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Wearables and mobile technologies in Autism Spectrum Disorder interventions: A systematic literature review

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ABSTRACT

Background: Nowadays, in the Internet of Things era, wearables, mobile technologies and enhanced communication and computing capabilities has led to the upsurge of innovative mobile health solutions. Many research efforts have taken place recently in the domain of autism spectrum disorders (ASD).

Method: The current paper presents a thorough review of the literature on the use of wearables and mobile technologies for ASD-related interventions. It intends to give insights and guidelines to researchers in order to develop more useful and closer to market products.

Results: We searched seven databases for research articles published after 2000. Of 4,722 articles initially retrieved, only 83 papers met the inclusion criteria. Several challenges still exist in the research efforts towards the development of applications exploiting the latest wearables and mobile technologies for ASD interventions: small number of participants in the studies, non-generalizable results, technology considerations, privacy, legal and ethical issues, etc. Subjective assessment is also another significant barrier for further adoption of the developed solutions.

Conclusions: The findings support the notion that this is a very promising sector which is expected to undergo an important increase in the coming years. There is a great need for highly customizable solutions. In parallel, researchers should focus on the importance of developing applications for the real world and not only for controlled environments. Further studies employing artificial intelligence and affective computing are needed to support both diagnosis and therapeutic interventions as well.

1. Introduction

1.1. *Autism Spectrum Disorder*

Autism spectrum disorder (ASD) is a neurodevelopmental disability characterized mainly by impaired social behaviour and communication ("Autism spectrum disorders", 2017). Current studies support that the male-to-female ratio is 3:1 (Loomes, Hull, & Mandy, 2017). According to Baio et al. (2018) approximately 1 in 59 children has been identified as having ASD. ASD may range in severity from a handicap that somewhat limits an otherwise normal life to a devastating disability that may require institutional care. It is a lifelong disability which not only limits the life of the person, but also causes significant stress for their family. The symptoms normally appear by the age of three. Environmental and genetic factors are suspected to be the main causes of ASD according to recent scientific evidence. Apart from impairments in the social domain, where the autonomic nervous system seems to play an

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important role, other autistic characteristics include limited range of interests combined with rigid and restricted or repetitive behaviors (stereotypes). Some of the main communication deficits may include: inconsistent eye contact, being slow or failing to respond to someone, talking about a favorite subject without noticing that others are not interested, having an unusual tone of voice, and being unable to understand other people's actions. They may also present echolalia or other repetitive behaviors, while having a lasting intense interest in certain topics (e.g. numbers, facts or details). It is also common for those with ASD to become upset by slight changes in their routine, as well as be more or less sensitive than other people to sensory input (e.g. noise, light, etc.). Apart from the challenges they experience, ASD people may also have super strengths, like: extremely improved memory, being able to learn things in detail, being strong visual and auditory learners, or even excelling in science (e.g. math, music, etc.).

1.2. Wearables and mobile technology

Over the last years, information and communication technologies (ICTs) have been widely utilized to help the healthcare industry. The European Union has funded various research and development projects involving the use of smartphones, wearables and other mobile devices in the healthcare industry to support the different stakeholders (patients, healthcare professionals, healthcare systems, etc.) (Koumpouros & Georgoulas, 2019). Currently, there is a great need for well-established solutions capable of managing effectively the flow of information between the different parties and actors in the healthcare industry. As today's citizens are on a constant move, the solutions offered should be able to follow them everywhere in a non-intrusive way. With almost 107 mobile subscriptions per 100 inhabitants, the number of mobile-cellular telephone subscriptions is greater than the global population (The World Bank, 2012; International Telecommunication Union (ITU, 2017; Mobile cellular subscriptions | Data, 2019), while the number of devices with broadband capabilities reached more than 1 billion worldwide (PWS, 2014). Growth in mobile cellular subscriptions in the last five years was driven by countries in the Asia-Pacific and Africa regions. Smartphones' capabilities have enabled the extension of more services on the move at any time and at any place. For example, the use of multiple-lens camera solutions, biometric sensors, augmented and virtual reality features, etc., ignited the development of innovative applications. Mobile health (mHealth) has already provided significant evidence of its potential with better access to knowledge and information, improved service delivery and reduced response time during crises (WHO. mHealth, 2011;Labrique, Vasudevan, Kochi, Fabricant, & Mehl, 2013). According to several studies, the mHealth's market size is booming ("mHealth Apps Market Size Worth mHealth Apps, 201711.8 Billion By 2025 CAGR: 44.2%", 2017mHealth Apps, 2017"mHealth Apps Market Size Worth $111.8 Billion By 2025 CAGR: 44.2%", 2017; Statista, 2019f), with more than 100.000 mHealth applications listed on app stores. It was estimated that in 2017, mHealth's global revenue would reach US$26 billion, a 61% growth for CAGR-Compound Annual Growth Rate (research2guidance, 2013). The proliferation of mHealth applications holds promise for better results in almost any interesting party (Koumpouros & Georgoulas, 2016). It is anticipated that mobile interaction will be facilitated by smart agents as the post-app era starts to dominate. Already, smartphone users can use virtual personal assistants (VPAs) and are exposed to richer experiences. New methods of biometric authentication are appearing (eye or finger detection, etc.) while smartphones are exploiting innovative technologies to sense the heart rate of the user. Moreover, wearables are providing many services using Internet of Things (IoT) and Machine Learning technologies. Due to IoT, these devices can easily exchange data between the device and network. Autonomous wearables employed with built-in connectivity features and advanced processing capabilities (e.g. smartwatches and Google Glass) are capable of running third-party applications. In contrast, passive wearables (e.g. Fitbit) can only provide biometric data. Health Band, Heart Rate Monitors, Smart ECG Meter and others are some of the wearable devices already available. Euromonitor reports that wearables will become the world's best-selling consumer electronics product after smartphones. Autonomous and smart wearables are projected to exceed 305 million units in 2020, with a compound annual growth rate of 55%. The worldwide wearables market is forecast to increase up to 8.2% from the prior year. Moreover, the market is expected to return to double-digit growth from 2019 until 2022 as smartwatches and other form factors grow in popularity, according to the (IDC: The premier global market intelligence company, 2019).

1.3. Potential use of mobile technologies and wearables in ASD

The use of assistive technologies in ASD can be really helpful in education as well as in other domains (i.e. communication, behavior, and sensory issues). The development of wearable and mobile technologies that target the aforementioned areas can improve both children's and parents' lives by providing a path to independence. Mobile technology and wearables are easily portable and discreet, and are rapidly advancing in terms of technology, size, functionality, and real-time applications. These technologies can be used in a variety of ways; for example, as a motivating teaching tool or strategy for increased independence or even for alternative and augmentative communication (AAC), which mainly focuses on communication issues and social interactions within autism (The Center of AAC & Autism, 2019). Behavior management can also be supported by mobile technologies that create regular schedules and routines to follow each day. The emergence and low cost of new mobile devices has dramatically changed how service providers deliver educational and behavioral services to individuals with ASD. Nowadays, smartwatches and other wearables have enough processing power and memory in order to assist children with ASD. The minimalism and comfort of these wearables (e.g. wearing on the wrist) make them accessible at anytime and anywhere and protect children from losing them. Another important feature of wearables is the option of using different materials that may work best with the individual sensory needs of the child. Moreover, the collection of health data from the integrated sensors can help in monitoring and controlling of the subject as needed (e.g. in stressing situations). Another useful characteristic of mobile technology is the provision of remote control by the parent devices (i.e. smart phones or tablets). As communication is a key issue in ASD, wearables can provide vocal output in different forms (i.e. text to speech,

Table 1
Research questions.

No.	Research question	Motivation
RQ1	What channels are used to publish research articles in ASD interventions exploiting wearables and mobile technologies?	To identify the different sources where the selected articles have been published.
RQ2	What is the frequency of the studies over time?	To identify the prevalence of mobile and wearable interventions in ASD over time.
RQ3	What technological approaches have been used?	To provide information on the different technological approaches (e.g. affective computing, etc.) in the selected articles.
RQ4	Which methods are used to assess the provided technological solutions?	To examine the assessment methodologies (objective or subjective) of the final solution.
RQ5	For what purposes have been applied the proposed solutions?	To identify the specific domains of intervention (e.g. learning, monitoring, etc.).
RQ6	What are the targeted symptoms/health conditions?	To identify the specific symptoms and health conditions that are studied in the selected articles.
RQ7	What are the targeted population?	To identify the population targeted by the interventions (e.g. parents, carers, patients, etc.)?
RQ8	What are the outcomes obtained by the application of the proposed solutions?	To analyze the results obtained from the selected articles.
RQ9	What type of devices have been used?	To provide information regarding the devices used in the interventions (e.g. mobile phone, wearables, smartwatch).
RQ10	What is the number and type of the users evaluated in the final solutions?	To investigate the need for participants in the pilot studies.

picture selection, etc.), while being highly customizable, thus, allowing children to choose the output type that best suits their needs. The integration of a micro-electro-mechanical system (MEMS) allow wearables to house the appropriate sensors in order to advance communication and interaction (e.g. speakers, microphone, heart rate sensors, etc.); for example, a wearable could provide visual signals by interpreting speech communication. The same technology could also help with social interaction, by providing children with appropriate ways to interact with others. Sensory feedback is also possible using wearables in order to manage stress and anxiety (Altogether Autism, 2019). To this end, stimulation can be triggered upon detection of stress and a sudden increase in heart rate or breathing by using the integrated sensors in the wearables. Artificial intelligence algorithms can support this process. As some children with ASD are sensitive to sounds and loudness, the wearables could identify certain sounds and levels of noise and allow them to play their own music which calm them in a time of stress. Behavioral therapy techniques can also be applied in mobile applications by a therapist. Motivation and rewards can also be provided to encourage that children behave in a certain way. Overall, wearables and mobile technology can provide help and assist children with ASD in several areas. Their portability along with the discretion and the ability of personalization support and enforce their use.

The current paper reviews the literature in order to identify current trends, future prospects and possible gaps related to the most modern mobile, smart and wearables technologies in the field of autism spectrum disorder.

2. Methodology

To conduct the systematic review, we followed the SLR (Systematic Literature Review) process proposed by Kitchenham (2004). According to this study, an SLR is a means of identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest. According to the methodology proposed, a series of ten research questions were defined along with their motivation (Table 1).

A search of peer-reviewed published literature was carried out in September 2018 for articles related to the use of mobile and wearable technologies in ASD interventions. A set of search terms criteria and resources was defined at a first step. SCOPUS, Science Direct, ACM Digital Library, IEEE-Xplore, PubMed, Wiley InterScience and GoogleScholar were the main sources. According to PICO (Stone, 2002), the keywords used (employing Boolean phrases) in the searches included the following: asd, autism, autistic, autism spectrum, autism spectrum disorder, developmental disability, developmental disorder, ADHD, technology, ICT, information and communication technology, mobile, mobile phone, mobile device, tablet, phablet, smartphone, smart phone, wearable, smartwatch, smart watch, app, iphone, android, ehealth, e-health, electronic health, information and communication technologies, mhealth, mobile health, m-health. The screening process was based on the following inclusion and criteria:

- Articles published after 2000
- Studies published in English
- Research from peer-reviewed journals or conferences, books and lecture notes
- Articles are focused on mobile or wearable solutions
- Papers must be in a full or short version (not abstracts)

For quality assessment purposes, we weighted the importance of the reviewed articles. The criteria used along with their weight are presented in Table 2. For conferences/workshops and papers published in the journals CORE Conference Ranking 2018 (CORE

Table 2
Quality assessment criteria.

No.	Quality assessment question	Weight
QC1	Is the technological solution presented in details?	Yes (+1), Partially (+0.5), No (+0)
QC2	Is the evaluation/assessment method specified?	Yes (+1) / No (+0)
QC3	Are there any empirical results from the evaluation phase?	Yes (+1) / No (+0)
QC4	Is the paper published in a recognized source?	Conferences, Workshops: CORE A* or A (+1.5), CORE B (+1), CORE C (+0.5), not included in CORE ranking (+0). Journals: ranked Q1 (+2), ranked Q2 (+1.5), ranked Q3 or Q4 (+1), no JCR ranking (+0) Other sources: (+0) Books, Lecture Notes: (+2)
QC5	What is the number of participants in the evaluation phase?	≥20 (+2), 10-19 (+1.5), 6-9 (+1), 1-5 (+0.5), 0 or not specified (+0)
QC6	Are any negative findings presented?	Yes (+1), No (+0)

Rankings Portal - Computing Research and Education n.d.) and Journal Citation Reports (JCR) 2018 (Ipscience-help.-thomsonreuters.com, 2019) were used accordingly.

According to Table 2, the maximum score for a study could be 8 points. The data extraction process was supported by the research questions defined in Table 1 and the information presented in Table 3.

3. Results

The initially retrieved publications were examined as a first step for potential inclusion based on their title and abstract, while we excluded any duplication. The remaining articles underwent a full text review. Additionally, the references of each selected article were examined to identify other relevant sources. The process followed was based on the PRISMA guidelines, as depicted in Fig. 1 (Moher, Liberati, Tetzlaff, & Altman, 2009).

The study was conducted in September 2018. Even though a great number of articles was retrieved in the first step (n = 4723), only a small percentage of them (21.7%, 1024 out of 4723) underwent a full text review. In the last step, 947 articles were discarded and only 77 articles were finally selected after applying the eligibility criteria described in previous sections. The following tables (Tables 4 and 5) summarize the list of the selected papers and the review results. Table 4 presents the selected articles along with the quality assurance results. Table 5 presents the technological solution of each study, the type and number of end users participated in each study, and its duration. Seven more papers were identified in the literature, but being review papers, they could not be used in our study. However, for the sake of completeness we mention them here. In (Chen, 2012) a review of the literature about multi touch devices in autism interventions is presented. Stephenson and Limbrick (2015) conducted a literature review on studies relevant to the use of smart devices by people with developmental disabilities, while Kagohara et al. (2013) reviewed the use of iPods, iPhones and iPads in educational settings. Zapata, Fernández-Alemán, Idri, and Toval (2015)) reviewed the usability of mHealth applications by people with various mental disabilities and Aresti-Bartolome and Garcia-Zapirain (2014) explored the literature for articles related to technology and ASD. A series of studies related to mobile technologies and their contribution in ASD is presented by Vlachou and Drigas (2017). Finally, Boucenna et al. (2014) conducted a literature review on interactive technologies in ASD.

According to the quality assessment process followed, the majority of examined papers (72.7%) are above the half of the total score. Five papers scored 7, one scored 7.5 and one paper achieved the maximum score (see Table 4). This fact confirms that the reviewed papers are appropriate for the research conducted.

RQ1. What channels are used to publish research articles in ASD interventions exploiting wearables and mobile technologies?

According to the results obtained from the review process the publication channels vary. The majority (65%) is published in journals, while 28.4% is reported in conference proceedings, only 3.7% is published in books and 2.5% in lecture notes. Almost a

Table 3
Data extraction.

No.	Extracted data
RQ1	Publication source should be extracted in order to answer the question.
RQ2	Publication year is required.
RQ3	The technological domain addressed should be presented (e.g. affective computing, artificial intelligence, etc.).
RQ4	The assessment methodology should be presented.
RQ5	Application’s targeted category (e.g. teaching, monitoring, etc.) should be defined.
RQ6	The health topic should be extracted to identify the health condition addressed.
RQ7	Categorization of the population targeted should be defined (e.g. patients, carers, teachers, etc.).
RQ8	The major findings of the evaluation process should be presented to reveal any problems and lessons learned.
RQ9	Details on the used technological device are required (hardware and software details).
RQ10	Details on the number per type of user participated on the evaluation/assessment phase.

