training and information through various avenues, such as disability organizations. It can be said that it is important for them to know about their grandchildren. As a study by Velasco et al. (2016) points out, grandparents' knowledge of the type of disabilities their grandchildren have and all the information they can receive firsthand will help avoid stress produced by the absence of such knowledge. Generally, grandparents do not have direct contact with grandchildren's doctors, educators, etc., so on certain occasions, they do not know how to react or how to help (Lee and Gardner, 2010). When grandparents are asked about their needs, they indicate that they want access to more information and assistance (p. 17). Grandparents of grandchildren with disabilities often experience increased information needs (Lee and Gardner, 2010). Some research indicates that they perceive receiving less social support than other family caregivers (Kresak et al., 2014). These situations either can be helpful or a hindrance. Similarly, the birth of a grandchild with a disability can be viewed as an element of family cohesion or stress (Lee and Gardner, 2010; Tumbarello, 2010). Some studies indicate that grandparents can be a stressor for parents facing their child's diagnosis (Lehmann et al., 2011). Emotional support from grandparents may be significantly related to higher self-esteem among mothers, as indicated by Trute's (2003) and Trute et al.'s (2008) research. Other studies indicate a possible weakening in the family unit if grandparents do not understand the new situation or if they cannot adapt to the new reality (Gardner et al., 2004).

Other findings indicate how internal resources, such as self-esteem or self-mastery, are associated with a lower level of stress and better mental health. The less social support grandparents have, the more stress they may experience in the early stages (Findler, 2014).

One notable aspect is how supportive grandparents are in family development with a grandchild who has a disability (Woodbridge et al., 2011). Grandparents can provide many types of support for their families, including informal, formal, economic, social, practical, and/or emotional (Poehlmann, 2003). A study by Kresak et al. (2014) demonstrated how informal support in particular can increase rates of family quality-of-life satisfaction (Cilleros and Gómez, 2016). However, Lee and Gardner (2010) found three influential variables in grandparents' participation and support: residential proximity; parent-grandparent relations; and knowledge about their grandchildren's disabilities.

As Muñoz et al. (2015) demonstrated, tasks related to basic activities of daily living are instrumental (e.g., rehabilitation, medical consultations, etc.), and care techniques (medication, exercise, or mobilization) are predominant with grandchildren who have a disability. According to Velasco et al. (2016), grandparents can contribute materially (shopping, errands, care, etc.) as caregivers and educators (economic support, aid with routines, etc.), providing instrumental and/or practical support. A fundamental form of support offered by grandparents is emotional (actively listening to children and grandchildren, giving advice, etc.).

Professionals, Disability, and Family

Grandparents' knowledge of their grandchildren's disabilities is essential and necessary, and the literature suggests that professionals should pay attention to how families define their experience of caring for a child with a disability (Martínez, 2008; Neely-Barnes and Dia, 2008). Thus, it is necessary to consider whether planning interventions for families of children with disabilities should be the same for all family members. As Neely-Barnes and Dia (2008) noted, parents' concerns and needs are very different from those of grandparents (Heller et al., 2000). Trute's (2003) research suggests that it is vital that professionals in child disability services employ a family-centric model that pays attention to the importance of grandparent support. It is also essential to involve them in most of the services available.

Support groups, as Lee and Gardner (2010) stated, are viewed as a means of coping and reducing stress. Most of these groups are created in early childhood centers (Orgaz, 2009). Attendance in these groups seems to provide opportunities for grandparents to receive emotional support and guidance, thereby helping them adjust to their grandchildren's disabilities (Ponce and Vega, 2012). They also facilitate their understanding of their grandchildren's disabilities and how they can be supportive. In addition, they can improve grandparents' overall well-being and provide a better parenting environment. Grandparents who have used these groups have reported that they found them useful for obtaining information about available services, providing a forum for sharing concerns, and reducing feelings of isolation (Kresak et al., 2014).

Studies About Family and Disability

It is necessary to highlight the scarcity of research that focuses on knowing the role, situation, and needs of grandparents of grandchildren with disabilities (Miller et al., 2012). Few studies have analyzed the relationship between grandparents and grandchildren under this condition (Velasco et al., 2016), being that children's parents generally are the protagonists in such studies (Mahoney and Perales, 2012), they provide information about grandparents' situations to researchers; thus, the firsthand perspectives of grandparents of grandchildren with disabilities are little known or researched.

Even less research focuses specifically on Down syndrome (Hodapp, 2008; Fidler et al., 2012). In a study by Hastings et al. (2002) on grandparents' support in families with children who have Down syndrome, the participants were 34 mothers and 27 fathers. Thus, we wish to highlight the importance and need to conduct research that focuses on grandparents' situation, role, and needs.

