The Digital Divide in Technologies for Autism: Feasibility Considerations for Low- and Middle-Income Countries

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Abstract

Digital technologies have the potential to empower individuals with autism and their families. The COVID-19 pandemic emphasized and accelerated the drive towards technology for information, communication, training, clinical care and research, also in the autism community. However, 95% of individuals with autism live in low- and middle-income countries (LMIC) where access to electricity, internet and the ever-increasing range of digital devices may be highly limited. The World Bank coined the term 'the digital divide' to describe the disparities in access to digital technologies between high-income and LMIC contexts. Here we evaluated the feasibility of six emerging technologies for autism spectrum disorders, and reflected on key considerations for implementation in LMIC contexts to ensure that we do not inadvertently widen the pre-existing digital divide.

Keywords Digital technology · Autism spectrum disorder · Digital disparities · Low-resource contexts · Africa · India

Introduction

Autism spectrum disorders (ASD) are neurodevelopmental disorders characterised by a wide range of features, including difficulty with social interaction and communication, restricted interests, and stereotyped behaviours (American Psychiatric Association, 2013). As a group people with ASD have a broad range of abilities, allowing some to lead independent and productive lives with varying levels of support, while others are severely affected by manifestations that may persist throughout the lifespan (Farley et al., 2009). However, there is growing evidence that early identification and treatment and a range of other interventions can reduce the manifestations and improve the functional outcomes of ASD for many affected individuals (Bradshaw et al., 2015; Dawson et al., 2012; Rogers & Dawson, 2010).

Given the global prevalence of ASD estimated in excess of 1% (Elsabbagh et al., 2012; Fombonne, 2009), the World Health Organization recognised ASD as a global public health concern and a major cause of disease burden (World Health Organization, 2013). However, 95% of individuals with ASD and other developmental disabilities live in low- or middle-income countries (LMIC) (Franz et al., 2017; Olusanya et al., 2018, 2020), where they are typically either undiagnosed or diagnosed much later than those living in high-income countries (HIC), and where they may receive no or very limited intervention and support (Daley, 2004; Lagunju et al., 2014; Pillay et al., 2021). Disparities in access to ASD screening, diagnosis, and treatment in low-resourced communities exist globally (Patel et al., 2008). Factors such as symptom severity, geographic location, socio-economic status (SES), race/ethnicity and culture impact both the age of first assessment and subsequent intervention (Lagunju et al., 2014; Williams et al., 2014).

Over the last 30 years, the rates of ASD and other disabilities have increased most significantly in sub-Saharan Africa (SSA) and in South-East Asia (Olusanya et al., 2018) where the majority of communities face significant challenges to access skilled professionals and appropriate services (de Vries, 2016; Franz et al., 2017; Saxena et al., 2007). Families who live in remote, low-resource areas typically have to travel considerable distances, sometimes for hours or days, for their children and adult family members to receive the services they need (Divan et al., 2012; Mahapatra et al., 2019). The lack of reliable transport infrastructure, shortage

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of trained professionals and lengthy waiting times may result in these visits taking days rather than hours (Daley, 2004; Durkin et al., 2015). Compounding the infrastructural challenges, people living in rural or remote areas of LMIC typically also have limited awareness of and poor knowledge about ASD. This, unfortunately, also includes educational and healthcare professionals (Bakare et al., 2009; de Vries, 2016; Franz et al., 2017; Ruparelia et al., 2014). Lack of knowledge about ASD combined with local cultural and traditional beliefs contribute to social stigma and discrimination, often depriving these already disadvantaged groups of opportunities to improve their health, education and community participation (Harrison et al., 2017; Harrison et al., 2017; Keusch et al., 2006; Michels et al., 2006).

Apart from gaps in clinical care and knowledge, there is also a significant disparity in the proportion of ASD research that has been conducted in LMIC as opposed to HIC settings. Taking sub-Saharan Africa as example, in a comprehensive scoping review Franz et al. (2017) showed that less than 1% of global ASD research had taken place in Africa. The review by Franz did not directly compare the proportion of research in all LMIC to research from all HIC, but it was clear that the majority of ASD research to date has come from HIC where the minority of people with ASD live.