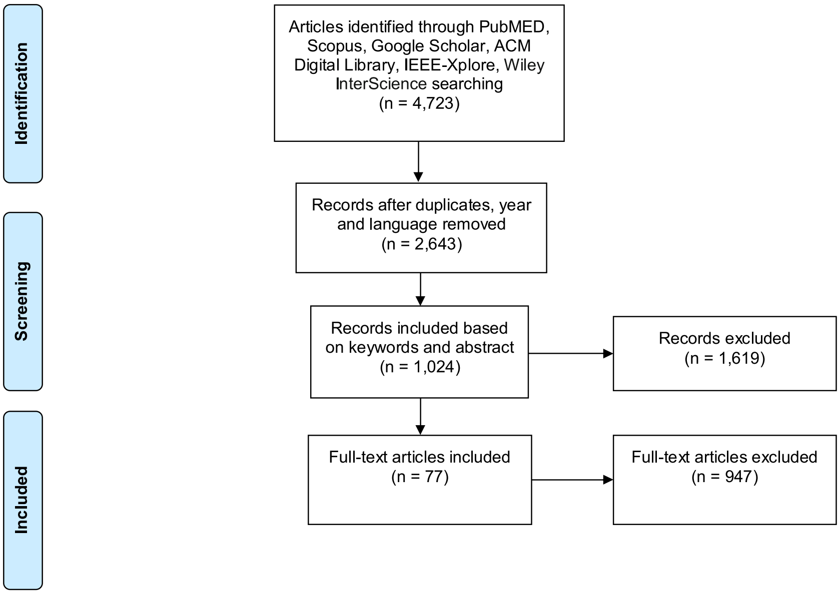

Fig. 1. PRISMA process followed.

quarter (22.9%) of the sources was published in medical journals. The rest of the articles were published in technology related conferences and journals. Computers & Education (Fernández-López, Rodríguez-Fórtiz, Rodríguez-Almendros, & Martínez-Segura, 2013; Mintz, Branch, March, & Lerman, 2012; Mintz, 2013), International Journal of Child-Computer Interaction (Doenyas, Şimdi, Özcan, Çataltepe, & Birkan, 2014; Fletcher-Watson, Pain, Hammond, Humphry, & McConachie, 2016, 2016b; Holt & Yuill, 2017), and Journal of Medical Systems (De Leo, Gonzales, Battagiri, & Leroy, 2011; Quezada et al., 2017) appeared three times each, while Research in Autism Spectrum Disorders (Neely, Rispoli, Camargo, Davis, & Boles, 2013; Smith, Spooner, & Wood, 2013) and the Journal of Autism and Developmental Disorders (Gentry, Kriner, Sima, McDonough, & Wehman, 2015) appeared once. Finally, Procedia Computer Science (Aziz, Abdullah, Adnan, & Mazalan, 2014; da Silva, Gonçalves, Guerreiro, & Silva, 2012; Silva, Gonçalves, & Silva, 2014; Tsiopela & Jimoyiannis, 2014) was the most frequent one, with four articles, followed by Research in Developmental Disabilities (Burke, Andersen, Bowen, Howard, & Allen, 2010; Cihak, Kessler, & Alberto, 2007; Vélez-Coto et al., 2017) with three articles. The rest of the publications are distributed in 32 journals, 23 conferences, three books and two Lecture Notes. It has been easier to find recognized journals than conferences. A significant percentage 27.3% (n = 15) of the journals have no JCR ranking, while 43.5% (n = 10) of the conferences have no CORE ranking. In computer science, a field of continuous growth and over-specialization, there is a tremendous growth of low-level journals and conferences (Andonie & Dzitac, 2010). Almost a third (30.1%) of the articles have been published in non-recognized sources, confirming that research in the field is still expanding (Fiordelli, Diviani, & Schulz, 2013; Koumpouros & Georgoulas, 2016, 2019; Kumar, Nilsen, Pavel, & Srivastava, 2013), and more recognized conferences in the examined field should emerge.

RQ2. What is the frequency of the studies over time?

The reviewed articles were published from 2007 onwards, with the majority (90.4%) of them being published after 2012. More than one third were published after 2016. Fig. 2 shows the frequency of papers per year.

RQ3 & RQ9. What technological solutions have been used?

Table 5 presents the distribution of the technological solutions employed per project. Almost one third (29.6%) of the published articles worked on assistive technologies. Twenty-six percent of the research conducted in the last years was related to Computer Assisted Instruction and 28.6% to Computer Mediated Communication. Affective Computing holds also a prominent position (20.8%) after 2007. Furthermore, 7.8% of the work is related to Serious Games, while Cloud Computing and Artificial Intelligence cover 2.6% each. A tie was presented for the most popular software platforms among the selected papers. Android and iOS were used equally (39.8%, n = 33 for each one of them). Web based apps were far behind even if appearing in second place (12%, n = 12). These results are in line with the needs of the ASD population, as described in the introduction section. To this end, communication issues and socialization are the top priority, followed by solutions trying to teach skills and train the end users in several fields. Additionally, the identification of behaviors and emotions is also important. Artificial intelligence (AI) on the other hand, has been implemented in only two studies (Coronato, De Pietro, & Paragliola, 2014; Rad & Furlanello, 2016) mainly to detect stereotypical behaviors.

RQ4. Which methods are used to assess the provided technological solutions?

Most of the papers utilized a combination of different methodologies for assessment purposes. More specifically, 33.8% used observation techniques (Alzrayer, Banda, & Koul, 2017; Bauminger et al., 2007; Chien et al., 2015; Cihak et al., 2007; da Silva et al., 2012; Fletcher-Watson, Pain et al., 2016, 2016b; Holt & Yuill, 2017; Hourcade, Williams, Miller, Huebner, & Liang, 2013; King, Thomeczek, Voreis, & Scott, 2014; Lyan, Amjad, Shaden, & Khalid, 2015; Mamun et al., 2016; Mintz, 2013; Mintz et al., 2012; Neely et al., 2013; Quezada et al., 2017; Rad & Furlanello, 2016; Rivera, Mason, Jabeen, & Johnson, 2015; Silva et al., 2014; Smith et al.,

Table 4
Selected papers and review results #1.

Ref.	QC1	QC2	QC3	QC4	QC5	QC6	QA Score
Zamfir et al., 2012	1	1	1	2	2	1	8
Fletcher-Watson, Pain et al., 2016, 2016b	1	1	1	1.5	2	1	7.5
Fernández-López et al., 2013	1	1	1	2	2	0	7
Teeters, 2007	1	1	1	2	2	0	7
Quezada et al., 2017	0.5	1	1	1.5	2	1	7
Roldán-Álvarez, Gomez, Márquez-Fernández, Martín, & Montoro, 2016	1	1	1	2	2	0	7
Zaffke et al., 2015	1	1	1	2	2	0	7
Mintz et al., 2012	0.5	1	1	2	2	0	6.5
Mintz, 2013	0.5	1	1	2	2	0	6.5
de Urturi et al., 2012	1	1	1	2	1.5	0	6.5
Vélez-Coto et al., 2017	0.5	1	1	2	2	0	6.5
Venkatesh et al., 2012	1	1	1	1.5	2	0	6.5
Chien et al., 2015	0.5	1	1	2	2	0	6.5
Escobedo et al., 2012	1	1	1	1.5	1.5	0	6
Gentry et al., 2015	0	1	1	2	2	0	6
Sano et al., 2012	0.5	1	1	1.5	1	1	6
Clark et al., 2015	0	1	1	2	2	0	6
Cheng et al., 2018	1	1	1	1	2	0	6
Abdullah & Brereton, 2015	1	1	1	1	2	0	6
Doenyas et al., 2014	1	1	1	1.5	0.5	1	6
Cihak et al., 2007	1	1	1	2	0.5	0	5.5
Coronato et al., 2014	1	1	1	2	0.5	0	5.5
King et al., 2014	0.5	1	1	2	1	0	5.5
Dibia, 2016	0.5	1	1	1.5	1.5	0	5.5
Fletcher-Watson, Pain et al., 2016, 2016b	0.5	1	1	1	2	0	5.5
Irwin, Preston, Brancazio, D'angelo, & Turcios, 2015	1	1	1	2	0.5	0	5.5
Boyd et al., 2017	0.5	1	1	1.5	1.5	0	5.5
Schuck et al., 2016	0	1	1	2	1.5	0	5.5
Alzrayer et al., 2017	1	1	1	2	0.5	0	5.5
De Leo et al., 2011	1	1	1	1.5	1	0	5.5
Khan et al., 2013	0.5	1	1	0	2	1	5.5
Artoni et al., 2018	1	1	1	1.5	1	0	5.5
Zheng & Motti, 2017	1	1	1	1.5	1	0	5.5
Rad & Furlanello, 2016	1	1	1	0	1.5	1	5.5
Washington et al., 2017	1	1	1	0	1.5	1	5.5
Burke et al., 2010	0.5	1	1	2	0.5	0	5
Di Palma et al., 2017	1	1	1	1.5	0.5	0	5
Torrado et al., 2017	1	1	1	1.5	0.5	0	5
Smith et al., 2013	1	1	1	1.5	0.5	0	5
Holt & Yuill, 2017	0.5	1	1	1.5	1	0	5
Hourcade et al., 2013	0.5	1	1	1.5	1	0	5
Bittner et al., 2017	0	1	1	2	1	0	5
Fletcher et al., 2010	1	1	1	0	1.5	0	4.5
Lyan et al., 2015	1	1	1	0	1.5	0	4.5
Bauminger et al., 2007	0.5	1	1	1	1	0	4.5
Uphold et al., 2016	0	1	1	1.5	1	0	4.5
Neely et al., 2013	0.5	1	1	1.5	0.5	0	4.5
Tsiopela & Jimoyiannis, 2014	1	1	1	0	1	0	4
Szydło & Konieczny, 2016	1	0	0	1	2	0	4
Rodrigues et al., 2012	0.5	1	1	0	0.5	1	4
Kientz et al., 2007	1	1	1	1	0	0	4
Campbell et al., 2017	0	1	1	0	2	0	4
Amiri et al., 2017	0.5	1	1	0	1.5	0	4
Silva et al., 2014	0.5	1	1	0	1	0	3.5
de Urturi et al., 2011	1	1	0	0	1.5	0	3.5
Mamun et al., 2016	0.5	1	0	2	0	0	3.5
Rivera et al., 2015	0	1	1	0	1	0	3
Northrup, Lantz, & Hamlin, 2016	0.5	1	1	0	0	0	2.5
da Silva et al., 2012	1	1	0	0	0	0	2
Duncan & Tan, 2012	1	0	0	1	0	0	2
Leijdekkers, Gay, & Wong, 2013	1	0	0	1	0	0	2
Gay & Leijdekkers, 2014	1	0	0	1	0	0	2
Cesário, Rodrigues, Li, Wu, & Nisi, 2016	1	0	0	1	0	0	2
Lubas et al., 2014	1	0	0	1	0	0	2
Torrado et al., 2016	1	1	0	0	0	0	2
Gomez, Torrado, & Montoro, 2016	0.5	0	0	1	0	0	1.5
Rani, Legino, Mudzafar, & Kamaruzaman, 2014	0.5	0	0	1	0	0	1.5
Boyd et al., 2015	0	0	0	1.5	0	0	1.5

(*continued on next page*)

Table 4 (*continued*)

Ref.	QC1	QC2	QC3	QC4	QC5	QC6	QA Score
Aziz et al., 2014	1	0	0	0	0	0	1
Mohanaprakash, Subedha, & Lakshmi, 2015	1	0	0	0	0	0	1
Goel & Kumar, 2015	1	0	0	0	0	0	1
Helmy & Helmy, 2016	1	0	0	0	0	0	1
Vukovic et al., 2016	1	0	0	0	0	0	1
Fazana et al., 2017	1	0	0	0	0	0	1
Ahmed, Hassan, & Rashid, 2017	1	0	0	0	0	0	1
Kamaruzaman, Rani, Nor, & Azahari, 2016	1	0	0	0	0	0	1
Husni & Budianingsih, 2013	1	0	0	0	0	0	1

2013; Teeters, 2007; Torrado, Gomez, & Montoro, 2017; Torrado, Montoro, & Gomez, 2016; Tsiopela & Jimoyiannis, 2014; Uphold, Douglas, & Loseke, 2016; Venkatesh, Greenhill, Phung, Adams, & Duong, 2012; Zamfir, Tedesco, & Reichow, 2012), 37.7% used questionnaires (Artoni et al., 2018; Bittner, Rigby, Silliman-French, Nichols, & Dillon, 2017; Boyd, Jiang, & Hayes, 2017; Burke et al., 2010; Campbell et al., 2017; Chien et al., 2015; Clark, Austin, & Craike, 2015; De Leo et al., 2011; de Urturi, Zorrilla, & Zapirain, 2011; de Urturi, Zorrilla, & Zapirain, 2012; Escobedo et al., 2012; Fernández-López et al., 2013; Fletcher-Watson, Pain et al., 2016, 2016b; Gentry et al., 2015; Khan, Tahir, & Raza, 2013; Lubas, Mitchell, & De Leo, 2014; Lyan et al., 2015; Mamun et al., 2016; Mintz, 2013; Mintz et al., 2012; Rivera et al., 2015; Sano et al., 2012; Tsiopela & Jimoyiannis, 2014; Vélez-Coto et al., 2017; Venkatesh et al., 2012; Zaffke et al., 2015; Zamfir et al., 2012; Zheng & Motti, 2017), 16.9% interviewed the participants (Abdullah & Brereton, 2015; Boyd, Hart Barnett, & More, 2015; Cheng, Luo, Lin, & Yang, 2018; de Urturi et al., 2012; Dibia, 2016; Escobedo et al., 2012; Fletcher-Watson, Pain et al., 2016, 2016b; Mintz, 2013; Mintz et al., 2012; Sano et al., 2012; Uphold et al., 2016), and only one study used focus groups (Zamfir et al., 2012). Depending on the characteristics of the application, each study used different instruments. One study (Gentry et al., 2015) utilized the Supports Intensity Scale (SIS) - Employment Subscale (Thompson et al., 2004) and the Employee Performance Evaluation Report (EPER) (Virginia Department of Aging & Rehabilitative Services, 2009) to evaluate the provided solution. The System Usability Scale (SUS) instrument (Brooke, 1996) along with open-ended user response questions were used by Sano et al. (2012) to evaluate the usability of the application. Clark et al. (2015) used the three domains of the 49-item Computer Technology Use Scale (Conrad & Munro, 2008) to measure computer self-efficacy, technology-related anxiety, and attitudes to technology. The Modified Checklist for Autism in Toddlers – Revised with Follow-up (M−CHAT-R/F) (Robins et al., 2014) was used by Campbell et al. (2017) to assess changes in quality of care for children at risk for autism spectrum disorders due to process improvement and implementation of a digital screening form. In Artoni et al. (2018), the evaluation of participants was based on the standard Vineland Adaptive Behavior Scales (VABS) which was administered to the children by a psychologist before and after the intervention, in order to compare their development and assess any progress in the user test period (Sparrow, 2011). VABS measures the personal and social skills of individuals from birth through adulthood. However, once more, a custom-made questionnaire was used to evaluate the satisfaction of the users by the technological platform. The Test of Gross Motor Development-2 (TGMD-2) (Ulrich, 2000) was used in another study to assess the object control skills and locomotor skills of participants (Bittner et al., 2017).