Research by Fernández and Izuzquiza (2017) on parental perceptions about Down syndrome's impact on the family exposes how greater importance is placed on the extended family, particularly grandparents, upon learning of the diagnosis. They stated the need to have better resources and support in relation to the disability, as well as to establish stable contact with other grandparents and families with similar characteristics. However, it was found that once the initial shock stage was overcome, grandparents became one of the main sources of support in the family environment, creating strong emotional bonds with their grandchildren.

General Objective, Specific Objectives, and Research Questions

Considering the reality above, the general purpose of this research is to determine and analyze the situation and needs of grandparents of grandchildren with Down syndrome from a personal perspective. This general objective can be operationalized into the following specific objectives:

- To realize the impact that the birth of their grandchildren exerts on grandparents.
- To analyze the needs that arise after learning about the diagnosis.
- To determine whether changes occur in grandparents' lives after the birth of their grandchildren.
- To determine whether grandparents perceive differences in existing relationships with their grandchildren with and without disabilities.
- To analyze the type of support role grandparents play within a family with a person who has a disability.
- To determine whether grandparents perceive changes in the relationships with their children since the birth of their grandchildren.
- To determine the primary source of support for grandparents of grandchildren with Down syndrome.
- To identify grandparents' needs throughout their grandchildren's life development.
- To discover grandparents' current and future concerns about their grandchildren's development.
- To analyze the influence that technology can exert on grandparents' relationships with their grandchildren.
- To find out whether, through technology, it is possible to offer more significant resources for grandparents who have grandchildren with disabilities.

The research questions that this study aims to answer are:

– What are the needs of grandparents of grandchildren with Down syndrome?
– Do technological devices support the relationship between grandparents and their grandchildren?
– Will technology be a facilitating factor in conducting this study?

MATERIALS AND METHODS

The qualitative research methodology was used in this study. It can be characterized as inductive, understanding the context and the people under a holistic perspective, being sensitive to the effects that the researcher causes to the people under study, and understanding study participants within their frame of reference, in which all perspectives are valid. It is a humanistic method that emphasizes the validity of the research, and that all contexts and people are potential study subjects (Quecedo and Castaño, 2002). Within this qualitative research, the phenomenological method was used, specifically because the objective was to describe and interpret experiences, emotions, and/or perceptions from different participants' unique perspectives, using their own words and/or expressions. This has implied that data collection and analysis were done simultaneously (Sampieri et al., 2014).

Participants

Of the participants, 75% were grandmothers (women) and 25% were grandfathers (men) of grandchildren with Down syndrome. The sample comprised married couples (grandfather and grandmother), in-laws, and grandmothers. They attended a support group through contact with the Down Syndrome Foundation, thanks to Early Intervention and/or other resources that their grandchildren have used and continue to use. Purposive or convenience sampling was used with a self-selected sample. Among the participants, 66.7% are married, 25% widowed, and 8.3% separated/divorced, with all between ages 65 and 85 (M = 76.41). Most have higher education (58.3%), 25% have secondary education, and 8.3% have primary education and/or no education. A total of 100% of the participants are retired. A total of 50% have had contact, although not close contact, with a disability before the birth of their grandchildren; approximately 33.3% have had previous close contact; and 16.7% have had no contact at all. Most of the sample has between one and eight grandchildren (91.7%), and almost all (83.3%) have only one grandchild with Down syndrome, while 16.7% have two. More than half their grandchildren with Down syndrome are age 14 or younger (64.3%), with the rest between ages 19 and 21 (35.7%). Almost 60% of the participants live near their grandchildren. The majority (58.3%) sees their grandchildren several times a week, 33.3% daily, and 8.3% not every week. Most were informed about their grandchildren's Down syndrome diagnosis after birth (85.7%), with only 14.3% learning about it before birth. None of the participants had another grandchild with another disability.

In the social and medical sciences, voluntary samples are standard (Sampieri et al., 2014), and this research reflects this, as it involves individuals who voluntarily agreed to participate in the study. Simultaneously, it is a self-selected sample, as the grandparents were proposed as participants and/or responded to an invitation from the Down Syndrome Foundation.

Inclusion criteria included:

- Being a grandparent
- Having one or more grandchildren with Down syndrome
- Belonging to the Down Syndrome Foundation of Madrid
- Attending or having attended a support group of the foundation
- Wishing to collaborate
- Wanting to participate
- Predisposition toward offering consent to allow the interviews to be recorded.

Finally, exclusion criteria were:

- Not being a grandparent
- Not having a grandchild with Down syndrome.

Instruments

The instrument developed for this research comprised two parts to gather data: the first sought sociodemographic information (see **Supplementary Annex I**); and the second used open-ended questions/topics to gauge grandparents' views and attitudes (see **Supplementary Annex II**). The second part was divided into diagnosis, family relationships, support, and needs/demands. Under *diagnosis*, feelings, communication, needs, and possible changes were discussed. Under *family relationships*, there were differences with their grandchildren with/without disability and what needs do they have. Under *support*, they were asked about the type of support role they believe they play in their families, possible changes in their relationships with their children after the diagnosis, and who or what is their most outstanding support. In the final topic, *needs/demands*, needs, changes, responses, resources, improvements, technological tools' usability, and future demands or concerns were discussed.