Emerging Digital Technologies for Autism Spectrum Disorder

In recent years, there has been a rapid increase in utilising technology for identification, intervention and training to address the various challenges in delivering health and other care to families living with ASD (Grynszpan et al., 2014; Odom et al., 2015; Ploog et al., 2013). Unlike traditional service delivery models (involving highly skilled professionals in one-to-one, in-person sessions), technology allows the possibility to increase access on a large scale at relatively low cost, and to utilise a diverse workforce in local settings where these services are poor or non-existent. Technology therefore has the potential to reduce the disparities in service delivery between HIC and LMIC communities (Naslund et al., 2017).

In a comprehensive review of technologies for ASD, Kientz et al. (2014) identified six main emerging interactive technology platforms (personal computers, robotics, virtual reality, shared active surfaces, sensing technologies, and mobile devices) and used a classification scheme to review these key technologies. The classification included examination of the technology in relation to domain of interest (e.g. social/emotional or language/communication), purpose (e.g. functional assessment or diagnosis/screening), the target end user (e.g. person with ASD or family/caregiver), setting (e.g. home or school), nature of the empirical support (e.g. descriptive or experimental research) and technology

maturity (e.g. design, prototype or publicly available). Odom et al., (2015) used similar criteria to examine technology for adolescents with ASD and presented a conceptual framework that identified the 'human' (user), 'activity' (purpose) and 'technology' as key constructs in relation to the 'context' (home, school, community). Building on these earlier reviews, below we present a brief summary of the same technologies and their purpose, settings for use, users and relative cost, using the Kientz et al., (2014) and Odom et al., (2015) frameworks. See Fig. 1 for a visual summary.

Personal Computers

Personal Computers (PCs) are found in most homes, schools, universities, offices and shops in high-income countries (International Telecommunication Union (ITU), 2010). Computer-based interventions for autistic children have been known since the early 1970s (Colby, 1973; Colby & Smith, 1971) and used by individuals with ASD and their caregivers to address a wide variety of areas that require attention, from early identification to rehabilitation in a variety of settings (Fig. 1). Today, online platforms (e.g. https://babynavigator.com, Florida State University, 2021) enable parents to track their child's development prompting them into action if a developmental delay is suspected. Web-based courses (e.g. www.autismnavigator.com, Wetherby et al., n.d.) provide professionals and families access to the latest evidence-based diagnostic tools and intervention techniques. Computer-based training of community-based health care providers has been shown to be as effective as in-person didactic training (Vismara et al., 2009). Even without access to the internet, standard desktop computers with audio-visual presentation software (e.g. PowerPoint) of ASD-related educational material for healthcare professionals, teachers and carers can improve knowledge about ASD. According to Statista (2020a) the average selling price of personal computers in 2019 was US$632 with prices ranging from around US$150 (for refurbished PCs) to several thousand dollars (Statista, 2020a).

Robotics

Robot-based diagnosis and treatment for ASD has been a rapidly developing area of research in HICs for more than a decade (Dautenhahn & Werry, 2004; Scassellati, 2007). Researchers investigating robotic interventions for ASD typically report increased engagement and levels of attention when robots are part of the interaction, including individuals who routinely are unlikely or unwilling to interact socially with their healthcare provider and teachers (Diehl et al., 2012; Scassellati, 2007). Robots have been designed to address a variety of behavioural objectives such as joint attention (Kumazaki et al., 2018), social interaction and

Technology

	Robotics	Virtual Reality	Shared Active Surfaces	Sensing Technologies	Personal Computers	Mobile Technologies
Relative Cost	$$$$	$$$	$$$	$$	$$	$
User						
Researcher	✔	✔	✔	✔	✔	✔
Clinician/therapist	✔	✔	✔	✔	✔	✔
Educator		✔	✔	✔	✔	✔
Person with ASD		✔		✔	✔	✔
Family/carer				✔	✔	✔
Setting						
Research facility	✔	✔	✔	✔	✔	✔
Clinic	✔	✔	✔	✔	✔	✔
School		✔	✔	✔	✔	✔
Work				✔	✔	✔
Home		✔		✔	✔	✔
Community				✔		✔
Purpose						
Intervention and education	✔	✔	✔		✔	✔
Diagnosis and screening		✔		✔	✔	✔
Functional or scientific assessment		✔		✔	✔	✔

Fig. 1 Summary of emerging technologies for ASD in terms of their purpose, settings for use, potential users, and relative cost

communication skills (David et al., 2020; Kim et al., 2012) in school, clinic or home settings (Dickstein-Fischer et al., 2011, 2017). However, most robotic interventions for ASD have not yet progressed passed the developmental stage and require skilled operators. As a result, their use at present is mostly limited to research and specialised clinical settings. Their costs are substantial, ranging from hundreds to upwards of thousands of U.S. dollars (Boccanfuso et al., 2017; Dickstein-Fischer et al., 2011, 2018) making them the most expensive of the technologies discussed here (Fig. 1).