RQ5. For what purposes have been applied the proposed solutions?

Fig. 3 depicts the categorization of the studied articles in terms of their final purpose. Twenty-one main categories were identified. The majority of research conducted was related to training (53%) of people with ASD, followed by monitoring (30.8%) and supporting (15.4%) activities (Fig. 4). The projects related to training focused mainly on social skills (58.3%). The rest of them were related to vocational skills (8.3%), various skills (8.3%), cooperation (4.2%), science (4.2%), numeracy (4.2%), vocabulary (4.2%), and first aids (8.3%). Monitoring solutions were targeted to biosignals (e.g. heart rate, etc.) in order to capture health related parameters mainly for remote monitoring. Almost half of them (44.4%) were trying to identify and analyze stereotypical behaviors, mainly by capturing hand movements. Social tasks were again the main focus (37%) of most of the supporting applications examined, followed by education (25%), physical activity (12.5%), attention deficit, anxiety (12.5%), and vocational skills (12.5%).

RQ6. What are the targeted symptoms/health conditions?

As the title of the paper declares, all solutions are targeted towards ASD. However, some solutions also targeted other pathologies or very specific symptoms. More specifically: one was related to patients with dementia (Goel & Kumar, 2015), two on Alzheimer disease (Goel & Kumar, 2015; Helmy & Helmy, 2016), two targeted general intellectual disabilities (Cihak et al., 2007; Zheng & Motti, 2017), one on other developmental disabilities (Uphold et al., 2016), one focused on complex communication needs (Vukovic et al., 2016), one with attention deficit (Dibia, 2016), and one more on special education needs (Kientz, Hayes, Westeyn, Starner, & Abowd, 2007).

RQ7 & RQ10. What are the targeted population, number and type of users evaluating the final solution?

Empirical evaluation involves real end-users (Fernandez, Insfran, & Abrahão, 2011). Table 5 gives a brief overview of the different categories of subjects and their number participating in each study, while Fig. 5 presents their distribution.

As shown in Fig. 5, less than 10 persons participated in most of the studies, while 7.3% had 11–20 subjects and 25.5% (n = 14) recruited 21–50 participants. Two studies had 51–100 participants and four had more than 100. Even though the involvement of a control group can provide valuable insights (Lavrakas, 2008), only a very limited number of projects (Escobedo et al., 2012; Lyan et al., 2015; Quezada et al., 2017; Teeters, 2007) included such a group. Moreover, the participation of parents seems to be very

Table 5
Selected papers and review results #2.

Ref.	Technological solution	Device used	S/W used	Type(number) of end users	Duration of evaluation (days)
Szydło & Konieczny, 2016	AC	Smartphone/Smartwatch (n.d.)	Android	Adult(25)	–
Rodrigues et al., 2012	AC	Smartwatch (eZ430-Chronos)	Desktop App	Child(5)	–
Goel & Kumar, 2015	AC	Wearable (GPS locator, GSM unit-wrist), Smartphone/Tablet (n.d.), PC	Android, Web Based App	–	–
Fletcher et al., 2010	AC	Wireless sensors (Electrodermal Activity, Photoplethysmograph, heart rate variability, accelerometer mounted on wrist, sock, foot/ankle), PC, Smartphone (n.d.)	Web Based App	n.d.(12)	–
Gay & Leijdekkers, 2014	AC	Smartphone/Tablet (n.d.), Wireless Sensors (Q sensor (accelerometer, skin temperature, skin conductivity mounted on wrist, Mindwave (Electroencephalography-EEG, Zephyr bioharness (heart rate, heart rate variability-HRV, respiration, body temperature and movement)) mounted on chest)	Android	–	–
Northrup et al., 2016	AC	Smartphone/Tablet (n.d.), Wireless Sensors (Neumitra (electrodermal activity) mounted on wrist)	iOS	–	–
Ahmed et al., 2017	AC	Smartphone (n.d.), Wireless sensor (Arduino (GPS, GSM, Pulse, Temperature) mounted on wrist or hat)	Android	–	–
Coronato et al., 2014	AC, AI	Smartwatch (eZ430-Chronos)	Desktop App	Adult(5)	–
Kientz et al., 2007	AC, AT	PC, Wireless sensor (accelerometers to detect repeated autistic behaviour, e.g. hand flapping, etc. mounted on thigh, waist, wrist), Video capturing	Desktop Apps	–	–
Torrado et al., 2017	AC, AT	Smartwatch (n.d.), Smartphone/Tablet (n.d.)	Android	Child(2)	9
Torrado et al., 2016	AC, AT	Smartwatch (n.d.)	Android	–	–
Fazana et al., 2017	AC, AT, CMC	Wireless sensors (6-axis accelerometer, gyroscope, Electro-dermal activity-EDA sensor, peripheral temperature sensor, GPS sensor, compass and heart rate monitor)	Mobile (n.d.)	–	–
Teeters, 2007	AC, CAI	PC223XP Color CCD Micro Camera, KWorld Xpert DVD Maker USB 2.0 Video, Capture Device, OQO hand-top computer model, Macbook	Desktop App	n.d.(20) + n.d.(10) control	–
Amiri et al., 2017	AC, CC	Smartwatch (Moto 360), Smartphone (n.d.)	Android	Child(2) + Adult(12) control	–
Leijdekkers et al., 2013	AC, CMC	Smartphone/Tablet (n.d.), Wireless sensor (Q sensor (accelerometer, skin temperature, skin conductivity) mounted on wrist)	Mobile (n.d.)	–	–
Di Palma et al., 2017	AC, SG	Tablet (n.d.), Wireless Sensors (Electroencephalography-EEG, Electrocardiography-ECG, chest belt), video unit, workstation	Mobile (n.d.), Desktop app	Child(5) (H/F)	180
Rad & Furlanello, 2016	AI	Wireless sensors (EXLs3 (three-axis accelerometer, gyroscope, magnetometer data) mounted on wrist)	–	Child(6)	–
Escobedo et al., 2012	AR, CMC	Smartphone (n.d.)	Android	Child(3) + Child(9) control	49
Cihak et al., 2007	AT	Handheld Computer (Axium X30), Kodak DX3600 Zoom camera	Windows Mobile	Child(4) with Low IQ	63
Burke et al., 2010	AT	Smartphone (iPhone), WalkAround costume	iOS	Adult(3)	–
Zamfir et al., 2012	AT	Smartphone (iPhone), Smart Device (iPod Touch), Tablet (iPad)	iOS	Teacher(29), Child(88)	–
Sano et al., 2012	AT	Smartphone/Tablet (n.d.)	Android	Teacher(8)	–
Schuck et al., 2016	AT	Tablet (iPad)	iOS	Child(12), Teacher(1)	42
Helmy & Helmy, 2016	AT	Smartphone/Tablet (n.d.)	Android	–	–
Lyan et al., 2015	AT	Tablet (iPad), Tobii x120 (eye tracker)	iOS	Child(8) + Child(6) control	–

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Table 5 (*continued*)

Ref.	Technological solution	Device used	S/W used	Type(number) of end users	Duration of evaluation (days)
Gomez et al., 2016	AT	Smartwatch (n.d.)	Android	–	–
Vukovic et al., 2016	AT	Smartphone (Prestigio Multiphone PSP5508DUO, Samsung Galaxy S5 mini, Xiaomi Redmi Note 4 g, Samsung Galaxy S5), Smartwatch (Samsung Gear S), PC	Android, Web Based App, Tizen	–	–
Clark et al., 2015	AT	Tablet (iPad)	iOS	Parent(90), Specialist(31)	–
Cheng et al., 2018	AT	Tablet (ViewSonic ViewPad 7e)	Android	Child(24)	21
Quezada et al., 2017	AT	Tablet (iPad, Samsung Galaxy Table 2)	IOS, Android	Child(21) + Child(28) control	–
Khan et al., 2013	AT	Smartphone (n.d.)	Android, iOS	Child(50) + Carer(50)	–
Uphold et al., 2016	AT	Smart Device (iPod Touch)	iOS	Adult(6)	–
Campbell et al., 2017	AT	Tablet (n.d.)	Mobile (n.d.)	Child(1191)	–
Zheng & Motti, 2017	AT	Smartwatch (n.d.), Smartphone (n.d.)	Android	Child(7)	–
Bittner et al., 2017	AT	Smartphone (n.d.), Sensor (Actiheart monitor (Electrocardiography-ECG))	Android, iOS	Child(6)	30
Chien et al., 2015	AT, CAI	Tablet (Asus TF101, Dr.eyeN101)	Android	Child(11), Parent(8), Specialist(3)	30
Washington et al., 2017	AT, CAI, SG	Wearable (Google Glass), Smartphone (n.d.)	Android	Child(14)	90
Mintz, 2013	AT, CMC	Smartphone (HTC Diamond and HTC Touch HD)	Android, Windows Mobile	Teacher(15), Parent(6), Child(10)	–
Abdullah & Brereton, 2015	AT, CMC	Tablet (iPad)	iOS	Child(11), Parent(10), Teacher(4)	180
Roldán-Álvarez et al., 2016	AT, SG	Tablet (n.d.), PC	Android, Web Based App	Child + Adult(25)	81
Mintz et al., 2012	ATA, CMC	Smartphone (HTC Diamond and HTC Touch HD)	Android, Windows Mobile	Teacher(7), Child(13), Parent(8)	300
Tsiopela & Jimoyiannis, 2014	CAI	Smartphone (n.d.), PC	Web Based App	Adult + Child(6) (HF + LF)	60
Gentry et al., 2015	CAI	Smart device (iPod Touch)	iOS	Adult(50)	84
Mohanaprakash et al., 2015	CAI	Smartphone/Tablet (n.d.)	Android	–	–
Duncan & Tan, 2012	CAI	Tablet (iPad)	iOS	–	–
Dibia, 2016	CAI	Smartwatch (Samsung Gear 2)	Android	Adult(10)	7
Zaffke et al., 2015	CAI	Smartphone (iPhone), Tablet (iPad)	iOS	Child(20)	–
Cesário et al., 2016	CAI	Smartphone (n.d.)	Mobile (n.d.)	–	–
Rani et al., 2014	CAI	Smartphone (n.d.)	Mobile (n.d.)	–	–
Vélez-Coto et al., 2017	CAI	Tablet(Android,iPad), PC	Android, iOS, Desktop App	L/F Child(102)	90
Venkatesh et al., 2012	CAI	Tablet (iPad)	iOS	Child(31) + Parent(16)	–
Smith et al., 2013	CAI	Tablet (iPad)	iOS	Child(3)	–
Neely et al., 2013	CAI	Tablet (iPad)	iOS	Child(2)	–
Kamaruzaman et al., 2016	CAI	Smartphone/Tablet (n.d.)	Mobile (n.d.)	–	–
Husni & Budianingsih, 2013	CAI	Smartphone/Tablet (n.d.)	Android	–	–
Doenyas et al., 2014	CAI	Tablet (iPad)	iOS, Web based app	Child(3)	14
Artoni et al., 2018	CAI	Tablet (iPad), PC	iOS	Child(7)	270
de Urturi et al., 2011	CAI, SG	Smartphone/Tablet (n.d.)	Android	Child + Adult(10)	–
Mamun et al., 2016	CC	Smartphone/Tablet (n.d.)	Web Based App	–	–

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Table 5 (*continued*)

Ref.	Technological solution	Device used	S/W used	Type(number) of end users	Duration of evaluation (days)
Aziz et al., 2014	CMC	Smartphone (n.d.)	iOS	–	–
da Silva et al., 2012	CMC	PC	Web Based App	–	–
Silva et al., 2014	CMC	PC	Web Based App	Child(9)	105
Fernández-López et al., 2013	CMC	Smartphone (iPhone), Smart Device (iPod Touch), Tablet (iPad)	iOS	Child(39)	180
Boyd et al., 2015	CMC	Tablet (iPad)	iOS	–	–
Rivera et al., 2015	CMC	Smartphone (n.d.)	Android	Child(5), Teacher(2), Specialist(2)	–
King et al., 2014	CMC	Tablet (iPad)	iOS	Child + Adult(6)	90
Fletcher-Watson, Pain et al., 2016, 2016b	CMC	Tablet (iPad)	iOS	Child(54)	180
Irwin et al., 2015	CMC	Tablet (iPad)	iOS	Child(4)	–
Boyd et al., 2017	CMC	Smartphone (n.d.), Wireless Sensor (Infrared, Distance)	Mobile (n.d.)	Child(10)	–
Alzrayer et al., 2017	CMC	Tablet (iPad)	iOS	Child(4)	4
De Leo et al., 2011	CMC	Smartphone (n.d.), PC	Windows Mobile, Web Based App	Child(3) + Teacher(3)	21
Holt & Yuill, 2017	CMC	Tablet (n.d.)	Mobile (n.d.)	Child(8)	7
Lubas et al., 2014	CMC	Smartphone/Tablet (n.d.)	Android, iOS	–	–
Hourcade et al., 2013	CMC	Tablet (n.d.), PC	Linux, MacOS, Windows	Child(8)	–
Bauminger et al., 2007	CMC, SG	Multi touch PC (DiamondTouch)	StoryTable application	Child(6) (H/F)	21
Fletcher-Watson, Pain et al., 2016, 2016b	SG	Tablet (iPad)	iOS	Child(41)	58
de Urturi et al., 2012	SG	Smartphone/Tablet (n.d.)	Android	Child + Adult(10)	–

AT: Assistive Technology; CMC: Computer Mediated Communication; AC: Affective Computing; SG: Serious Games; CAI: Computer Assisted Instruction; AI: Artificial Intelligence; AR: Augmented Reality; CC: Cloud Computing; MID: Moderate Intellectual Disabilities; ASD: Autistic Spectrum Disorder; VC: Various Conditions; SN: Special Needs; DEM: Dementia; ALZ: Alzheimer; AD: Attention Deficiency; CCN: Complex Communication Needs; DD: Developmental Disabilities; ID: Intellectual Disabilities; n.d.: Not defined; H/W: Hardware; S/W: Software; H/F: High-functioning; L/F: Low-functioning.

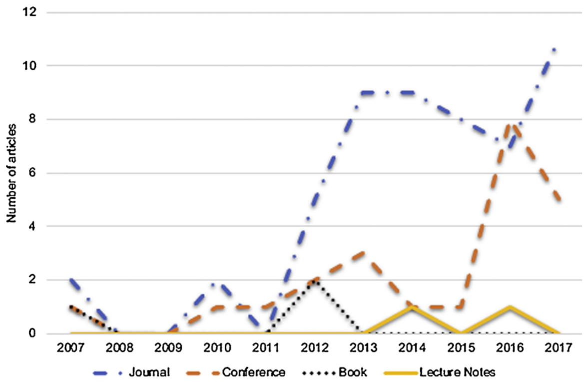

Fig. 2. Publications per year and type.

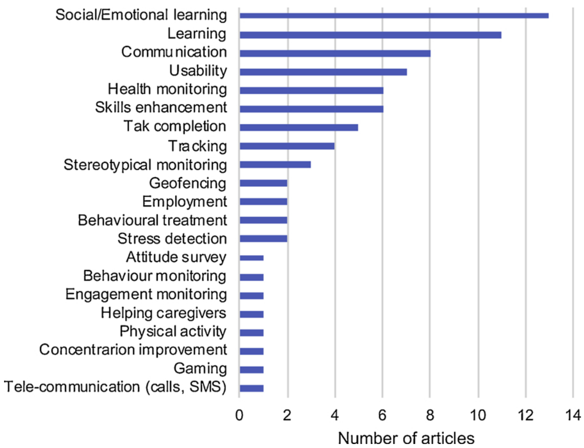

Fig. 3. Categorization of studies.