Procedure

Recruiting for the study focused on grandparents belonging to two support groups from the Down Syndrome Foundation of Madrid, one of which is Early Care (for children 0–6 years old), while the other is the School for Families (for youths ages 6–21 years). The director of the Early Attention Center, Psychologists, and Social Workers from the School for Families group was contacted and given a description of the study's purpose and methodology. It also explained how it would follow ethical standards and require informed consent from each participant, while guaranteeing confidentiality and anonymity. Due to COVID-19 (García-Peñalvo et al., 2020, 2021), the individual interviews were conducted either through online video calls and/or by phone during March and April 2020, when all participants were confined to their homes. The importance of today's digital technology as a means of facilitating this research during the pandemic is noteworthy. Without it, this study would not have been possible. Therefore, the technological means used by both researchers and participants was of critical importance as a helpful resource and facilitator in this research. The use of technology during the project's first stage was essential, facilitating the study's design, sample selection, interviews with participants, and analysis of the results.

Data Analysis

The qualitative content analysis procedure began with an examination of the data and imposition of a structure (Sampieri et al., 2014), i.e., analyzing the interviews conducted to identify several specific themes that would later be grouped into general categories, or meta-categories. Within these categories, sub-categories were created based on existing themes. Once these were determined, a conceptual map was drawn up. An analysis was made of word frequency in each interview. Specifically, a word cloud was created with the 20 most frequent and relevant words. Concepts, themes, categories, links, and patterns present in the data were discovered, giving them meaning and allowing for interpretation to shape them according to the research objective (Sampieri et al., 2014). Coding was conducted based on the various meta-categories and categories (Sánchez-Gómez et al., 2017). To this end, each interview was analyzed in detail several times. Subsequently, participants' experiences were described according to their perspectives, language, and expressions (Sampieri et al., 2014). Several analysis matrices were created. The first one analyzed the presence of content within each of the meta-categories. The degree of content on research, valuable resources related to that field, and personal experiences also were analyzed. The second matrix entailed creating an association of each interview's content (textual quotations) with each meta-category. Thus, a discursive linkage and detailed analysis of each category for each interview were established (Sánchez-Gómez et al., 2017). Furthermore, the analysis required an in-depth understanding of the context surrounding the information collected to reconstruct facts and stories to link the results with available knowledge and generate a theory based on the data (Sampieri et al., 2014).

Based on a proposal by Lincoln and Guba (1985) – reflected in a scientific article by Vicario et al. (2013) – the quality assessment in qualitative research in this study comprised:

- Internal credibility validity (participant observation, data triangulation, researcher, theoretical, methodological and disciplinary, critical judgment of colleagues, collection of referential material, and participant checks)
- External transferability validity (theoretical sampling, exhaustive descriptions, and data collection)
- Dependability reliability (identification of the researcher and their role, detailed descriptions of the informants, identification and description of the analysis and data collection techniques, and delimitation of the physical, social, and interpersonal context)
- Confirmability objectivity (participant checks, mechanical data collection, and triangulation).

We used the *Qualitative Research Assessment, Elements for Critical Reading (Adapted from Critical Skills Appraisal Program (CASP) and Health Cara Libraries Unit (HCLU). Evidence-based Health Cara: An open learning resource for health care practitioners. Oxford:* CASP and HCLU, 1999*)* as a guide or checklist to assess the quality of our qualitative research, as it followed the order of the general research process, which includes phases such as justification, collection of information, presentation and analysis of the results, discussion, and preparation and dissemination of the final report (Vicario et al., 2013).

Data Collection Techniques

The data collection techniques used in this study have a strong technological component. Both the first contact established with each participant and each of the audio interviews (those conducted by video call and those conducted by phone) were recorded in M4A format[1].

To achieve the greatest completeness of the qualitative analysis (Sánchez-Gómez et al., 2017), this study used three data collection techniques: verbal (interviews); non-verbal (emotions and non-verbal communication expressed by each participant); and complementary (images, texts, books, videos, drawings, magazines, etc.).

The verbal data collection technique used different technological tools, such as computers, cell phones, tablets, recording apps, etc. The second information collection technique, non-verbal, used observation facilitated by the technological devices utilized to conduct the interviews. Finally, the complementary information collection technique entailed computerization of all the documents that various participants provided.

RESULTS

From the discourse-based categorization, the conceptual map was extracted and divided into two groups: (1) grandparents of grandchildren with Down syndrome $\leq$14 years old (58.33%) and (2) $>$14 (41.67%). Each group was organized into six meta-categories or main axes – diagnosis, disability, supports, concerns, family relationships, and demands – and 22 categories (see **Figure 1**).