Virtual Reality

Virtual Reality (VR) technologies provide realistic safe and repeatable simulated real-world environments well-suited for teaching individuals with ASD the necessary skills required for independent living and employment (Parsons et al., 2004; Standen & Brown, 2005). VR based interventions for ASD have been used for improving social skills (Kandalaft et al., 2013), teaching individuals how to navigate and cross streets (Saiano et al., 2015), use public transport or find a table in a café or restaurant (Parsons et al., 2006). Virtual learning environments have been used for distance education to teach social and communication skills in low or under-resourced areas (Stichter et al., 2014). Head-mounted VR devices (like the Oculus Quest for example—https://www.oculus.com/compare/) are easily portable, not difficult to operate and can therefore be used in most settings and cost around US$300 (https://www.oculus.com/compare/, Facebook Technologies, 2021) for the hardware alone. Most state-of-the-art VR technologies for ASD, however, require powerful computers with advanced specifications and access to high speed broadband internet costing thousands rather than hundreds of US dollars (Fig. 1).

Shared Active Surfaces

Collaborative Interface (CI) or Shared Active Surface (SAS) technologies are large touch-screen computer-based interactive surfaces that can be placed on tabletops, be operated by more than one person simultaneously and therefore be utilized to enhance social and collaborative face-to-face interaction among multiple users (Dietz & Leigh, 2001; Travers & Fefer, 2016) Several published studies have documented the potential of using SAS technologies and cooperative games to improve social skills such as eye contact, sharing of emotions, showing interest toward a partner, and collaborative play in children with ASD (Bauminger-Zviely et al., 2013; Ben-Sasson et al., 2013; Gal et al., 2016). Multi-user surfaces are not easily transportable due to their size and weight. By its nature, touchscreen devices are not hardwearing and therefore susceptible to damage that could render them unserviceable and very expensive to repair or replace. It is possible that this technology could be useful in very specific settings such as specialist schools, clinics or research facilities (Fig. 1). However, they may not represent a very naturalistic opportunity for assessment or intervention for individuals with ASD. Commercially available multi-user touch tables currently cost from US$6,500 excluding any software (POP Communications, 2010).

Sensing Technologies

Sensing technologies (STs) embedded in everyday accessories such as glasses, wrist watches, clothing, or ultra-thin adhesive epidermal patches have been used to collect specific data to identify ASD symptoms (Cabibihan et al., 2017). STs include a variety of devices for tracking eye movement to detect atypical gaze (Constantino et al., 2017; Vidal et al., 2012; Ye et al., 2012), physical activity trackers to detect stereotypical behaviours (Goodwin, et al., 2011; Min & Tewfik, 2010; Sarker et al., 2018), sensors to detect internal state changes related to stress and anxiety (Fletcher et al., 2010; Goodwin et al., 2006), and sensors to detect atypical prosody and speech (Paul et al., 2005; Warren et al., 2010). However, many wearable physiological and physical activity-sensing devices require direct contact with the skin and may not be tolerated by some children with ASD (Cabibihan et al., 2017). Smart watches (e.g. the Apple Watch) are increasingly utilized both for assisting and monitoring individuals with ASD (Koumpouros & Kafazis, 2019) in any setting (Fig. 1). Sensing technologies are relatively expensive. The average selling price of smartwatches is around US$300 (Gartner, 2018; International Data Corporation, 2019) and typically require additional computer software and hardware, as well as highly skilled professionals to analyse and use collected data.