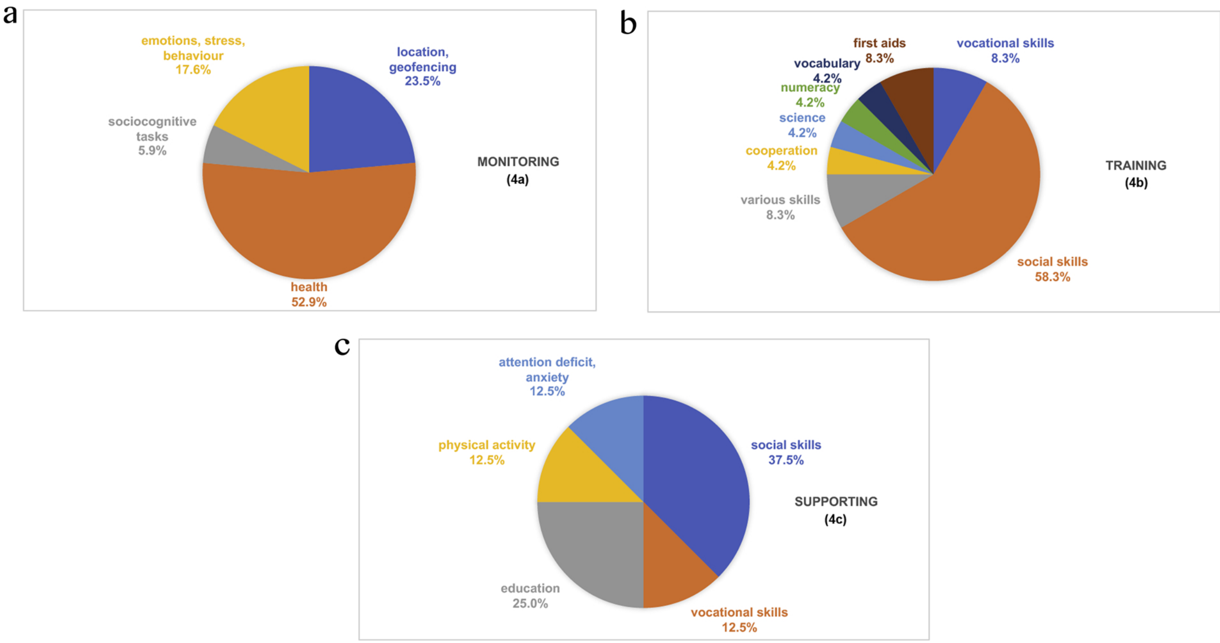

Fig. 4. Application sectors: (a) monitoring, (b) training, (c) supporting.

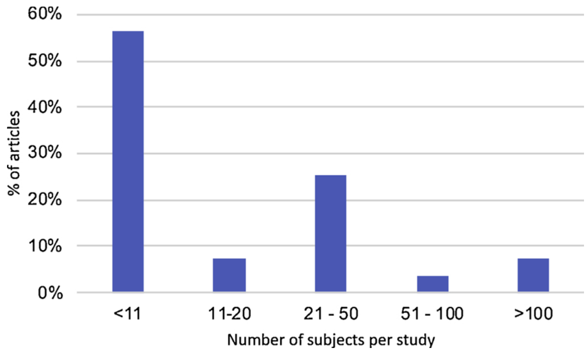

Fig. 5. Number of subjects participating in studies.

limited too. Only one study had 90 parents, one had 16 and the others had less than 10.

RQ8. What are the main outcomes, limitations and future plans for each study examined?

The major findings (limitations and future steps) are presented in Table 6.

4. Discussion

The publications are spread out in a variety of journals (there are 65 different publication sources for the total of 77 papers identified). This could be an indicator that there is no specialized source as regards the topic researched in the current study. The diversity of the publication sources could be explained due to the high adaptability of the emerging mobile and wearable technologies, which allows them to be applied in different fields (Fiordelli et al., 2013; Koumpouros & Georgoulas, 2016, 2019). As it appears, researchers target the journals even though the publication in a journal may take years, as opposed to only a few months in a conference. The convergence of ICTs and autism along with the new computing methods (artificial intelligence and deep learning) and the production of low-cost sensors, provide a fertile soil for applying innovative solutions to solve real-life problems of the targeted population. Thus, journals are preferred by researchers as being the most “prestigious” and impactful source to publish their studies. The distribution of published articles (Fig. 2) could be expected as smartphones appeared after 2007 (when the first iPhone was announced) and wearables and sensors technology had many restrictions in the past. The average time for developing and testing a mobile application is around three months, while needing even more time for publishing the research findings. Even though smartphone ownership and mobile technology has experienced significant growth since 2012 (Statista, 2019b, 2019c; Statista, 2019d) the upsurge in mHealth research started in 2008 with the appearance of the first Android technology. In view of the results, research related to the use of wearables and mobile technology for developing interventions in autism is expected to undergo an important increase in the coming years.

As far as the technological solutions are concerned, according to recent data, in the second quarter of 2018, 88% of all smartphones sold to end users were phones with the Android operating system, while iOS held only 11.9% (Statista, 2019a, 2019e). This trend of Android versus iOS appears quite early, from 2010 where Android percentages were double the ones of iOS. Someone could expect that Android would be more frequently used in the papers studied, as it is an open source platform able to be ported to different devices and connect to different sensors. On the opposite side, Apple’s operating system - watchOS - is the most used smart wrist wear operating system at this time. So, on the one hand, Android’s characteristics contribute to its adoption, while on the other hand, iOS dominates the wearables market. Concerning wearable technology, it may comprise different types of flexible sensors that can be integrated into textile fiber, clothes, and elastic bands or directly attached to the human body. These sensors are able to measure several physiological signs, such as heart rate (HR), electromyogram (EMG), electrocardiogram (ECG), electrodermal activity (EDA), body temperature, arterial oxygen saturation (SpO2), blood pressure (BP) and respiration rate (RR) (Pantelopoulos & Bourbakis, 2010). Additionally, MEMS based miniature motion sensors such as accelerometers, gyroscopes, and magnetic field sensors are widely used for measuring activity related signals. Smartwatches on the other hand, have already integrated such sensors and are currently the most successful wearable devices on the market (Statista, 2019g). In the frames of the current research, the population targeted (children with ASD) imposes cost-effective, widely available solutions that do not cause additional problems (e.g. anxiety, stress, etc.) to the end users. This is of great importance when dealing with persons with ASD who may have sensory sensitivities. For example, many children may experience hypersensitivity to clothing, noise, etc. (Cheretta, 2016). This is a crucial issue that should be taken into account when developing solutions integrating wearable devices. Smartwatches and bracelets seem to be a more ideal solution for the population examined than other sensors that are more obtrusive (e.g. patches, etc.). However, the problem is that smartwatches and bracelets cannot measure the whole range of desired signals, while some of them (like Fitbit) have been claimed of not being reliable enough for medical purposes (Edwards, 2018). Although relatively few applications have been identified in the field of AI, it is anticipated to dominate the field in the short future, as it can be applied in several types of data (Jiang et al., 2017). However, other technological advances, like cloud computing and big data have yet to appear. This can be explained by the fact that the examined population is rather small and the data gathered are still isolated in different locations. This could be considered as an obligation to pursue a more centralized and open approach where all researchers from different disciplines

Table 6
Major findings of the reviewed studies.

Ref.	Scope	Outcomes	Limitations	Future Plans
Cihak et al., 2007	Training patients to complete various vocational related tasks	Increased task performance and maintained skills 4 weeks later	Task complexity was defined as increased motor responses, students had extensive CBI experience, all students were motivated to wear the device with no resistance	Tasks that include cognitive demands, different settings, skills
Mintz et al., 2012	Supporting social and everyday skills with the help of the HANDS software	Improved social skills and life skills	Short duration, no clear quantifiable results, no firm conclusions on impact for focus domains	–
Burke et al., 2010	Evaluating methods that result in better employment opportunities for autistic young adults	Improved performance and after the introduction of the Performance Cue System (PCS)	Participants had good communication skills (not generalizable to those with fewer communication skills)	Study between Performance Cue System (PCS) and use of adaptive skills
Aziz et al., 2014	Improving social skills of children with autism	An app was developed that helps children with ASD to communicate better and improve their social life	–	–
Di Palma et al., 2017	Capturing physiological signals supported by serious games, in order to correlate data to the engagement of the child, whether modifications could be made for each child and to see the tolerability of the equipment	Reduction in Root Mean Square of Successive Differences, Respiratory Sinus Arrhythmia during serious games play	Small sample, very specific results, small movements not recorded	Sensors mounted on wrists, bigger sample
Tsiopela & Jimoyiannis, 2014	Development of pre-vocational skills for children with ASD	Students with ASD can benefit from Web-assisted instructional interventions	–	Transfer of skills to real things and situations
Mintz, 2013	Supporting social and everyday skills with the help of the mobile HANDS software	Positive response to behavioral intervention through mobile device	–	Consideration to use of technology in school and out of school, multi-platform design, work with children to identify needs, identify which children will benefit most, use on other platforms
da Silva et al., 2012	Customized content for children to increase various skills by addressing their interests	ICT system that can be customized for children with ASD	The teacher has to be trained to use the app	Development of framework to customize various settings for children with autism
Silva et al., 2014	Customized content for children to increase various skills by addressing their interests	Improved attention and motivation as well as different behavioral patterns by using customized ICT system	The teacher has to be trained to use the app	Development of framework to customize various settings for children with autism
Fernández-López et al., 2013	Development of cognitive skills with various educational activities	The use of the platform had positive effects in the development of various skills for children with special needs	Non-random sample, no control group, from many places (too general)	–
Szydło & Konieczny, 2016	Remote system for monitoring patient health	A universal remote health monitoring system has been developed	–	Adding more devices, add usability for more health conditions
Rodrigues et al., 2012	Detecting and recognizing stereotypical movements of children with ASD through a smartwatch	The smartwatch detects 75% of stereotype ASD movements	The algorithm detects many false positive in movements	Improve the algorithm in movement detection
Coronato et al., 2014	Detecting and recognizing stereotypical movements of children with ASD through a smartwatch	Smartwatch can detect very well stereotype ASD movements	Few trials	Bigger sample. Automatic detection of context by the device and categorizing the movements according to it
Escobedo et al., 2012	Supporting children with ASD in improving their communication skills	Appropriately designed assistive technologies such as MOSOCO help improve social learning and social skills	Not context aware, too specific (classroom based social skills training), not necessary the tool that helped but the training	Similar instrument but outside the classroom, with people that don't know how it works, new tools for parents/teachers
de Urturi et al., 2011	Teaching first aid skills to people with ASD	Mobile apps like this can help people with ASD learn better and improve their therapy	–	–

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Table 6 (*continued*)

Ref.	Scope	Outcomes	Limitations	Future Plans
Gentry et al., 2015	Reducing the need for personal training and increasing work performance for people with ASD	Workers with ASD who received PDA support required significantly less job coaching which persisted for 12 weeks	Random population. Not all symptoms of autism present. Investigators did not attempt to match the characteristics of one group to the other	More research for workers with ASD, if supporting technologies lead to better results, research on how to better use technology for these people
Mamun et al., 2016	Remote system that screens patients for autism	Framework created that provides 3-layer assessment process that screens and confirms autism	No feedback system	More features, clinical approval
Boyd et al., 2015	Evaluation of the usage of iPads for the improvement of social skills in children with ASD	A review of current research indicates that there are five important considerations for evaluation: (a) the ability to customize the application, (b) the motor skills the student needs to operate the system, (c) the resources and time needed for the intervention, (d) the research or evidence-based practices behind the application, and (e) the cost of using the specific device and application	The iPad is new in ASD research, not many applications for research	Investigate how schools use the iPads in classrooms. Extend the research to other types of tablets
Rivera et al., 2015	Effects of mobile technology intervention for student praise and the effects of that on special students	The prompting increases teacher performance	Difficulty in measuring on- and off-task behaviors of students. Samsung galaxy player and HIIT application did not operated as expected some times. Student academic achievement was not recorded	How it helps academically besides just the behaviour
King et al., 2014	Observation of iPad use in people with ASD and evaluating its use in research or in an educational setting	iPads® can, and are, being used in schools appropriately to support children and young adults with ASD	Small sample, short time of observation, apps were chosen randomly from teachers, random data collection	More research to determine that iPads help
Kientz et al., 2007	Assessing different technologies that help caregivers care for children with special needs	The results show how technologies can be used to support caregivers	Difficulties in relying on input from children, various considerations for the wearable technology (size, position, damage proof), ethic and privacy concerns	Help detect early symptoms of autism through computing system. Aid data collection in schools and increase collaboration. Help to support autism related research. Sound analysis for vocal stimming behaviour, adapting functional behaviour assessment technologies for home-based care
Mohanaprakash et al., 2015	Helping children with ASD to improve their social skills and reduce echolalia	Application developed that assists children with ASD with echolalia	–	–
Teeters, 2007	Improving social skills of children with autism through video recordings	Easier analysis of facial expressions for people with ASD through a camera	–	Make video test self-administered. Social cues detectable real time by the wearable tool. Make less cumbersome to wear
Zamfir et al., 2012	Assessing the visual support app iPrompts in how it helps in an educational setting when used by teachers	The iPrompts app can be used in educational settings to help visually teachers and students with ASD	–	Phase 2 of study = extend the app to Android devices, enhanced features (visual checklists, cloud storage, syncing), make software accessible outside the handheld device, production of training materials for using the product in educational settings
Fletcher-Watson, Pain et al., 2016, 2016b	Designing games for children with ASD with their help	App designed with the help of children with ASD, in which they show interest over 2 months	Maximum skill level or age not defined, not enough customization options, not sure if cooperative design is better	–

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Table 6 (*continued*)

Ref.	Scope	Outcomes	Limitations	Future Plans
Duncan & Tan, 2012	App that helps people with ASD to complete various tasks using visual support	A plan for the development of an iPad app that will help ASD users to complete work and lessen supervision required	–	–
de Urturi et al., 2012	Educate individuals with autism in first aid	The application has proved that it is possible to enrich and increase the education/therapy impact through the introduction of ICTs	–	More users with autism that use the tool, more groups
Leijdekkers et al., 2013	Helping children with ASD to understand emotions better by taking pictures, recording videos and by wearing a sensor	The developed App helps children with ASD to understand their emotions with the help of sensors and a mobile app	–	–
Goel & Kumar, 2015	Wearable band and accompanying web application that helps locate patients with various conditions, and lets them make calls and send SMS	System developed for locating people through a wristband along with a companion app	–	Windows application, further applications using the band
Dibia, 2016	Assisting people with attention deficit to conentrate and reduce their anxiety	The smartwatch app helped the users reduce their anxiety/stress levels and was easy to use	–	Bigger field study, in depth analysis of the effects of the app
Fletcher et al., 2010	Creation and application of sensors that will be comfortable to wear in order to collect wirelessly physiological data	Sensors and technology that is capable in collecting data autonomously comparable to data gathered with traditional sensors, easily and more reliably in naturalistic settings	–	–
Sano et al., 2012	Application that is easy to use in order to record challenging behaviors of people with ASD	The annotation tool was preferred by teachers and was faster and more accurate than traditional methods	–	Systemic study to compare to classic annotation methods, live monitoring of physiological values, infrastructure to share and visualize data for multiple users
Gay & Leijdekkers, 2014	Reading of sensor data along with recognition of facial expressions for the detection and understanding of emotions	The created App helps children with ASD to better understand their emotions with the help of sensors and a mobile app	Cost of sensors	Trials in a real school, trials at home of users
Fletcher-Watson, Pain et al., 2016, 2016b	iPad based intervention for the improvement of social skills	Analyses did not reveal statistically significant effects of intervention on the primary outcome, nor on other measures, including parent-report measures taken immediately following the intervention period. This does not mean that no gains were made – in contrast, substantial improvements in both groups across the majority of measures was recorded	New measure was used at the 6-month follow-up, no measurement immediately post intervention, the new measure was not established or validated	Combine other technology interventions with other training. Use of specific apps monitored over time. Evaluate iPad skills in general
Irwin et al., 2015	Recognizing speech and presenting it audiovisually	Training speech-in-noise, with explicit focus on cueing visible articulation may facilitate perception of auditory-only speech in noise in children with ASD	Small sample, no untrained control group	–
Boyd et al., 2017	Training of a person with ASD on socially accepted distances in social situations	Testing the design choices to create a dynamic visualization shows that children with autism respond to real time information during a conversation	Training required, time to get comfortable with the system, 90 degrees of detection	Smaller sensors in various places, 180 degrees of detection