Down syndrome was the main theme of the interviews. **Figure 2** displays the 20 most frequent words in the grandparents' discourse. Generally, they spent a large part of the discourse talking about their grandchildren with disabilities, early intervention, disability (of their grandchildren or as a concept), the foundation, support groups, and/or the functions/support that they perform. An analysis matrix was created to analyze the presence of content from each discourse in each meta-category (see **Figure 3**). Three factors were analyzed in each meta-category: content present in research; resources concerning the field of research; and personal experiences. The procedure comprised analyzing each factor in each category belonging to each participant's discourse. Each analysis factor was weighted from 1 to 3, with 1 indicating "no content of this typology is presented," 2 indicating "content is presented, but in an ambiguous and unclear manner," and 3 indicating "the content represented corresponds to this typology 100%." In the six meta-categories, the score in the analysis of personal experiences (yellow) is the highest because the main objective of the research is to determine each participant's situation and needs. In almost all the interviews, they related their experiences.

We found the most differences depending on the meta-category that we observed in the analysis of valuable resources in the field of research (pink). Under "demands," the participants reported more useful and/or necessary resources for themselves and/or their families, including support groups and assistance from the foundation, society, and/or the government. This is reflected in participants' statements, e.g., "That is the public environment, (where) more things and activities are offered to children with disabilities (8.33%)," "We have been shown the resources available at the foundation (8.33%)," "I signed up for all the courses (16.67%)," "Governments should do more on their part (8.33%)," "There should continue to be more resources and new resources to provide more freedom and autonomy (8.33%)," and "It would be greatly improved if it were a social duty to inform with reality (8.33%)." The categories in which the most resources are mentioned were "family relationships" and "diagnosis." Under "family relationships," they cited essential people who have been supportive and/or helpful in different situations as resources, e.g., "I have met many people through my grandson (8.33%)," "Now we are all united, parents, grandparents, siblings, uncles, and aunts (8.33%)," "My husband (8.33%)," "My wife (8.33%)," and "A priest friend

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[1] All recordings, both first contacts and entire interviews, are available to speakers in M4A format upon request.