Mobile and Smartphone Technologies

It is estimated that around 74% of the population in HIC and around 45% of those living in LMIC own a smartphone while the estimates for tablet ownership are close to 50% and 20% respectively (Silver, 2019; Statista, 2020b). Even simple features such as task lists, calendars and address book applications can improve the day-to-day independence of school-going young people with ASD (Gentry et al., 2010; Hedges et al., 2018). Smartphone applications can potentially provide parents and carers with objective early screening (Egger et al., 2018; Kanne, et al., 2018) and intervention tools (Law et al., 2018; Parsons et al., 2019; Rogerson et al., 2019). Using online social media platforms (e.g. WhatsApp, Twitter, Facebook) can for some open the door to social engagement and being part of a community (Hedges et al., 2018; van Schalkwyk et al., 2017). The release of the first Apple iPhone in 2007 set in motion the rapidly evolving novel domain of healthcare referred to as 'mobile health' or 'mHealth'. Currently, there are more than 100,000 mHealth applications ('apps') available globally for download from app stores (Statista, 2021). Despite a paucity of empirical evidence, Smartphone apps for ASD continue to disrupt older technologies in several areas such as communication devices (e.g. WhatsApp) and access to personal medical information. The average selling price of smartphones in 2020 was US$309 (Statista, 2020b) with a wide range between lower specification smartphones (< US$100) and ultra-premium phones (> US$1,000) (International Data Corporation, 2020). Similar to PCs, mobile and smartphone technologies are used by individuals with ASD as well as their caregivers and service providers in most settings and for a wide variety of objectives but at relatively lower cost than many of the other emerging technologies for ASD (Fig. 1).

The 'Digital Divide' Between High-Income and Low/Middle-Income Countries

The World Development Report published by the World Bank in 2016 focused on digital technologies in a publication entitled 'Digital Dividends' (World Bank, 2016). The report pointed out that digital technologies have spread rapidly across the globe, but that the 'digital dividends'—the developmental benefits of using these technologies—had lagged behind. The report emphasized that emerging technologies had disproportionately benefited the higher-educated and wealthier sectors of society, and commented that nearly 60% of the world still had no access to the internet. The internet therefore remains unavailable, inaccessible and unaffordable to a majority of the world's population. "For digital technologies to benefit everyone everywhere therefore requires closing the remaining digital divide, especially

in internet access" (World Bank, 2016, p. 2). Figure 2 shows a graphic representation of fixed internet users (panel A) and mobile phone subscriptions (panel B) in HIC and LMIC between 2000 and 2017 (data from ITU, 2019 and World Bank, 2020) to illustrate the digital divide. Panel A shows how internet usage increased significantly from 2000 in HIC and LMIC settings, but indicates that the digital divide had increased, rather than reduced, over time with fewer than 40% of households in LMIC having fixed internet access, in contrast to more than 90% in HIC. Panel B shows that the digital divide has remained across the last 2 decades in terms of mobile/cellular subscriptions, but indicates that both in HIC and LMIC settings there were more than 90 subscriptions to mobile/cellular networks per 100 inhabitants by the end of 2017.

The COVID-19 pandemic that swept across the globe from the end of 2019, throughout 2020 and into 2021 very

rapidly shifted the majority of the world from in-person interactions towards remote interactions using technology for information, communication, teaching and research, including in the ASD community. A collection of commentaries about the impact of COVID-19 on ASD research (Amaral & de Vries, 2020) showed many examples of technological solutions, pivoting of research towards remote modalities, and so on. However, a few notable examples from lower-resource environments and LMIC expressed concern that the COVID-19 pandemic may simply have magnified pre-existing digital (and social) disparities (see e.g. de Vries et al., and Divan et al., in the Amaral and de Vries commentaries, 2020).

In order to ensure that we do not inadvertently increase the digital divide in the global ASD community, there is therefore a need to reflect on the feasibility of the increasing number and types of digital technologies for ASD. In