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Table 6 (*continued*)

Ref.	Scope	Outcomes	Limitations	Future Plans
Schuck et al., 2016	App designed to support classroom behaviour in children with ASD	The prototype application was well received by both the classroom staff and students, and was consistently used in the classroom over a 6-week period	Lacks statistical power to draw conclusions about diagnostic and demographic factors. Unique setting that the children were already accustomed to a universal token economy system prior to the introduction of iSelfControl. Generalizability of the tool needs to be further examined	Further development of iSelfControl, evaluation of long term intervention with both special and general education settings and with control conditions, more children with and without the disorder, experimental controls and generalizability across settings and populations
Helmy & Helmy, 2016	Tracking of patients, geofencing and detection of what activity they are doing	The developed App detects location and activities accurately with low delay	–	Better battery usage, time limits, transitions, trials with more people, iOS edition
Lyan et al., 2015	How easy are AAC apps to use by children with ASD	Conduction of a usability study of two apps and making suggestions from it about future AAC apps for children with ASD	Younger ASD kids get quickly bored	Eye tracker glasses for more accurate results instead of Tobii X120
Gomez et al., 2016	How useful are smartwatches in improving the behaviour of children with ASD	A proposal for smarwatch uses in ASD to detect situations and help an individual self-regulate	–	–
Vukovic et al., 2016	Locating and geofencing of people with complex communication needs	An app has been developed that locates people with complex communication needs, as well as a study in how to design such an app	–	Better UI design for the smartwatch, full usage of smartwatch features
Torrado et al., 2017	Usage of a smarwatch to self-regulate during emotional events	Both users were able to employ effective, customized emotional self-regulation strategies by means of the system, recovering from the majority of mild stress episodes and temper tantrums experienced in the nine days of experiment in their classroom	–	Detect events from physiological data, carers to evaluate the effectiveness of the the app, more users
Clark et al., 2015	Survey of the attitude of parents and carers towards usage of iOS apps in order to help with ASD, and their attitude towards ICT	iPad applications are not being used by professionals to a degree that is consistent with their favorable attitudes toward them. iPad use has been enthusiastically adopted by many parents; however, there appears a need for training in their use and research to establish an evidence base	–	Scientific proof of the results of iPad usage
Northrup et al., 2016	Usage of a wireless sensor and a smartphone to detect the stress levels of a child with ASD and to alert the caregiver	The resulting system is neuma-CFD, a coordinated technological system for in situ monitoring of stress levels to identify correlations in the user's stress increases and contextual events. The system delivers in situ alerts to caregivers via a smartphone or similar handheld devices	Not easy for children to wear sensor, issue with washing hands	–
Cheng et al., 2018	Use of 3D graphics to detect and understand emotions through facial expressions	The experimental group was much better at recognizing emotions than the control group, as well as good performance of using a mobile learning system	Shy children, did not talk too much, needed time for bonding, small sample	Bigger sample, more emotions in the app, real people in virtual scenarios
Bauminger et al., 2007	Use of cooperative multi touch table in order to improve social skills	The participants demonstrated progress in better social behaviour as well as less autistic behaviours	–	Bigger sample, check if results are repeated, bigger sessions

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Table 6 (*continued*)

Ref.	Scope	Outcomes	Limitations	Future Plans
Alzrayer et al., 2017	Training children with ASD to request things through the use of an iPad	The participants improved their multistep requesting through iPads, as well as generalizing their skills	Participants under control of verbal cue in order to use the iPad for requesting (not spontaneous). Participants exhibited challenging behaviours, not generalizable, lack of social validity data (teachers, parents)	Evaluating the attitudes of parents and teachers about the use of iPad interventions, acquiring and keeping social skills
Quezada et al., 2017	Which operations are the easiest for people with autism to complete on touch devices	The easiest operations for users with ASD to perform on touch devices are Keystroke, Drag, Initial Act and Tapping	–	Evaluate drag size, image size, guidelines for design and development of apps for people with ASD, more tests
De Leo et al., 2011	Helping children with ASD communicate through pictures on smart devices instead of a physical folder	PixTalk helped the children communicate as well as those trying to communicate with the children	Small sample	Bigger sample, improve UI, more charateristics (sound or pictures from smartphone)
Fazana et al., 2017	Integrating various wearable technologies to monitor children with ASD, to be able to communicate better and to monitor their health	Proposal for a solution with AAC, location tracking and health monitoring features for children with ASD	Privacy, safety of health data, issues in transfering data in wireless networks	Combine existing AAC and wearable technologies and extract functional requirements from both into one comprehensive solution
Roldán-Álvarez et al., 2016	Evaluation of the help of mobile technologies in educational settings, specifically through two apps	The use of technology could have a positive influence when performing learning activities, as it motivates them and assists traditional methods	–	–
Khan et al., 2013	Evaluation of how difficult it is for people with ASD to use mobile apps, along with a proposal for an app	The more user friendly and better in terms of usability apps are, people with autism will find it easier to communicate through them	–	–
Zaffke et al., 2015	Review of existing apps for stories and development of one for presenting flashcards, creating stories that can be customized and remotely controlled	The users can create more customized learning content, create flashcards and stories and employ the use of audio and visual learning all through one app	Small sample, not many people participated in the second part of the study	Two devices to be able to be connected without the use of wifi, and be able to draw custom images
Uphold et al., 2016	Study if people with developmental disabilities can use an iPod touch device in order to manage their recreation tasks	Participants learned to program their iPod touch and maintained the skill during the second intervention. For generalization, participants programmed self-selected exercises into the device and performed each exercise successfully	Small sample, all participants in the same facilities	Usage for a full fitness regime, more time between exercise, social validation of the facilities by peers and employees
Abdullah & Brereton, 2015	For children with ASD to be able to communicate about their everyday activities and for teachers to be able to understand their everyday lives better	Children communicated better through the app, and teachers had more insight in their daily lives	–	Notes with sound, written notes, emoticons, stories with pictures
Cesário et al., 2016	Help children achieve goals by learning steps, to have a schedule with images, and for parents to assess their progress and achievements	App developed that acts as a communication tool between children and parents	–	Research with people, recording of challenging behaviors and what triggers them
Ahmed et al., 2017	Solar powered tracking device that also detects physiological data	Proposal for a solution that tracks location, physiological data and can be charged by the sun, as well as a companion app	–	–
Rani et al., 2014	Framework for an app that shows a visual schedule for children with ASD	Model proposed for a visual schedule geared towards ASD children	Differences between urban and suburban children in smart device knowledge. Difference in relationships between teachers, carers and parents (require time to build and are complex)	–

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Table 6 (*continued*)

Ref.	Scope	Outcomes	Limitations	Future Plans
Campbell et al., 2017	To assess changes in quality of care for children at risk for ASD due to process improvement and implementation of a digital screening form	Accurate documentation in the electronic health record of screening results increased from 54% to 92% and appropriate action for children screening positive increased from 25% to 85%	–	–
Vélez-Coto et al., 2017	Training skills in children with ASD through pictures	Improvement of training of perceptive and cognitive skills in people with L/F ASD	Few sessions, same situations of training, type of device, standarized instruments should have been used	Interventions with different goals, usage in real situations and not in a lab setting
Venkatesh et al., 2012	Usage of multimedia in children with ASD that are on waiting lists and there is no therapists available	The system is successful at delivering early therapy intervention to children with ASD as well as adapting to the childrens' performance	Parents did not understand the usage of some tasks, the task protocol needed to be explained to some parents, recording in playpad was hard at some moments	New categories of themes, bigger sample
Smith et al., 2013	Using computers to teach science to children with ASD	The performance of the students increased as they answered more questions correctly after the intervention	Not evident which part of the intervention helped specifically, only the iPad supported animations in slides, no hyperlinks in slides, ordering issues	Every part of the intervention should be a different study. Introducing the intervention naturally among other training, and discover what parts of the intervention cause anxiety to the student
Neely et al., 2013	Comparison of traditional learning and learning through an iPad, and how much do challenging behaviors occur	The use of an iPad leads to less challenging behaviour and more academic engagement in relation to traditional techniques	–	To isolate iPad influence, control for histories of reinforcement. Efficiency between traditional and iPad delivered instruction. Expand to other academic demands
Kamaruzaman et al., 2016	Designing a smartphone app that teaches basic numeracy to children with autism	Explored how to design and build an app that teaches basic numeracy to children with ASD	–	–
Husni & Budianingsih, 2013	Application that teaches basic vocabulary	App developed that teaches children basic vocabulary skills	–	–
Doenyas et al., 2014	Teach sequencing skills in children with ASD	The sequencing skills of the participants improved throughout the sessions	HTML5 issues between versions of iOS (required tweaking of browsers). Not implemented various levels of skills with iPad. Low language skills of the children. Poor fine motor skills	Custom cues for the children. Prevent app from being swapped. Detecting iPad skill and changing tasks accordingly. Speaking section. Various difficulty levels
Holt & Yuill, 2017	Using two connected tablets to promote cooperation skills in children with ASD	The dual tablets increased the collaborative activity between ASD children than when sharing a single tablet	Small sample	Generalizability and scope of collaborative technology designs, some materials may be more effective, long-term benefits of collaborative activities
Lubas et al., 2014	Analysis of AAC apps and design propositions in order to be useful for children with ASD	Focus on the design process of an AAC app and development of such an app from feedback	Limited research in AAC	Multi-disciplinary approach, app that works in different settings, data collection inside the app, maximize communication improvements for a wide range of users
Artoni et al., 2018	Examining if ICT can help in rehabilitation of children with ASD based in Applied Behavioural Analysis	An app (ABCD SW) was developed to see if it and ICT technology can enhance ABA rehabilitation therapy for children with autism. The results seem to suggest that.	Small sample, non-homogenous, informal selection, sample bias cannot be excluded, not representative (cannot generalize)	Evaluate progress child by child, parent training in advance, technology-enhanced learning in a fully controlled safe environment
Amiri et al., 2017	Detecting stereotypical movements in ASD through a smartwatch and cloud computing	There was an accuracy of 96.7% in detecting autistic behaviors making it an accurate tool	–	–

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Table 6 (*continued*)

Ref.	Scope	Outcomes	Limitations	Future Plans
Chien et al., 2015	Implementing the traditional photocard system in tablet format	iCAN reduced content-preparation time by over 70% while also enhancing children with autism's willingness to learn and interact with others	Small sample	Integrating iCAN into the curriculum of schools. Improving the interaction methods of the app. Enhancing the interface. Expanding the methodology to more children. Incorporate a longitudinal case study
Zheng & Motti, 2017	Smartwatch app that assists children with intellectual disabilities in educational settings	Users were enthusiastic about adopting the technology in the classroom	–	–
Hourcade et al., 2013	Evaluation of tablet apps in how much of a difference they make in helping children wih ASD with social skills	The children using the apps had more and much better social interactions	Small sample, small difference between children, same number of interventions with and without the apps	Larger study with more locations involved. Increase frequency of activities. Activities for low functioning children too. Better mood in children could be researched in a different study. Analyze what the children created
Torrado et al., 2016	Usage of smartwatch for self-regulation during emotional events and use of a smartphone to control the settings	Study of how useful are smartwatches for self-regulation and proposal for a smarwatch app to detect and help ASD individuals self-regulate	–	Inference mechanism of stress episodes, caregivers should evaluate the effects of the strategies implemented, further experiments with more users
Bittner et al., 2017	Usage of an app to promote physical activity	The use of the EB app elicited greater values for peak energy expenditure and peak heart rate response while performing locomotor skills but no differences were observed while performing object control skills	Heart pulse was used in children with ASD increases with very mild physical movement so it was not indicative of physical exercise. Maximum exercise and oxygen consumption were not measured. Results aren't usable for more intense ASD conditions. Small range of ages (5 to 10 years old)	–
Rad & Furlanello, 2016	Detecting and recognizing stereotypical movements on people with ASD through neural networks	Showed how useable and adaptable a neural network is for detecting stereotype autism movements, that learns through the wrist wearable	Problematic for online adaptation	Transductive transfer learning strategy
Washington et al., 2017	Helping children recognize emotions using the Google Glasses	The device can act as a powerful training aid when used periodically in the home, interactive video content from wearable therapy sessions should be augmented with sufficient context about the content to produce long-term engagement, the design of wearable systems for children with ASD should be heavily dependent on the functioning level of the child	Participants recruited from single geographical area of high-tech families, big income families, different versions of onboarding because of different times of recruitment, audio was only recorded for a fraction of the study, short battery life of the Glass, eye-tracking would have allowed for a more accurate measure	Additional gamification, more reinforcing feedback, activities that leverage parent review, how audio analysis can further emotion recognition accuracy, other devices (Microsoft hololens), active learning techniques to correct classifications, alternative games and activities that can update the active learning model

(medicine, technology), should be able to store and access the data irrespective of their origin (owner, time and place generated). Such a pool of valuable data would significantly help in the emergence of innovative products and applications. Research taking place in areas like emotion recognition, behavioral analysis, attention deficit, stress, anxiety, etc., is still in an infant stage. Affective computing, artificial intelligence, along with the Internet of Things and the appearance of new sensors and MEMS (Ramadoss, 2013) can push further the research community to deal with these conditions. The same applies to other areas, such as addressing deficits in cooperation which is also a major issue for persons with ASD.

The findings reveal that technology assessment is a very challenging, time-consuming but necessary task in any research effort. Focusing on mHealth applications, the evaluation is even more challenging since there is no gold standard. Most researchers tend to examine the stars rating system used in commercially available apps (Pustozerov, Von Jan, & Albrecht, 2016). However, each application should be evaluated according to the scope it intends to serve (Jake-Schoffman et al., 2017). For example, content is examined in order to compare the developed features with clinical guidelines, evidence-based protocols, and behaviour change; usability testing evaluates the functionality of the application for a specific target group; efficacy tests whether the application impacts an outcome of interest through a variety of study designs (e.g. randomized trials, etc.); and, observational techniques investigate how its use is associated with behavioral or clinical outcomes. An interesting finding is that the majority (86.2%) of questionnaires used were custom-made. Based on the review findings, someone could question the results of most of the published studies, as they do not utilize already reliable and valid instruments, but rather develop their own ones. In one study (Fernández-López et al., 2013), even though the researchers tested the reliability of the questionnaires used, they didn't assess their validity, or use any gold standards or any established methodology to evaluate those questionnaires. According to what has been presented, the subjective satisfaction and assessment of mHealth solutions seems to be a really difficult and challenging task, since there is no gold standard nowadays. There is however, an apparent need for the development of instruments that can capture the different aspects of the subject's satisfaction (Koumpouros, 2016). Finally, it is considered important in the methodology of any research effort to report users' experience with the used mobile technologies in order to improve the completeness of the papers.