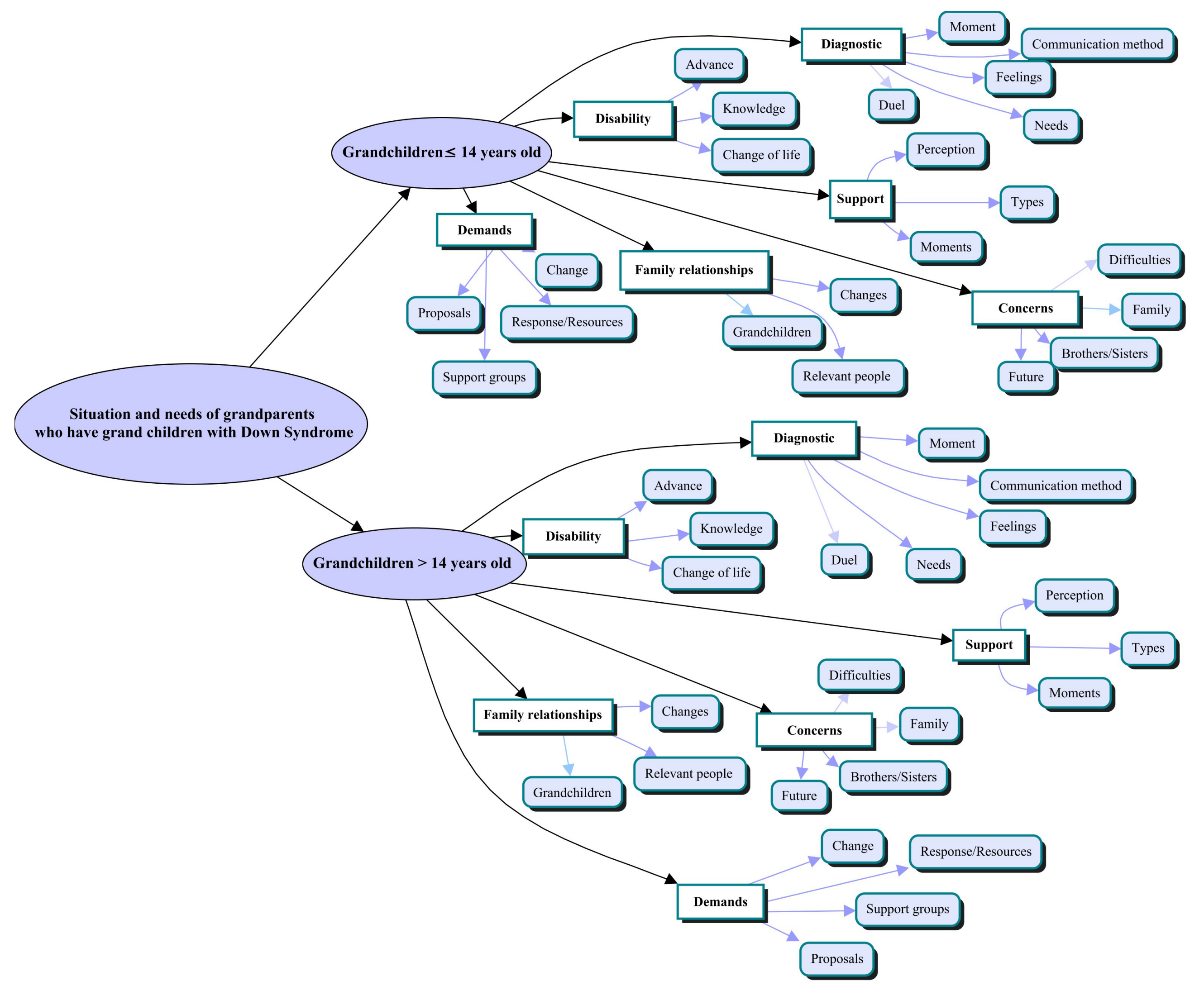

FIGURE 1 | Conceptual map.

(8.33%)." Under "diagnosis," they presented resources related to the moment they heard about the diagnosis and, also, of human nature, e.g., "Someone who speaks to you with total sincerity and trying to help you (8.33%)," "Doctors were closer, who was not silent (8.33%)," and "That they told us differently (8.33%)." The subsequent meta-categories, in terms of resources, would be "concerns" and "disability," e.g., "There are more and more competencies and more involvement (8.33%)," "Now they have much more freedom (8.33%)," "Now the children are very well-assisted (8.33%)," "They will look for a solution that will be the best among what is available (8.33%)," "When I am 30 (years old), there will be more resources (8.33%)," "Now they are already attended to, there are many associations that all families go to (8.33%)," and "There are many companies that provide jobs for people with disabilities (8.33%)." They cited fewer resources under "support," as they presented and perceived themselves as a valuable and natural resource for their families, e.g., "Having the child always at home, that support (8.33%)," "I act more like a second mother than a grandmother (8.33%)," "Helping my daughter, my grandson, and being there for whatever they want (8.33%)," "We do everything for him and him (8.33%)." Referring to the content present in each meta-category of each interview, in the area of investigation (purple), very high scores near the maximums were registered, i.e., most of the analyzed content was found under "diagnosis," "support," "concerns," "family relationships," and "demands." Most referred to substantial changes in the social and disability field from the past to the present, e.g., "Today, we can be happy that it is not like a few years ago (8.33%)," "They were as if they were isolated, mongoloid, hidden (8.33%)," "Now nothing has to do with it (8.33%)," "I felt sorry for them; now I see it differently (8.33%)," and "It has changed a lot (8.33%)." However, all meta-categories generally provided a large volume of content to analyze, as they all

FIGURE 2 | Word cloud.

presented personal and particular situations and demands or needs that they perceived.

A second analysis matrix was created to establish a relationship between the different discourses with each meta-category. Two tables were created – discourses by meta-categories of grandparents of grandchildren with Down syndrome ≤14 years old and >14 – with the objective of establishing similarities and differences between the two.

Diagnosis

Regarding the moment they were informed about their grandchildren's disability, most stated having heard about it after birth. Only two (grandparents of two grandchildren with Down syndrome) found out during pregnancy. Most affirmed that it was an unexpected moment of significant impact. Approximately 8.33% stated that they preferred not to know beforehand to avoid making those last months of pregnancy worse. Also, 8.33% said that they would have aborted these children upon diagnosis. Communication was by phone or in person. For half the participants, it was their daughters who revealed it to them. In other cases, it was doctors and/or other health personnel (33.33%). Another family member notified another 16.67%, and another 16.67% would have preferred to be told differently. They remembered the situation as being very intense. Their first feelings upon the diagnosis were negative (anger, pain, shock, anxiety, crying, or grief). Approximately 58% reported the importance of mourning as a relevant aspect to be able to move forward, while 16.67% noted more negative feelings when the grandchild with Down syndrome was their first grandchild. Approximately 25% explained the situation generated at that moment in terms of other people close to them: They did not know whether to call or not, whether to visit them, whether to congratulate them, etc. Several participants (33.33%), when expressing their feelings, placed importance on having life experience to cope with the situation better. Half relied on faith/beliefs as a support in the face of certain events. Concerning their initial feelings after diagnosis, they all pointed out how certain feelings disappeared or changed completely over time (from negative feelings to happiness, joy, satisfaction, pride, etc.). Finally, 41.67% described having a feeling of double suffering (for the grandchild and daughter). Concerning needs expressed at the time of being informed of the diagnosis, they cited a need to be alone (8.33%), better forms of communication (P9/P10), access to medical and psychological staff (8.33%), crying and mourning (8.33%), and/or being with the family (8.33%). Several grandparents (33.33%) did not express specific needs during these first moments after hearing of the diagnosis due to the support provided by their daughter and/or their inner circle, and/or family acceptance. There was a perceived need for information about their grandchild's disability in the early stages, but half had viewed it as unimaginable to have a grandchild with a disability in their family; thus, they were not previously informed. Referring to the diagnosis, there were no major differences between the two groups: They all reported on a moment and a situation lived and perceived years ago with similar characteristics.