Fig. 2 Internet users and mobile phone subscriptions in HIC and LMIC between 2000 and 2017 (data from ITU, 2019 and World Bank, 2020). Panel A shows the percentage of households with access to fixed internet; Panel B shows the number of mobile/cellular subscriptions per 100 individuals
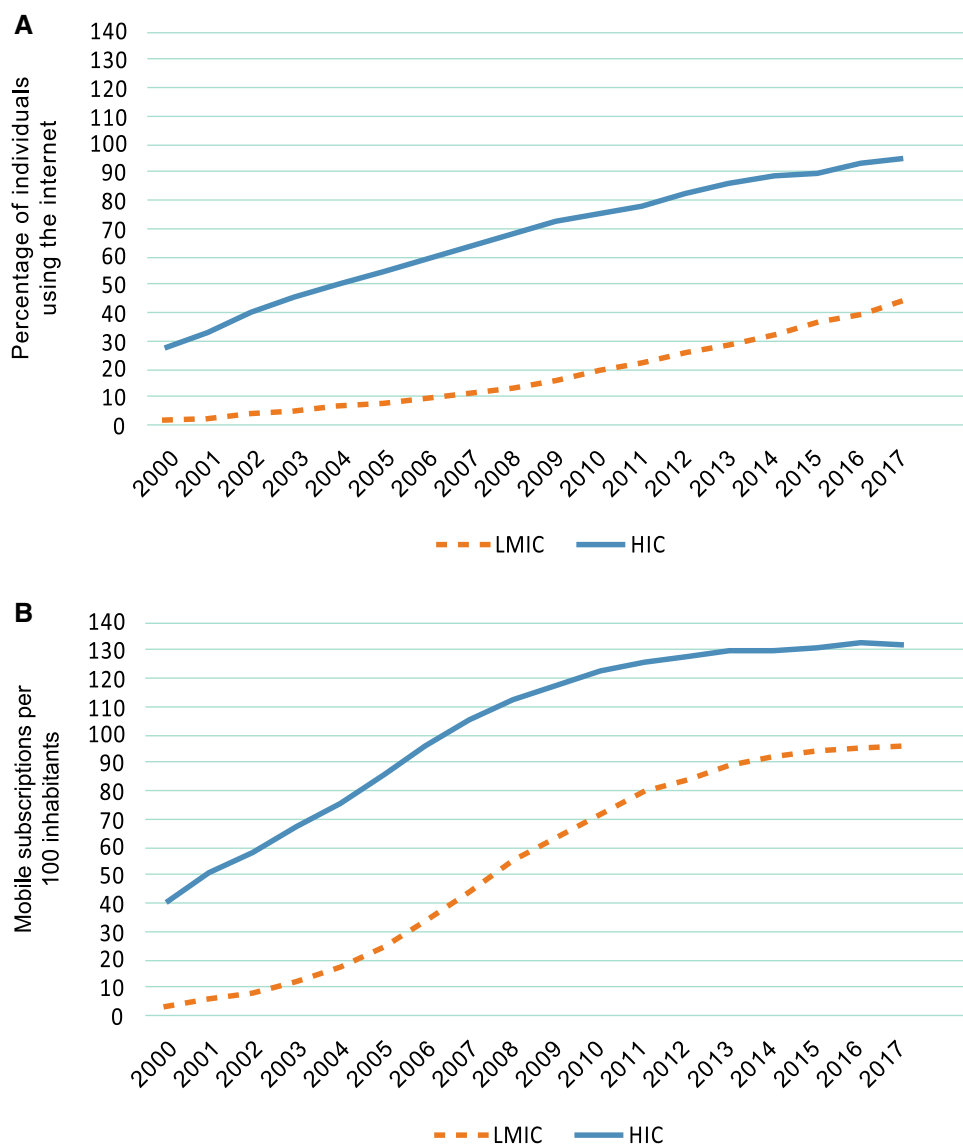
the implementation science research literature, feasibility is defined as the extent to which a treatment or innovation can be used or carried out by a specific agent or used successfully within a given context (Karsh, 2004; Proctor et al., 2011). Feasibility is conceptually linked to a number of other implementation outcomes, including the accessibility, affordability, acceptability/cultural appropriateness, and scalability of a treatment or innovation. Short definitions of these key implementation science terms as relevant to digital technologies are presented in Table 1.

Combining the global drive towards digital technologies for ASD, the fact that the majority of people with ASD live in LMIC, and the pre-existing digital divide as outlined by the World Bank, there is a significant risk that, without due reflection and consideration of the real-world feasibility of technologies, the global ASD community may increase this digital divide, and thus compound the well-known disparities that exist between HIC and LMIC in health, education, social integration and economic outcomes of families who live with ASD.

Here, we therefore set out to evaluate the six key technologies outlined earlier in terms of their overall feasibility for implementation in LMIC and low-resource contexts.

Methods

Study Participants and Procedure

A narrative feasibility evaluation was performed by three reviewers with clinical and research expertise in the use of technologies for ASD in LMIC. Each reviewer was provided with access to a recent review of digital technologies for autism, and to PDFs of all publications summarised in the background review of the six emerging technologies for ASD. After review of the literature each reviewer was

asked to provide feasibility ratings of the implementation constructs selected.

Implementation Science Constructs Evaluated

In order to evaluate feasibility, four implementation constructs were selected for this study—acceptability, accessibility, appropriateness and scalability (see Table 1 for definitions). After rating each construct, reviewers were asked to provide an 'overall feasibility' judgment incorporating all constructs. In the absence of any existing criteria for feasibility rating of technologies, reviewers were asked to rate constructs as 'very low', 'low', 'high' or 'very high'. Reviewers were asked to provide comments and a narrative motivation for their ratings. The three reviewers were then asked to reach consensus on their feasibility rating for all categories through an iterative process until consensus was reached. Weighted kappa scores were calculated for initial ratings in relation to consensus ratings. Narrative comments were collated as collective motivation for final ratings.