Ethical and legal challenges are also main concerns in research projects. These are related to privacy protection and confidentiality, ethics approval and informed consent, transparency of the collected data management by the final system and during pilots and validation studies, as well as IT-security and identity management. Data security and privacy are areas that require legal and policy attention to ensure that users' data are properly protected. Even though privacy and security issues were a concern in the studied projects, the development of both the technology and the regulations require more efforts. Protection of data, unwanted sharing of sensitive information with third parties (Bielecki, 2012), accidental exposure or leaking of health data are some of the critical security issues arising in any project. Careful considerations regarding data sharing should comply with the relevant EU laws and Directives, i.e. General Data Protection Regulation (European Commission, 2012), Directive 95/46/EC (European Parliament, 1995), Directive 2002/58/EC (European Parliament, 2002) and Charter of Fundamental Right (European Parliament, 2000). It is obvious, that one of the biggest issues in conducting research in an ASD population is always the limited number of subjects involved. This is due to two main reasons: the limited number of ASD patients per country and the ethics and legal aspects in order to conduct research with "sensitive" target groups. The latter, has become even more difficult due to the new European regulation relevant to protection of private and sensitive data (General Data Protection Regulation - GDPR) (European Commission, 2012). On the other hand, there should be representative users and a sufficient number of them in order to obtain valid results (Riihiaho, 2000). This is still a challenge according to the results of the current paper. Furthermore, the limited participation of parents in the examined studies (Table 5 and Fig. 5) could also be related to privacy and security issues. It can be considered as an inhibitor and indication of their reluctance to expose their children to any research studies. Many could be the reasons for such an attitude. They may be afraid of the experiments to be conducted on their children, not understand the context of the research, be ashamed and afraid of any kind of potential publication which will include their children, or not have the time to participate because of the many obligations they have already (e.g. children's' therapies, etc.).

The distribution of projects between the different target groups (85.2% patients, 5.7% parents, 2.8% teachers, 2.6% carers, 1.5% specialists) reveals that an extremely limited number of research efforts target other categories than the patients themselves. This can also be considered as an interesting area of future research efforts. According to the research findings (Table 6), we can summarize the major problems and limitations faced by the projects:

- Small sample
- Short duration of observation
- Not clear, quantifiable results
- Not generalizable results
- Low accuracy in measurements or/and many false positive
- Need for training of end users (e.g. teachers, parents, etc.)
- No use of control groups
- No use of random sample
- Not easy to conclude if the tool or the training has ultimately helped
- Considerations of technologies (cost, size, battery life, position, washing hands, not easy to wear sensors to children, etc.)
- Not highly customizable solutions
- ASD kids get quickly bored
- Privacy and security concerns
- Requires time to build a relationship with children

- Research does not check if the skills have been retained

Regarding future steps, research activities should target statistically accepted results. To this end, any research activity should employ a statistically significant number of subjects in order to conclude in satisfactory results regarding usage, and user subjective and objective satisfaction, using existing valid and reliable instruments able to capture the users' satisfaction in an early research stage (Koumpouros, 2016). The transfer of skills to real conditions is another real challenge. It is crucial that research efforts should focus on applications testing under real conditions and not only in a controlled environment. In this way, the transferability of the proposed solutions will be a step closer to the market. An advanced Technology Readiness Level (TRL) (European Commission, 2014) is mandatory towards helping persons with ASD. Furthermore, the applications should be highly customizable in order to meet the wide range of needs and individualities of the targeted population. In the case of ASD, this is considered even more important, since the pathology itself is actually a spectrum and thus, the needs of each individual may drastically differ. To this end, it is extremely important to have a comprehensive study of the demands of end-users at an early stage, in order to design as much as possible a generic solution capable of adapting to specialized needs. This can be supported by an iterative strategy of design, evaluation and redesign (Nielsen, 1993), which includes the various end users from the very beginning. Cooperative design could be considered an asset for this population. Usability testing and subjective evaluation is a challenging but critical task in any research project (Koumpouros, 2016; Koumpouros, Papageorgiou, Karavasili, & Koureta, 2016). The individualities of ASD make subjective assessment even more important. User-friendliness is also another big issue for the wider target groups (carers, specialists, parents) involved. Complexity and long periods of training should be avoided in order to attract the desired groups to use the proposed applications. To this end, the already existing attitudes should be seriously taken into account in the design phase. Finally, an interdisciplinary approach is required in order to produce a close to market solution with high potential of success. Behavioral sciences should be a part of any research effort in the field. Behavioral intervention technologies (BITs) is also another area of application of mobile health solutions exploiting interdisciplinary teams which fits to ASD domain. Self-assessment, self-monitoring, psychoeducation, goal setting, and feedback are some of the interventions addressed by BITs (Mohr, Burns, Schueller, Clarke, & Klinkman, 2013). This could lead to better adoption rates of the final solutions by the end users and has already been proved in many other areas (Spruijt-Metz et al., 2015).

From a clinical point of view, several arguments can be put forward regarding the use of technologies in ASD. Sensing technologies are essential towards addressing the various challenges faced within ASD; for example, many symptoms can improve as individuals learn to cope with their environments under the right conditions (Dawson, 2008). Wearables and mobile applications that use sensors are vital nowadays in the screening and therapy of ASD. Eye trackers have been used for the early detection of ASD by observing the gaze patterns of the subjects (Frazier et al., 2016; Nakano et al., 2010). The detection of stereotypical behaviors is also another field of application of sensing technologies. The data collected by the accelerometers, are being processed to obtain velocity and displacement with respect to time, while using machine learning techniques these data are converted to meaningful measures (Amiri et al., 2017; Rad & Furnalello, 2016; Rodrigues, Gonçalves, Costa, & Soares, 2012; Coronato et al., 2014). Electrodermal activity, skin temperature and heart rate are also used to measure stress levels which is a common symptom in persons with ASD. Such technologies can be proved valuable for detecting, even remotely, stressing symptoms for diagnosis purposes or for highlighting the need for context evaluation. Moreover, these tools allow researchers to gain insight on the internal states of individuals with ASD, who are unable to communicate their feelings. Other devices, like the Language ENvironment Analysis (LENA, LENA Research Foundation, Boulder, CO, USA) have been developed to detect speech patterns in order to be used as early ASD screening and treatment tools. To this end, vocal prosody and speech detectors are being used to detect atypical vocal patterns for the early diagnoses of ASD, while gamification techniques are provided for treatment purposes in ASD. By engaging the full body movements of the player (using a Kinect sensor), combined with traditional learning targets (e.g. social skills and attention skills), serious games can enhance motor skills of children with ASD. Virtual reality and avatars are also being used to for social skill learning. In the same direction, humanoid robots are employed for treatment plans for children with ASD. Unlike avatars, where high fidelity animation of facial expressions and body gestures are accurately simulated, which are essential to closed-loop autonomous treatment programs, the majority of autism oriented social robots have limited training targets (e.g. raising an arm). They have been used for joint attention study, for interventions on repetitive behaviors and affective states, for interventions on verbal communication skills, and for intervention on imitation of children with ASD. Other innovative technologies (clothing and wearables) target to relieve and calm the wearer. This is achieved in various ways: by adding weights and pressure, minimizing sensory distractions, controlling temperature, etc.

Regarding the technologies used in the examined studies, evidence supports that wearables and mobile technologies can help in both treatment and diagnosis (see Table 6). Such technologies have been used for supporting and improving social and life skills. Other interventions have proven to be useful when it comes to communication, behavioral and attention deficits. Moreover, cognitive skills have been improved by innovative educational applications. Therapists, carers and teachers can be considerably helped using the developed technologies (e.g. less time spent per individual, remote and continuous monitoring, achieve with more ease and quicker the desired therapeutic outcomes, etc.). Other applications have successfully improve the treatment regarding the understanding of emotions. Furthermore, stressful situations and tantrums can be automatically recognized and related to specific situations. In the same direction, stereotypical movements can be detected with high accuracy and related to stressing events. Thus, therapists can be effectively helped to identify and follow more accurate approaches for custom-made treatments: automatic detection of stereotypical behaviors can be used for early diagnosis of ASD, screening of essential health data can be facilitated by the examined technologies, and early therapy interventions can be delivered through technologies when therapists are not available. Other results suggest that ICTs can help in rehabilitation of children with ASD exploiting applied behavioral analysis methodologies and techniques. Finally, technologies can significantly help professionals in monitoring progress towards the targeted therapeutic outcomes (e.g. in education, communication, behavior, etc.).

5. Conclusions

The emergence of new technologies promises significant solutions in the near future. In addition, the growing penetration of smartphones and sensors is supporting this growth and has encouraged researchers to develop new tools to help people with ASD (Solomon, 2012). However, several limitations hinder the extended adoption of the solutions. The successful commercialization of the developed solutions is still an issue from the research examined. According to the study, an extremely limited number of products has the potential to be further commercialized. More efforts are needed to conclude in applications that can really help persons with ASD in real world settings. However, early findings suggest that mobile technology and wearables can and will have significant clinical impact in ASD as they have great potential for helping specialists in early detection of ASD symptoms, remote monitoring of patients, as well as treatment of certain symptoms.

Conflict of interest

No conflict of interest exists.

References

Abdullah, M. H. L., & Brereton, M. (2015). MyCalendar. *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction on - OzCHI' 15,* 1–9. https://doi.org/10.1145/2838739.2838785.

Ahmed, I. U., Hassan, N., & Rashid, H. (2017). Solar powered smart wearable health monitoring and tracking device based on GPS and GSM technology for children with autism. *2017 4th International Conference on Advances in Electrical Engineering (ICAEE),* 111–116. https://doi.org/10.1109/ICAEE.2017.8255337.

Altogether Autism (2019). *Altogether autism.* April 9, Retrieved fromhttps://www.altogetherautism.org.nz/multi-sensory-environments-use-people-autism/.

Alzrayer, N. M., Banda, D. R., & Koul, R. (2017). Teaching children with autism spectrum disorder and other developmental disabilities to perform multistep requesting using an iPad. *Augmentative and Alternative Communication, 33*(2), 65–76. https://doi.org/10.1080/07434618.2017.1306881.

Amiri, A., Peltier, N., Goldberg, C., Sun, Y., Nathan, A., Hiremath, S., ... Mankodiya, K. (2017). WearSense: Detecting autism stereotypic behaviors through smartwatches. *Healthcare, 5*(1), 11. https://doi.org/10.3390/healthcare5010011.

Andonie, R., & Dzitac, I. (2010). How to write a good paper in computer science and how will it be measured by ISI web of knowledge. *International Journal of Computers Communications & Control,* 432–446. https://doi.org/10.15837/ijccc.2010.4.2493.

Aresti-Bartolome, N., & Garcia-Zapirain, B. (2014). Technologies as support tools for persons with autistic Spectrum disorder: A systematic review. *International Journal of Environmental Research and Public Health, 11*(8), 7767–7802. https://doi.org/10.3390/ijerph110807767.

Artoni, S., Bastiani, L., Buzzi, M. C., Buzzi, M., Curzio, O., Pelagatti, S., ... Senette, C. (2018). Technology-enhanced ABA intervention in children with autism: A pilot study. *Universal Access in the Information Society, 17*(1), 191–210. https://doi.org/10.1007/s10209-017-0536-x.

Autism spectrum disorders (2017). *Autism spectrum disorders.* April 4, Retrieved fromhttps://www.who.int/news-room/fact-sheets/detail/autism-spectrum-disorders.

Aziz, M. Z. A., Abdullah, S. A. C., Adnan, S. F. S., & Mazalan, L. (2014). Educational app for children with autism Spectrum disorders (ASDs). *Procedia Computer Science, 42*, 70–77. https://doi.org/10.1016/j.procs.2014.11.035.

Baio, J., Wiggins, L., Christensen, D. L., Maenner, M. J., Daniels, J., Warren, Z., ... Dowling, N. F. (2018). Prevalence of autism Spectrum disorder among children aged 8 years — Autism and developmental disabilities monitoring network, 11 sites, United States, 2014. *MMWR Surveillance Summaries, 67*, 1–23. https://doi.org/10.15585/mmwr.ss6706a1.

Bauminger, N., Goren-Bar, D., Gal, E., Weiss, P. L., Yifat, R., Kupersmitt, J., ... Zancanaro, M. (2007). Enhancing social communication in High-functioning children with autism through a Co-located interface. *2007 IEEE 9th Workshop on Multimedia Signal Processing,* 18–21. https://doi.org/10.1109/MMSP.2007.4412808.

Bielecki, M. (2012). *Leveraging mobile health technology for patient recruitment: An emerging opportunity.* Northbrook, IL: Blue Chip Patient Recruitment.

Bittner, M. D., Rigby, B. R., Silliman-French, L., Nichols, D. L., & Dillon, S. R. (2017). Use of technology to facilitate physical activity in children with autism spectrum disorders: A pilot study. *Physiology & Behavior, 177*, 242–246. https://doi.org/10.1016/j.physbeh.2017.05.012.

Boucenna, S., Narzisi, A., Tilmont, E., Muratori, F., Pioggia, G., Cohen, D., ... Chetouani, M. (2014). Interactive technologies for autistic children: A review. *Cognitive Computation, 6*(4), 722–740 doi:10.100712559-014-9276-x.

Boyd, L. E., Jiang, X., & Hayes, G. R. (2017). ProCom. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI' 17,* 2865–2877. https://doi.org/10.1145/3025453.3026014.

Boyd, T. K., Hart Barnett, J. E., & More, C. M. (2015). Evaluating iPad technology for enhancing communication skills of children with autism Spectrum disorders. *Intervention in School and Clinic, 51*(1), 19–27. https://doi.org/10.1177/1053451215577476.

Brooke, J. (1996). *SUS - A quick and dirty usability scale.* https://doi.org/10.1002/hbm.20701.

Burke, R. V., Andersen, M. N., Bowen, S. L., Howard, M. R., & Allen, K. D. (2010). Evaluation of two instruction methods to increase employment options for young adults with autism spectrum disorders. *Research in Developmental Disabilities, 31*(6), 1223–1233. https://doi.org/10.1016/j.ridd.2010.07.023.

Campbell, K., Carpenter, K. L. H., Espinosa, S., Hashemi, J., Qiu, Q., Tepper, M., ... Dawson, G. (2017). Use of a digital modified checklist for autism in toddlers – Revised with follow-up to improve quality of screening for autism. *The Journal of Pediatrics, 183*, 133–139. https://doi.org/10.1016/j.jpeds.2017.01.021 e1.

Cesário, V., Rodrigues, J., Li, H., Wu, I., & Nisi, V. (2016). Crescendo. *Proceedings of the The 15th International Conference on Interaction Design and Children - IDC' 16,* 571–576. https://doi.org/10.1145/2930674.2935997.

Chen, W. (2012). Multitouch tabletop technology for people with autism Spectrum disorder: A review of the literature. *Procedia Computer Science, 14*, 198–207. https://doi.org/10.1016/j.procs.2012.10.023.

Cheng, Y., Luo, S., Lin, H., & Yang, C.-S. (2018). Investigating mobile emotional learning for children with autistic spectrum disorders. *International Journal of Developmental Disabilities, 64*(1), 25–34. https://doi.org/10.1080/20473869.2016.1206729.