Disability

Most of the sample (75%) noted advances in society in the area of disability. They were mostly aware of changes and improvements in rights, self-determination, and freedom for people with disabilities. Others (33.33%) referred to changes in their perception of disability since the birth of their grandchild. 16.67% spoke of the importance of referring to people with disabilities as people, not merely as children with a disability. In this aspect, we found differences between the two groups—those belonging to the first group expressed and perceived changes in society. However, only 8.33% of the second group referred directly to this issue. They reported obtaining the best knowledge about their grandchildren's disability from their daughters (41.67%), their partner (8.33%), the foundation (58.33%), and individual searches for information (33.33%). Approximately 25%, in a positive tone, indicated that they had met different people thanks to their grandchildren with Down syndrome. Some participants spoke of changes in their lives because of the birth of their grandchildren, e.g., less freedom (8.33%); skipping vacations (8.33%), and abandonment of preferences (25%). Among other aspects, 25% said they had undergone changes and have been able to integrate them into their lives. Furthermore, 16.67% perceived the changes as positive. In this aspect, both groups made similar contributions.

Supporters

The grandparents perceived themselves as fully supportive of their family after the birth of grandchildren with a disability, assisting with their care through informal, instrumental, or practical tasks (e.g., feeding, showering, dinner, taking them to early intervention, summer, extracurricular activities, sleeping, caring, taking them to school, help with routines, etc.); social tasks (relationships with family/friends); and

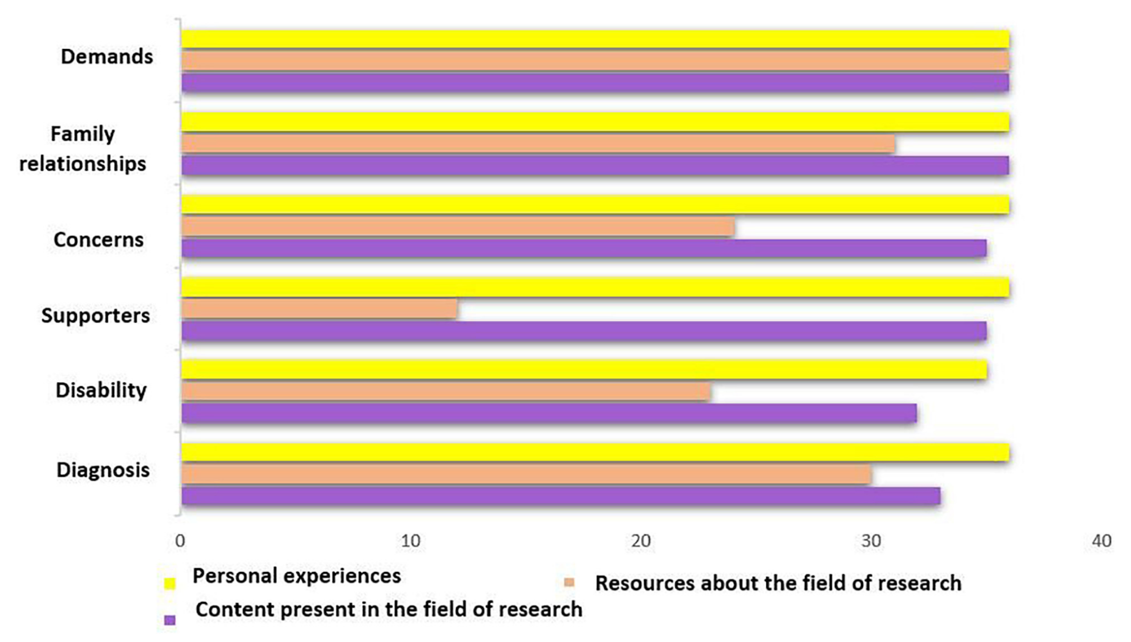

FIGURE 3 | Analysis of the presence of content by meta-categories.

emotional tasks (under challenging moments in the beginning). Approximately 33.33% said they also provided economic support without providing any details beyond their willingness to provide for whatever is necessary for their grandchildren. Approximately 33.33% referred to the importance of support based on the expression "day by day." Approximately 25% say that they temporarily have taken full care of their grandchildren to give their daughters time off. There is an individual difference in the language of the second group compared with that of the first in terms of a more supportive contribution to their grandchildren when they were younger.