Results

Feasibility Evaluation of Technologies for ASD in LMIC

Categorical Ratings

Figure 3 shows the consensus rating of each of the technologies in terms of their accessibility, affordability, acceptability/cultural appropriateness, scalability and overall feasibility in LMIC. Individual ratings showed weighted kappa scores of 0.714–1.000 for accessibility, 0.850–1.000 for affordability, 0.615–1.000 for acceptability/cultural appropriateness and 0.850–1.000 for scalability. Overall feasibility showed weighted kappa scores ranging from 0.850–1.000.

Table 1 Implementation constructs evaluated in this study in relation to digital technologies

Construct	Definition	Reference
Feasibility	The extent to which a new technology can be used successfully within a given setting	Karsh (2004)
Accessibility	The ease or difficulty for users to access a particular technology. Distance is often an important indicator to measure the accessibility of resources	Ye et al. (2019)
Affordability	The true cost of implementing a particular technology. The construct depends on the costs of the particular technology, the cost of implementation, and the cost of accessing the technology in a particular location	Proctor et al. (2011)
Acceptability and cultural appropriateness	The perceived fit, relevance, or compatibility of the technology to a particular user, provider, community or setting	Proctor et al. (2011)
Scalability	The ability of a technology (shown to be efficacious on a small scale and/or under controlled conditions) to be expanded under real world conditions to reach a greater proportion of the eligible population, while retaining effectiveness	Aarons et al. (2017)

Fig. 3 Feasibility of evidence-based technologies for autism spectrum disorder in low and middle-income countries (LMIC)

	Robotics	Virtual Reality	Shared Active Surfaces	Sensing Technologies	Personal Computers	Mobile Technologies
Accessibility	Very low	Low	Very low	Low	High	Very high
Affordability	Very low	Low	Very low	Low	High	High
Acceptability and cultural appropriateness	Low	Low	High	High	High	Very high
Scalability and sustainability	Very low	Low	Very low	Low	High	Very high
Overall feasibility for use in LMIC settings	Very low	Low	Low	Low	High	Very high

Narrative Motivation for Feasibility Ratings

Accessibility

As shown in Fig. 2, the 'digital divide' is strongly associated with the income classification of countries, and represents the gap between high-resource and low-resource settings in physical access to ICT and related skills/resources to use these technologies (Dutta et al., 2015; World Bank, 2016). However, access to and usage of technology is also associated with gender, level of education, literacy, urbanisation and socioeconomic status (Alozie & Akpan-Obong, 2017; World Bank, 2016). In most LMIC, use of ICT is skewed towards young educated males of higher SES living in large towns or cities (Gomez, 2014; Wesolowski et al., 2015; World Bank, 2016). Even within LMIC there are therefore higher- and lower-resourced communities with differential access to technology. Most of the technologies reviewed here require access to reliable power supply. In sub-Saharan Africa 60% of people and in South-East Asia 30% of people do not have direct access to electricity (World Bank, 2016). In addition, health services such as remote consultations utilising interactive video conferencing (telemedicine) depend on access to a PC and reliable internet connection with sufficient speed and bandwidth. Fewer than 25% of households in sub-Saharan Africa own a working computer, and even fewer connect to the internet using fixed (wired) broadband services (Gillwald, 2013; ITU, 2019). Access to PCs is becoming more widespread in LMIC as public access computing venues including libraries and internet cafes are being set up in many towns and villages (Gomez, 2014). In many underserved communities in Africa, mobile phone sharing or informal telecentres (where mobile phones can be used for a

fee) are also improving access to ICT services. Close to 70% of people living in the poorest 20% of households globally have access to and are familiar with mobile phones (World Bank, 2016). Familiarity and proficiency with the technology are known to contribute to implementation success of technology-based healthcare initiatives (Zurovac et al., 2011, 2012). For these reasons, consensus ratings for accessibility were 'very high' for smartphone-based technologies, 'high' for personal computers, 'low' for sensing and virtual reality technologies, and 'very low' for robotics.