Cheretta, C. (2016). *Children with autism and hypersensitivity – Communication tips to help.* March 22, Retrieved fromhttp://www.autism-society.org/children-autism-hypersensitivity-communication-tips-help/.

Chien, M.-E., Jheng, C.-M., Lin, N.-M., Tang, H.-H., Taele, P., Tseng, W.-S., ... Chen, M. Y. (2015). iCAN: A tablet-based pedagogical system for improving communication skills of children with autism. *International Journal of Human-computer Studies, 73*, 79–90. https://doi.org/10.1016/j.ijhcs.2014.06.001.

Cihak, D. F., Kessler, K. B., & Alberto, P. A. (2007). Generalized use of a handheld prompting system. *Research in Developmental Disabilities, 28*(4), 397–408. https://doi.org/10.1016/j.ridd.2006.05.003.

Clark, M. L. E., Austin, D. W., & Craike, M. J. (2015). Professional and parental attitudes toward iPad application use in autism Spectrum disorder. *Focus on Autism and Other Developmental Disabilities, 30*(3), 174–181. https://doi.org/10.1177/1088357614537353.

Conrad, A. M., & Munro, D. (2008). Relationships between computer self-efficacy, technology, attitudes and anxiety: Development of the computer technology use scale (CTUS). *Journal of Educational Computing Research, 39*(1), 51–73. https://doi.org/10.2190/EC.39.1.d.

CORE Rankings Portal - Computing Research & Education. (n.d.) Retrieved from http://www.core.edu.au/conference-portal.
Coronato, A., De Pietro, G., & Paragliola, G. (2014). A situation-aware system for the detection of motion disorders of patients with Autism Spectrum disorders. *Expert Systems With Applications, 41*(17), 7868–7877. https://doi.org/10.1016/j.eswa.2014.05.011.
da Silva, M. L., Gonçalves, D., Guerreiro, T., & Silva, H. (2012). A web-based application to address individual interests of children with autism Spectrum disorders. *Procedia Computer Science, 14*, 20–27. https://doi.org/10.1016/j.procs.2012.10.003.
Dawson, G. (2008). Early behavioral intervention, brain plasticity, and the prevention of autism spectrum disorder. *Development and Psychopathology, 20*, 775–803.
De Leo, G., Gonzales, C. H., Battagiri, P., & Leroy, G. (2011). A smart-phone application and a companion website for the improvement of the communication skills of children with autism: Clinical rationale, technical development and preliminary results. *Journal of Medical Systems, 35*(4), 703–711. https://doi.org/10.1007/s10916-009-9407-1.
de Urturi, Z. S., Zorrilla, A. M., & Zapirain, B. G. (2011). Serious game based on first aid education for individuals with autism spectrum disorder (ASD) using android mobile devices. *2011 16th International Conference on Computer Games (CGAMES),* 223–227. https://doi.org/10.1109/CGAMES.2011.6000343.
de Urturi, Z. S., Zorrilla, A. M., & Zapirain, B. G. (2012). *A serious game for android devices to help educate individuals with autism on basic first aid.* 609–616. https://doi.org/10.1007/978-3-642-28765-7_74.
Di Palma, S., Tonacci, A., Narzisi, A., Domenici, C., Pioggia, G., Muratori, F., ... Billeci, L. (2017). Monitoring of autonomic response to sociocognitive tasks during treatment in children with Autism Spectrum disorders by wearable technologies: A feasibility study. *Computers in Biology and Medicine, 85*, 143–152. https://doi.org/10.1016/j.compbiomed.2016.04.001.
Dibia, V. (2016). FOQUS. *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility - ASSETS' 16,* 311–312. https://doi.org/10.1145/2982142.2982207.
Doenyas, C., Şimdi, E., Özcan, E.Ç., Çataltepe, Z., & Birkan, B. (2014). Autism and tablet computers in Turkey: Teaching picture sequencing skills via a web-based iPad application. *International Journal of Child-computer Interaction, 2*(1), 60–71. https://doi.org/10.1016/j.ijcci.2014.04.002.
Duncan, H., & Tan, J. (2012). A visual task manager application for individuals with autism *. *Journal of Computing Sciences in Colleges, 27*(6), 49–57.
Edwards, C. (2018). *Wearable health technology: Fads or the future?* September 5, Retrieved fromhttps://www.medicaldevice-network.com/features/wearable-health-technology-trends/.
Escobedo, L., Nguyen, D. H., Boyd, L., Hirano, S., Rangel, A., Garcia-Rosas, D., ... Hayes, G. (2012). MOSOCO. *Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems - CHI' 12,* 2589. https://doi.org/10.1145/2207676.2208649.
European Commission (2012). General data protection regulation: Proposal for a regulation of the european parliament and of the council. From EC justice. *Data protection*. Retrieved from ec.europa.eu/justice/data-protection/document/review2012/com_2012_11_en.pdf.
European Commission (2014). *HORIZON 2020 – WORK PROGRAMME 2014-2015, general annexes, extract from part 19 - commission decision C(2014)4995.* Retrieved fromhttps://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf.
European Parliament (2000). Charter of fundamental rights of the european union (2000/C 364/01). *Official Journal of the European Communities*. Retrieved from www.europarl.europa.eu/charter/pdf/text_en.pdf.
European Parliament and the Council of 12 July 2002 (2002). *Directive 2002/58/EC: Processing of personal data and the protection of privacy in the electronic communications sector.* Retrieved fromeur-lex.europa.eu/eli/dir/2002/58/oj.
European Parliament and the Council of 24 October 1995 (1995). *Directive 95/46/EC: Protection of individuals with regard to the processing of personal data and the free movement of such data.* Retrieved fromdata.europa.eu/eli/dir/1995/46/oj.
Fazana, F., Alsadoon, A., Prasad, P. W. C., Costadopoulos, N., Elchouemi, A., & Sreedharan, S. (2017). Integration of assistive and wearable technology to improve communication, social interaction and health monitoring for children with autism spectrum disorder (ASD). *2017 IEEE Region 10 Symposium (TENSYMP),* 1–5. https://doi.org/10.1109/TENCONSpring.2017.8070018.
Fernandez, A., Insfran, E., & Abrahão, S. (2011). Usability evaluation methods for the web: A systematic mapping study. *Information and Software Technology,* 789–817. https://doi.org/10.1016/j.infsof.2011.02.007.
Fernández-López, Á., Rodríguez-Fórtiz, M. J., Rodríguez-Almendros, M. L., & Martínez-Segura, M. J. (2013). Mobile learning technology based on iOS devices to support students with special education needs. *Computers & Education, 61*, 77–90. https://doi.org/10.1016/j.compedu.2012.09.014.
Fiordelli, M., Diviani, N., & Schulz, P. J. (2013). Mapping mhealth research: A decade of evolution. *Journal of Medical Internet Research*. https://doi.org/10.2196/jmir.2430.
Fletcher, R. R., Dobson, K., Goodwin, M. S., Eydgahi, H., Wilder-Smith, O., Fernholz, D., ... Picard, R. W. (2010). iCalm: Wearable sensor and network architecture for wirelessly communicating and logging autonomic activity. *IEEE Transactions on Information Technology in Biomedicine, 14*(2), 215–223. https://doi.org/10.1109/TITB.2009.2038692.
Fletcher-Watson, S., Pain, H., Hammond, S., Humphry, A., & McConachie, H. (2016). Designing for young children with autism spectrum disorder: A case study of an iPad app. *International Journal of Child-computer Interaction, 7*, 1–14. https://doi.org/10.1016/j.ijcci.2016.03.002.
Fletcher-Watson, S., Petrou, A., Scott-Barrett, J., Dicks, P., Graham, C., O'Hare, A., ... McConachie, H. (2016). A trial of an iPad TM intervention targeting social communication skills in children with autism. *Autism, 20*(7), 771–782. https://doi.org/10.1177/1362361315605624.
Frazier, T. W., Klingemier, E. W., Beukemann, M., Speer, L., Markowitz, L., Parikh, S., ... Delahunty, C., et al. (2016). Development of an objective autism risk index using remote eye tracking. *Journal of the American Academy of Child and Adolescent Psychiatry, 55*, 301–309.
Gay, V., & Leijdekkers, P. (2014). Design of emotion-aware mobile apps for autistic children. *Health and Technology, 4*(1), 21–26. https://doi.org/10.1007/s12553-013-0066-3.
Gentry, T., Kriner, R., Sima, A., McDonough, J., & Wehman, P. (2015). Reducing the need for personal supports among workers with autism using an iPod touch as an assistive technology: Delayed randomized control trial. *Journal of Autism and Developmental Disorders, 45*(3), 669–684. https://doi.org/10.1007/s10803-014-2221-8.
Goel, I., & Kumar, D. (2015). Design and implementation of android based wearable smart locator band for people with autism, dementia, and alzheimer. *Advances in Electronics, 2015*, 1–8. https://doi.org/10.1155/2015/140762.
Gomez, J., Torrado, J. C., & Montoro, G. (2016). Using smartwatches for behavioral issues in ASD. *Proceedings of the XVII International Conference on Human Computer Interaction - Interacción' 16,* 1–2. https://doi.org/10.1145/2998626.2998646.
Helmy, J., & Helmy, A. (2016). The alzimio app for dementia, autism & alzheimer's: Using novel activity recognition algorithms and geofencing. *2016 IEEE International Conference on Smart Computing (SMARTCOMP),* 1–6. https://doi.org/10.1109/SMARTCOMP.2016.7501720.
Holt, S., & Yuill, N. (2017). Tablets for two: How dual tablets can facilitate other-awareness and communication in learning disabled children with autism. *International Journal of Child-computer Interaction, 11*, 72–82. https://doi.org/10.1016/j.ijcci.2016.10.005.
Hourcade, J. P., Williams, S. R., Miller, E. A., Huebner, K. E., & Liang, L. J. (2013). Evaluation of tablet apps to encourage social interaction in children with autism spectrum disorders. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI' 13,* 3197. https://doi.org/10.1145/2470654.2466438.
Husni, E., & Budianingsih (2013). Mobile applications BIUTIS: Let's study vocabulary learning as a media for children with autism. *Procedia Technology, 11*, 1147–1155. https://doi.org/10.1016/j.protcy.2013.12.307.
IDC: The premier global market intelligence company (2019). *Worldwide quarterly wearable device tracker.* Retrieved fromhttps://www.idc.com/tracker/showproductinfo.jsp?prod_id=962.
International Telecommunication Union (ITU) (2017). *ICT facts and figures 2017.* Retrieved fromSwitzerland, Geneva: International Telecommunication Union. https://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx.
Ipscience-help.thomsonreuters.com (2019). *2018 JCR data release.* Retrieved fromhttp://ipscience-help.thomsonreuters.com/incitesLiveJCR/8275-TRS.html.
Irwin, J., Preston, J., Brancazio, L., D'angelo, M., & Turcios, J. (2015). Development of an audiovisual speech perception app for children with autism spectrum disorders. *Clinical Linguistics & Phonetics, 29*(1), 76–83. https://doi.org/10.3109/02699206.2014.966395.
Jake-Schoffman, D. E., Silfee, V. J., Waring, M. E., Boudreaux, E. D., Sadasivam, R. S., Mullen, S. P., ... Pagoto, S. L. (2017). Methods for evaluating the content, usability, and efficacy of commercial mobile health apps. *JMIR MHealth and UHealth, 5*(12), e190. https://doi.org/10.2196/mhealth.8758.

Jiang, F., Jiang, Y., Zhi, H., Dong, Y., Li, H., Ma, S., ... Wang, Y. (2017). Artificial intelligence in healthcare: Past, present and future. *Stroke and Vascular Neurology, 2*(4), 230–243. https://doi.org/10.1136/svn-2017-000101.

Kagohara, D. M., van der Meer, L., Ramdoss, S., O'Reilly, M. F., Lancioni, G. E., Davis, T. N., ... Sigafoos, J. (2013). Using iPods® and iPads® in teaching programs for individuals with developmental disabilities: A systematic review. *Research in Developmental Disabilities, 34*(1), 147–156. https://doi.org/10.1016/j.ridd.2012.07.027.

Kamaruzaman, M. F., Rani, N. M., Nor, H. M., & Azahari, M. H. H. (2016). Developing user interface design application for children with autism. *Procedia - Social and Behavioral Sciences, 217*, 887–894. https://doi.org/10.1016/j.sbspro.2016.02.022.

Khan, S., Tahir, M. N., & Raza, A. (2013). Usability issues for smartphone users with special needs - Autism. *2013 International Conference on Open Source Systems and Technologies,* 107–113. https://doi.org/10.1109/ICOSST.2013.6720615.

Kientz, J., Hayes, G., Westeyn, T., Starner, T., & Abowd, G. (2007). Pervasive computing and autism: Assisting caregivers of children with special needs. *IEEE Pervasive Computing, 6*(1), 28–35. https://doi.org/10.1109/MPRV.2007.18.

King, A. M., Thomeczek, M., Voreis, G., & Scott, V. (2014). iPad ® use in children and young adults with Autism Spectrum disorder: An observational study. *Child Language Teaching and Therapy, 30*(2), 159–173. https://doi.org/10.1177/0265659013510922.

Kitchenham, B. (2004). *Procedures for performing systematic reviews*Joint Technical Report, Computer Science Department, Keele Universityhttps://doi.org/10.1112/2.3308.

Koumpouros, Y. (2016). A systematic review on existing measures for the subjective assessment of rehabilitation and assistive robot devices. *Journal of Healthcare Engineering, 2016*, 1–10. https://doi.org/10.1155/2016/1048964.

Koumpouros, Y., & Georgoulas, A. (2016). *mHealth R&D activities in Europe. M-health innovations for patient-centered care.* IGI Global.

Koumpouros, Y., & Georgoulas, A. (2019). *The rise of mHealth research in Europe.* 1–29. https://doi.org/10.4018/978-1-5225-8021-8.ch001.

Koumpouros, Y., Papageorgiou, E., Karavasili, A., & Koureta, F. (2016). PYTHEIA: A scale for assessing rehabilitation and assistive robotics. *World Academy of Science, Engineering and Technology, International Journal of Medical, Health, Biomedical, Bioengineering and Pharmaceutical Engineering, 10*(11), 522–526.

Kumar, S., Nilsen, W., Pavel, M., & Srivastava, M. (2013). Mobile health: Revolutionizing healthcare through transdisciplinary research. *Computer, 46*, 28–35. https://doi.org/10.1109/MC.2012.392.

Labrique, A. B., Vasudevan, L., Kochi, E., Fabricant, R., & Mehl, G. (2013). mHealth innovations as health system strengthening tools: 12 common applications and a visual framework. *Global Health, Science and Practice, 1*(2), 160–171. https://doi.org/10.9745/GHSP-D-13-00031.

Lavrakas, P. (2008). *Encyclopedia of survey research methods.* 2455 Teller Road, Thousand Oaks California 91320 United States of America: Sage Publications, Inchttps://doi.org/10.4135/9781412963947.

Leijdekkers, P., Gay, V., & Wong, F. (2013). CaptureMyEmotion: A mobile app to improve emotion learning for autistic children using sensors. *Proceedings of the 26th IEEE International Symposium on Computer-Based Medical Systems,* 381–384. https://doi.org/10.1109/CBMS.2013.6627821.

Loomes, R., Hull, L., & Mandy, W. P. L. (2017). What is the male-to-Female ratio in autism Spectrum disorder? A systematic review and meta-analysis. *Journal of the American Academy of Child and Adolescent Psychiatry*. https://doi.org/10.1016/j.jaac.2017.03.013.