Concerns

More than half (58.33%) said that they knew they would not be alive when their grandchildren are older. There was a more significant number of direct references to their possible absence in their grandchildren's lives in the first group than in the second. Approximately 33.33% noted that they worried about their daughters' future, not theirs. Regarding of difficulties, 41.67% expressed concerns about problems in their grandchildren's communication. Almost everyone in the first group pointed that their grandchildren were adolescents, which differed from the second group, whose grandchildren are no longer in that stage, so they are not worried about it. Half the participants say they are aware of their role as grandparents vs. their children's role as parents, i.e., they realize that they are not the ones who must make crucial decisions. Approximately 25% expressed concern for the future of the siblings of their grandchildren with Down syndrome, but they all expressed concern about the future of their grandchildren with this disability. The first group expressed concerns related to adolescence, the near future, family, friendships, a future they still perceive as far away, etc. However, the second group was concerned about these grandchildren's future after leaving school, i.e., their professional/work prospects, university education, new friendships, etc. Furthermore, 8.33% expressed concern over grandparents' low visibility compared with parents in the realm of grandchildren with a disability. Another 8.33% expressed concern about how it is sometimes the environment that may limit opportunities for those with a disability. Some also expressed their fear of possible abuse of people with disabilities as adults. It is worth mentioning the 8.33% of the grandparents expressed a very different vision of the future when they were born compared with the one they have now. One grandparent in the second group expressed concern over how the current situation with their granddaughters with Down syndrome (21 and 20 years old) is not similar to that of other girls of the same age without disabilities. These concerns were not cited by anyone in the first group.

Family Relationships

Around 50% of the sample noted that their Down syndrome grandchildren's birth led to substantial changes in their lives, for the better, in terms of their relationships with their daughters. However, 16.67% said that they have not perceived any changes, and that the relationship between them and their daughters is similar to that before the birth. Regarding who they rely on the most when they need it, they cited their partner (33.33%), daughter (25%), the foundation/support group (58.33%), work colleagues (8.33%), a religious association of people with disabilities and their families (8.33%) and/or a priest (8.33%). Approximately 16.67% said they did not need any particular support. Approximately

58.33% described perceiving differences in their relationships with their grandchildren with and without disabilities vs. 41.67% who did not. Approximately 16.67% emphasized that the external environment, not the family itself, creates the most differences for their grandchildren. In this aspect, there were no notable differences between the two groups of grandparents. It is worth noting that several participants remarked on the importance of new technologies today, referring to how they create a stronger and more frequent link with their grandchildren.

Demands

Most of the sample (75%) referred to changes over time in their information needs and how these gradually have been satisfied through their families (41.67%), the foundation (100%), or by their own means (66.66%). They all emphasized the importance of attending support meetings at the Down Syndrome Foundation of Madrid, viewing this as fundamental for their personal and social development, as well as to remain informed about Down syndrome developments and getting to know their grandchildren better (8.33%). Approximately 25% noted that the group is something unique and private – a safe place. Another 25% pointed out how important Dr. Jesús Flórez has been to them in everything related to Down syndrome. If we focus on the proposals expressed, we must highlight grandparents' desire for greater social and governmental involvement toward people with disabilities (33.33%), more information from the beginning (16.67%), greater realization of grandparents' role (8.33%), offering people with disabilities the same opportunities as other citizens (8.33%), treating these people with respect as the people they are (8.33%), a closer relationship with health personnel (8.33%), and an increase in available resources (8.33%). In addition, 25% referred to the importance of the coexistence of special and regular education. However, a clear difference exists between the two groups when it comes to making demands. Everyone in the first group made them, while only 19.67% in the second group made any.