Affordability

As shown in Fig. 1, robots are by far the most expensive of the technologies reviewed here, ranging from several hundreds to upwards of thousands of US dollars, and typically require highly skilled technicians to operate and maintain them (Scassellati et al., 2012). Shared active surfaces and sensing technologies can also be very expensive, particularly when they require importing into LMIC. Costs associated with purchasing and installation of specialist equipment, software licencing, training and maintenance are likely to limit or even preclude the use of most technology platforms in LMIC community settings (Weiss et al., 2014). In most LMIC the internet connection speed and bandwidth required for technologies like telemedicine, IVC and VR are typically only available in large cities and can be up to four times more expensive than in HIC (ITU, 2016). It is also cheaper to access the internet using pre-paid mobile broadband data than fixed broadband services in these countries (ITU, 2016). Given the lower cost of android smartphones and greater access to cheaper mobile broadband services, an estimated 3.8 billion people worldwide were connecting

to broadband internet services using their smartphones in 2019, 75% of whom from LMIC (Groupe Spéciale Mobile Association, 2020). For these reasons consensus ratings for affordability were 'high' for smartphone-based technologies and personal computers, 'low' for sensing and virtual reality technologies, and 'very low' for shared active surfaces and robotics.

Acceptability and Cultural Appropriateness

Telemedicine can transport specialist clinicians virtually to meet with families in their homes in low-resourced communities where in-person care is not available. However, telemedicine may not be acceptable to all. Some cultural groups do not allow any photography or video recordings of people at all (Boujarwah et al., 2011) or disapprove of the use of mobile phones by women in public (Wei & Kolko, 2005). In addition, it is not known how culturally acceptable virtual environments, the use of avatars, or participating in virtual reality-based activities would be in the culturally diverse communities in LMIC. Cultural beliefs often limit the adoption and use of technologies in LMIC (Bartneck et al., 2007; Rojas-Méndez et al., 2017). Many investigators of mHealth have highlighted the fact that access to mobile phones do not necessarily mean ownership of the device (Kumar et al., 2016). Sharing of or paying for mobile phone use is common practice and important in many African societies (Wesolowski et al., 2012). Ethical issues around confidentiality of health information and stigma therefore need careful consideration when determining if such services are appropriate and acceptable (Kaplan, 2006). However, given the increasing availability of cheaper mobile phones, the practice of sharing seems to be declining (Kumar et al., 2016; Wesolowski et al., 2015). Engaging the intended end-user community early should facilitate addressing local cultural, as well as practical challenges which may impede successful implementation (Grinker et al., 2012; Pickard et al., 2016). For these reasons, consensus ratings for acceptability/cultural appropriateness were 'very high' for smartphone-based technologies, 'high' for personal computers, sensing technologies and shared active surfaces, and 'low' for virtual reality and robotics.

Scalability

Technology can potentially address many of the challenges faced by people with ASD who live in LMIC. Successful use of such tools will depend on it being effective, acceptable, affordable and—importantly—have the capacity to reach individuals in under-served areas and to be applied on a large scale in a variety of settings (Kazdin & Rabbitt, 2013). A very overt aim of technology should therefore be to reach people wherever they are. Enabling community participation can further build capacity by increasing the number of people who can deliver services to those in need (Patel et al., 2008). Technology best suited to achieve this in LMIC would have to be familiar and widely used, not be dependent on uninterrupted electricity supply, and be able to receive and send information effectively and at low cost from almost anywhere. Advanced technologies such as VR and robotics typically require highly skilled people to operate and maintain them, as well as reliable and powerful internet and electricity infrastructure. Very high procurement and service costs are additional and important barriers to their widespread use. Even though PCs are increasingly accessible to many people in LMIC and telemedicine is gaining traction as a novel means of providing services to those in need who live in areas not well served by healthcare professionals, mobile phones today can perform most of the functions traditionally done on PCs. Accessing the internet via widely available mobile broadband services, using solar powered batteries to recharge the mobile phone's power supply, sharing of phones or informal telecentres represent some of the ways in which mobile phones can overcome many of the unique challenges faced in LMIC. The evolution of mobile technology, the ever-expanding mobile broadband network as well as phones and data becoming more affordable, gives mobile health (mHealth) the greatest scalability potential to expand the reach of health, educational and other services to those in need. For these reasons, consensus ratings for scalability were 'very high' for smartphone-based technologies, 'high' for personal computers, 'low' for sensing technologies, shared active surfaces and virtual reality, and 'very low' for robotics.

Overall Feasibility

Taking together all implementation-related constructs, consensus ratings for overall feasibility in LMIC were 'very high' for smartphone-based technologies, 'high' for personal computers, 'low' for sensing technologies, shared active surfaces and virtual reality technologies, and 'very low' for robotics.