Lubas, M., Mitchell, J., & De Leo, G. (2014). User-centered design and augmentative and alternative communication apps for children with autism Spectrum disorders. *SAGE Open, 4*(2), 215824401453750. https://doi.org/10.1177/2158244014537501.

Lyan, A.-W., Amjad, A.-G., Shaden, A.-Z., & Khalid, A.-N. (2015). A usability evaluation of arabic mobile applications designed for children with special needs — Autism. *Lecture Notes on Software Engineering, 3*(3), 203–209. https://doi.org/10.7763/LNSE.2015.V3.191.

Mamun, K. A. A., Bardhan, S., Ullah, M. A., Anagnostou, E., Brian, J., Akhter, S., ... Rabbani, M. G. (2016). Smart autism — A mobile, interactive and integrated framework for screening and confirmation of autism. *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC),* 5989–5992. https://doi.org/10.1109/EMBC.2016.7592093.

mHealth Apps (2017). *mHealth apps market size worth $111.8 billion by 2025 | CAGR: 44.2%.* August, Retrieved fromhttps://www.grandviewresearch.com/press-release/global-mhealth-app-market.

Mintz, J. (2013). Additional key factors mediating the use of a mobile technology tool designed to develop social and life skills in children with Autism Spectrum disorders: Evaluation of the 2nd HANDS prototype. *Computers & Education, 63*, 17–27. https://doi.org/10.1016/j.compedu.2012.11.006.

Mintz, J., Branch, C., March, C., & Lerman, S. (2012). Key factors mediating the use of a mobile technology tool designed to develop social and life skills in children with Autistic Spectrum disorders. *Computers & Education, 58*(1), 53–62. https://doi.org/10.1016/j.compedu.2011.07.013.

Mobile cellular subscriptions | Data (2019). *Mobile cellular subscriptions | Data.* Retrieved fromhttps://data.worldbank.org/indicator/IT.CEL.SETS.

Mohanaprakash, T., Subedha, V., & Lakshmi, D. (2015). Assisting echolalia (Repetitive speech patterns) in children with autism using android mobile app. *International Journal Of Advanced Information And Communication Technology, 12*(1)https://doi.org/10.1401/ijaict.2015.12.04.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine, 6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097.

Mohr, D. C., Burns, M. N., Schueller, S. M., Clarke, G., & Klinkman, M. (2013). Behavioral Intervention Technologies: Evidence review and recommendations for future research in mental health. *General Hospital Psychiatry, 35*, 332–338. https://doi.org/10.1016/j.genhosppsych.2013.03.008.

Nakano, T., Tanaka, K., Endo, Y., Yamane, Y., Yamamoto, T., Nakano, Y., ... Kitazawa, S. (2010). Atypical gaze patterns in children and adults with autism spectrum disorders dissociated from developmental changes in gaze behaviour. In: *Proc. Biol. Sci. R. Soc. 277*, 2935–2943.

Neely, L., Rispoli, M., Camargo, S., Davis, H., & Boles, M. (2013). The effect of instructional use of an iPad® on challenging behavior and academic engagement for two students with autism. *Research in Autism Spectrum Disorders, 7*(4), 509–516. https://doi.org/10.1016/j.rasd.2012.12.004.

Nielsen, J. (1993). *Usability engineering.* Morgan Kaufmann Publishers Inchttps://doi.org/10.1145/1508044.1508050.

Northrup, C. M., Lantz, J., & Hamlin, T. (2016). Wearable stress sensors for children with autism Spectrum disorder with in situ alerts to caregivers via a mobile phone. In: *Iproceedings, 2*(1), e9. https://doi.org/10.2196/iproc.6119.

Pantelopoulos, A., & Bourbakis, N. G. (2010). A survey on wearable sensor-based systems for health monitoring and prognosis. *IEEE Transactions on Systems Man and Cybernetics Part C, 40*(1), 1–12. https://doi.org/10.1109/TSMCC.2009.2032660.

Price Waterhouse Coopers (PWS) (2014). *Emerging mHealth: Paths for growth.* Price Waterhouse Coopers.

Pustozerov, E., Von Jan, U., & Albrecht, U. V. (2016). *Evaluation of mHealth applications quality based on user ratings. Studies in health technology and informatics*237–240. https://doi.org/10.3233/978-1-61499-664-4-237.

Quezada, A., Juárez-Ramírez, R., Jiménez, S., Noriega, A. R., Inzunza, S., & Garza, A. A. (2017). Usability operations on touch mobile devices for users with autism. *Journal of Medical Systems, 41*(11), 184. https://doi.org/10.1007/s10916-017-0827-z.

Rad, N. M., & Furlanello, C. (2016). Applying deep learning to stereotypical motor movement detection in autism spectrum disorders. *2016 IEEE 16th International Conference on Data Mining Workshops (ICDMW),* 1235–1242. https://doi.org/10.1109/ICDMW.2016.0178.

Ramadoss, R. (2013). *MEMS devices for biomedical applications.* Retrieved fromhttps://electroiq.com/2013/10/mems-devices-for-biomedical-applications/.

Rani, N. M., Legino, R., Mudzafar, N., & Kamaruzaman, M. F. (2014). Embedded visual schedule application towards autistic children development: A prelimenary study. *2014 IEEE 6th Conference on Engineering Education (ICEED),* 129–132. https://doi.org/10.1109/ICEED.2014.7194701.

research2guidance (2013). *Mobile health Market report 2013-2017. The commercialization of mHealth applicationsvol. 3.* research2guidance.

Riihiaho, S. (2000). *Experiences with USABILITY EVALUATION METHODS.* HELSINKI UNIVERSITY OF TECHNOLOGY Laboratory of Information Processing Science.

Rivera, C. J., Mason, L. L., Jabeen, I., & Johnson, J. (2015). Increasing teacher praise and on task behavior for students with autism using mobile technology. *Journal of Special Education Technology, 30*(2), 101–111. https://doi.org/10.1177/0162643415617375.

Robins, D. L., Casagrande, K., Barton, M., Chen, C.-M. A., Dumont-Mathieu, T., & Fein, D. (2014). Validation of the modified checklist for autism in toddlers, revised with follow-up (M-CHAT-R/F). *PEDIATRICS, 133*, 37–45. https://doi.org/10.1542/peds.2013-1813.

Rodrigues, J. L., Gonçalves, N., Costa, S., & Soares, F. (2012). Stereotype movement recognition in children with ASD. *Procedia Engineering, 47*, 668–671. https://doi.org/10.1016/j.proeng.2012.09.235.

Roldán-Álvarez, D., Gomez, J., Márquez-Fernández, A., Martín, E., & Montoro, G. (2016). *Mobile devices as assistive technologies for ASD: Experiences in the classroom.*

187–197. https://doi.org/10.1007/978-3-319-40355-7_18.

Sano, A., Hernandez, J., Deprey, J., Eckhardt, M., Goodwin, M. S., & Picard, R. W. (2012). Multimodal annotation tool for challenging behaviors in people with autism spectrum disorders. *Proceedings of the 2012 ACM Conference on Ubiquitous Computing - UbiComp' 12 (P. 737)*. https://doi.org/10.1145/2370216.2370378.

Schuck, S., Emmerson, N., Ziv, H., Collins, P., Arastoo, S., Warschauer, M., ... Lakes, K. (2016). Designing an iPad App to Monitor and Improve Classroom Behavior for Children with ADHD: iSelfControl Feasibility and Pilot Studies. *PloS One, 11*(10), e0164229. https://doi.org/10.1371/journal.pone.0164229.

Silva, M. L., Gonçalves, D., & Silva, H. (2014). User-tuned content customization for children with autism Spectrum disorders. *Procedia Computer Science, 27*, 441–448. https://doi.org/10.1016/j.procs.2014.02.048.

Smith, B. R., Spooner, F., & Wood, C. L. (2013). Using embedded computer-assisted explicit instruction to teach science to students with autism spectrum disorder. *Research in Autism Spectrum Disorders, 7*(3), 433–443. https://doi.org/10.1016/j.rasd.2012.10.010.

Solomon, O. (2012). *The uses of technology for and with children with autism spectrum disorders. Handbook of technology in psychology, psychiatry and neurology: Theory, research, and practice*. Nova Science Publishers, Inc.

Sparrow, S. S. (2011). *Vineland adaptive behavior scales. Encyclopedia of clinical neuropsychology*. New York, NY: Springer New York2618–2621. https://doi.org/10.1007/978-0-387-79948-3_1602.

Spruijt-Metz, D., Hekler, E., Saranummi, N., Intille, S., Korhonen, I., Nilsen, W., ... Pavel, M. (2015). Building new computational models to support health behavior change and maintenance: New opportunities in behavioral research. *Translational Behavioral Medicine, 5*, 335–346. https://doi.org/10.1007/s13142-015-0324-1.

Statista (2019a). *mHealth (mobile health) industry market size projection from 2012 to 2020 (in billion U.S. dollars)*. Retrieved fromhttps://www.statista.com/statistics/295771/mhealth-global-market-size/.

Statista (2019b). *Number of mobile phone users worldwide 2015-2020 | Statista.* Retrieved fromhttps://www.statista.com/statistics/274774/forecast-of-mobile-phone-users-worldwide/.

Statista (2019c). *Number of smartphone users worldwide 2014-2020 | Statista.* Retrieved fromhttps://www.statista.com/statistics/330695/number-of-smartphone-users-worldwide/.

Statista (2019d). *Projected global mHealth market size 2012-2020 | Statistic.* Retrieved fromhttps://www.statista.com/statistics/295771/mhealth-global-market-size.

Statista (2019e). *Smartwatch OS share worldwide 2022 | Statistic.* Retrieved fromhttps://www.statista.com/statistics/750328/worldwide-smartwatch-market-share-by-platform/.

Statista (2019f). *Total mHealth market size worldwide 2025 forecast | Statistic.* Retrieved fromhttps://www.statista.com/statistics/938544/mhealth-market-size-forecast-globally/.

Statista (2019g). *Wearables unit sales share worldwide from 2014 to 2018, by category.* Retrieved fromhttps://www.statista.com/statistics/538159/share-of-global-wearables-sales-by-category/.

Stephenson, J., & Limbrick, L. (2015). A review of the use of touch-screen mobile devices by people with developmental disabilities. *Journal of Autism and Developmental Disorders, 45*(12), 3777–3791. https://doi.org/10.1007/s10803-013-1878-8.

Stone, P. W. (2002). Popping the (PICO) question in research and evidence-based practice. *Applied Nursing Research*. https://doi.org/10.1053/apnr.2002.34181.

Szydło, T., & Konieczny, M. (2016). Mobile and wearable devices in an open and universal system for remote patient monitoring. *Microprocessors and Microsystems, 46*, 44–54. https://doi.org/10.1016/j.micpro.2016.07.006.

Teeters, A. (2007). *Use of a wearable camera system in conversation: Toward a companion tool for social-emotional learning in autism.* Master of ScienceMassachusetts Institute of Technology.

The Center of AAC and Autism (2019). *The center of AAC and autism.* April 9, Retrieved fromhttps://www.aacandautism.com.

The World Bank (2012). *2012 information and communications for development: Maximizing mobile. Report for the international bank for reconstruction and development*Retrieved fromhttps://siteresources.worldbank.org/EXTINFORMATIONANDCOMMUNICATIONANDTECHNOLOGIES/Resources/IC4D-2012-Report.pdf.

Thompson, J. R., Bryant, B., Campbell, E. M., Craig, E. M., Hughes, C., Rotholz, D. A., ... Wehmeyer, M. (2004). *Supports intensity scale.* Washington, DC: American Association on Mental Retardation.

Torrado, J. C., Gomez, J., & Montoro, G. (2017). Emotional self-regulation of individuals with autism Spectrum disorders: Smartwatches for monitoring and interaction. *Sensors, 17*(6), 1359. https://doi.org/10.3390/s17061359.

Torrado, J. C., Montoro, G., & Gomez, J. (2016). The potential of smartwatches for emotional self-regulation of people with autism spectrum disorder. *Proceedings of the 9th International Joint Conference on Biomedical Engineering Systems and Technologies,* 444–449. https://doi.org/10.5220/0005818104440449.

Tsiopela, D., & Jimoyiannis, A. (2014). Pre-vocational skills laboratory: Development and investigation of a web-based environment for students with autism. *Procedia Computer Science, 27*, 207–217. https://doi.org/10.1016/j.procs.2014.02.024.

Uphold, N. M., Douglas, K. H., & Loseke, D. L. (2016). Effects of using an iPod app to manage recreation tasks. *Career Development and Transition for Exceptional Individuals, 39*(2), 88–98. https://doi.org/10.1177/2165143414548572.

Vélez-Coto, M., Rodríguez-Fórtiz, M. J., Rodriguez-Almendros, M. L., Cabrera-Cuevas, M., Rodríguez-Domínguez, C., Ruiz-López, T., ... Martos-Pérez, J. (2017). SIGUEME: Technology-based intervention for low-functioning autism to train skills to work with visual signifiers and concepts. *Research in Developmental Disabilities, 64*, 25–36. https://doi.org/10.1016/j.ridd.2017.02.008.

Venkatesh, S., Greenhill, S., Phung, D., Adams, B., & Duong, T. (2012). Pervasive multimedia for autism intervention. *Pervasive and Mobile Computing, 8*(6), 863–882. https://doi.org/10.1016/j.pmcj.2012.06.010.

Virginia Department of Aging and Rehabilitative Services (2009). *Employee performance evaluation report*Richmond, VA: VDARS.

Vlachou, J., & Drigas, A. (2017). Mobile technology for students & adults with autistic Spectrum disorders (ASD). *International Journal of Interactive Mobile Technologies, 11*(1), 4. https://doi.org/10.3991/ijim.v11i1.5922.

Vukovic, M., Car, Z., Fertalj, M., Penezic, I., Miklausic, V., Ivsac, J., ... Mandic, L. (2016). Location-based smartwatch application for people with complex communication needs. *2016 International Multidisciplinary Conference on Computer and Energy Science (SpliTech),* 1–7. https://doi.org/10.1109/SpliTech.2016.7555937.

Washington, P., Wall, D., Voss, C., Kline, A., Haber, N., Daniels, J., ... Winograd, T. (2017). SuperpowerGlass. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 1*, 1–22. https://doi.org/10.1145/3130977 3.

WHO. mHealth (2011). *New horizons for health through mobile technologies: Based on the findings of the second global survey on eHealth, Vol. 3*. World Health Organization.

Zaffke, A., Jain, N., Johnson, N., Alam, M. A. U., Magiera, M., & Ahamed, S. I. (2015). *iCanLearn: A mobile application for creating flashcards and social StoriesTM for children with autism.* 225–230. https://doi.org/10.1007/978-3-319-14424-5_25.

Zamfir, B., Tedesco, R., & Reichow, B. (2012). *Handheld "App" offering visual support to students with autism Spectrum disorders (ASDs)*. 105–112. https://doi.org/10.1007/978-3-642-31534-3_16.

Zapata, B. C., Fernández-Alemán, J. L., Idri, A., & Toval, A. (2015). Empirical studies on usability of mHealth apps: A systematic literature review. *Journal of Medical Systems, 39*(2), 1. https://doi.org/10.1007/s10916-014-0182-2.

Zheng, H., & Motti, V. G. (2017). WeLi. *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility - ASSETS' 17,* 355–356. https://doi.org/10.1145/3132525.3134770.