DISCUSSION

The present study aimed to analyze the situations and needs of grandparents of grandchildren with Down syndrome. Regarding the moment they heard about the diagnosis, they reported having negative feelings, corresponding with Findler's (2014) study. However, over time, they reported that these feelings diminished almost completely, corresponding with Velasco et al. (2016). Several described medical personnel's role as cold/dismissive. Lehmann et al. (2011) pointed out this same aspect, referring to how these professionals may view grandparents as peripheral to the nuclear family. Some grandparents pointed to the importance of faith and belief. This corresponded with Yamashiro and Matsukura (2014) and Lehmann et al. (2011), who agreed with this idea as an important element of learning and/or a tool for coping with having a grandchild with a disability. Most reported changes in their lives since their grandchildren's birth, and one can compare this narrative to other studies (Woodbridge et al., 2011; Miller et al., 2012; Findler, 2014; Kresak et al., 2014; Yang et al., 2018) that describe how grandparents often delayed their life goals. Some of the literature (Heller et al., 2000; Trute, 2003; Miller et al., 2012; Yang et al., 2018) corresponded with the present study's findings in terms of types of support that grandparents provide to their families in the face of disability, i.e., informal, instrumental, practical, social, emotional, and economic. Similar to Heller et al.'s (2000) research, several grandparents noted how they provided more support to their grandchildren in the past than they do today. Similar to some participants, Miller et al. (2012) referred to how grandparents express and talk about their future death and the lack of their presence in their grandchildren's lives as adults. Many mentioned how relationships with their daughters improved since their grandchildren's birth, corresponding with findings by Lehmann et al. (2011), Velasco et al. (2016), and Yang et al. (2018). Results from Bruns and Foerster (2011) found that grandparents often cited their spouse as being the most supportive person in their lives. Research by Miller et al. (2012) affirmed the existence of tensions in the marriages of grandparents who have grandchildren with disabilities and possible conflicts derived from this situation. It should be noted that this research does not refer to this type of behavior, but rather the opposite. According to research by Woodbridge et al. (2011), and in line with some participants in this study, grandparents tend to use the same parenting style with grandchildren with and without disabilities, although several noted some differences. Grandparents' concerns in this study are diverse. Among them is a clear concern for the future, thereby relating to research by Gallagher et al. (2010), Miller et al. (2012), and Yang et al. (2018). Several grandparents in the present study also pointed out their concern for the future of the siblings of their grandchildren with disabilities, corresponding with results from Lee and Gardner (2010), Miller et al. (2012), and Yang et al. (2018). Gallagher et al. (2010); Findler (2014), and Yang et al. (2018) attached importance to grandparents' narratives that exposed their current situation as a wonderful experience, replete with happiness and a perception of personal growth since the birth of their grandchildren with this disability. These discourses are comparable to those from participants in the present study. However, some expressed their wish for more access to information related to the disability in the beginning, corresponding with Gallagher et al. (2010) and Velasco et al. (2016). However, they also emphasized the importance of having been able to educate themselves gradually. Several studies (Woodbridge et al., 2011; Velasco et al., 2016; Yang et al., 2018) highlighted grandparents' sense of having little knowledge of and/or contact with disabilities in general, corresponding with participants in the present study. Some studies (Trute, 2003; Lee and Gardner, 2010; Kresak et al., 2014) found that grandparents place great importance on support groups with ongoing assistance, which all participants in the present study also expressed, stressing that these groups are an essential means of providing knowledge, support, and understanding.

Methodological Limitations

Some of the limitations that this research has encountered and/or presents in relation to the participants include the following:

- Similar age range
- Similar sociodemographic characteristics
- Little cultural diversity.

Limitations related to the central theme of the research include the following:

- Insufficient and limited existing research related to the field under study.

Finally, social limitations related to this research include the following:

- COVID-19, which functioned as an impediment to recruiting participants and conducting interviews/focus groups face-to-face
- Scarce governmental participation and involvement
- Limited social consideration of the role of grandparents with grandchildren who have disabilities.

Future Research Directions

This study comprised an important starting point for future lines of research related to grandparents, mainly considering their testimonies in the first person. Future studies could examine factors related to grandparents' well-being, support needs, and relationships established with their children in greater depth, which would require multigenerational research. In addition, it would be interesting to conduct these studies while taking into account different cultures, races, lifestyles, and/or socio-cultural characteristics. Thus, more resources and specialized, personal, and necessary care could be offered to grandparents of grandchildren with disabilities.

It is essential to consider and keep qualitative research very much in mind to realize and develop proposed future lines of research.

CONCLUSION

The results from this research are of great relevance and interest for further study of the important topic of grandparents with grandchildren who have disabilities – in this case Down syndrome. On the part of the participants, there is full recognition of the social progress of disability from the past to the present and the relevance that this change has had in their lives. Some describe the double suffering (grandchild and children) that they experienced after the birth. There is a perceived need to work more on self-determination in people with disabilities, which would prevent grandparents from worrying about the siblings of their grandchildren with Down syndrome. In examining the accounts, they also expressed a need for continuous training and information, as well as uninterrupted contact with people in a similar situation.

Thus, it can be deduced that the results presented in this research would not have been obtained without the use of modern technology. Furthermore, as some of the participants emphasized, these new technologies were important for them, as it provided a link to their grandchildren, particularly nowadays. For all these reasons, it is essential to emphasize technology's importance in this study on several levels. Finally, it should be noted that most of the demands that grandparents made can be answered or facilitated through technological means, thereby achieving greater agility in procedures, requests, and support, as well as minimizing demands.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MM-C and RM-S: development and theoretical approach. MS and RM-S: methodological part, sample design, elaboration of collection techniques (quality, validity, and reliability), field work with the other authors, and data analysis and results. RM-S, MS, MM-C, JM, and FG-P: assembly of the conclusion and discussion with the theoretical part, and synthesis and translation. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.661205/full#supplementary-material

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