Discussion

Digital technologies have a very significant potential to improve the lives of people who live with ASD, and an increasing volume of ASD technology research has emerged in recent years. The COVID-19 pandemic accelerated the drive towards remote technologies for all aspects of life across the globe. However, mindful that most people with ASD live in low- or middle-income countries (LMIC), and given the pronounced digital divide between high-income countries (HIC) and LMIC, we set out to explore

the feasibility of implementing these technologies in LMIC settings. We selected four implementation constructs—accessibility, affordability, appropriateness, scalability—for consensus evaluation towards an overall feasibility rating. Review of the technologies identified and highlighted a range of exciting developments in ASD research over the last 2 decades. Feasibility ratings, however, showed how technologies had very different strengths and weaknesses across different implementation constructs when the 'implementation lens' was focused on LMIC contexts. Of all technologies examined, mobile/cellular technologies showed the most consistent 'high' and 'very high' ratings across implementation constructs and had the highest overall feasibility ratings for implementation in LMIC. Taken together, mobile technologies therefore seem to have the greatest potential to ensure we do not inadvertently increase the pre-existing digital disparities between individuals with ASD and their families who live in HIC versus LMIC.

The narrative findings of the study underlined the fundamental importance of the *context* for technology. Earlier work by Kientz et al., (2014) and Odom et al., (2015) recognised the importance of 'context' as a variable. However, previous research used the term to refer to home, school, clinic, research as 'context'. To date, no ASD technology research has used the term to refer to the macro-economic and/or cultural and linguistically diverse 'contexts' where people with ASD live. We propose to use the term 'setting' to refer to the specific place where a technology might be used (such as the school, home or clinic), and to use the term 'context' to refer to the broader socio/economic/cultural/linguistic environment into which a technology may be implemented. While robotics, shared active surfaces and virtual reality technologies may have significant potential application in various HIC contexts, the feasibility of implementation may look significantly different in LMIC contexts. It is laudable and important to examine how technology can be used to address the practical and day-to-day challenges of people who live with ASD. However, the global ASD community is culturally, linguistic, socio-economically and geographically immensely diverse. If our overarching goal is to address the disparities in access to ASD screening, diagnosis, and treatment between HIC and LMIC contexts using technology, these technologies need to be designed from the outset not only with the end-user, purpose, domain and setting in mind, but also with the accessibility, affordability, acceptability and scalability of the technology in the specific context and community of the end-user in mind. This highlights the need for all technological developments for ASD to include contextual implementation science evaluation (Proctor et al., 2011). Figure 4 represents our adaptation of the conceptual framework as presented by Odom et al., (2015) to incorporate the contextual implementation science lens (see Fig. 4). We propose that it is of fundamental
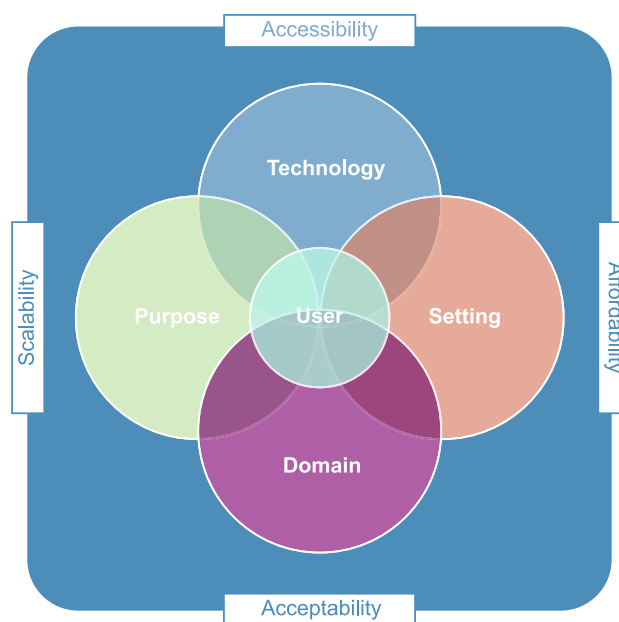

Fig. 4 Key considerations in the development of technologies for low- and middle-income countries

importance to incorporate this broader view of 'context' to ensure that our technological solutions reduce, rather than inadvertently increase, the digital divide.

Limitations of the Study

We acknowledge that this was a feasibility evaluation through expert consensus. The participants included only three expert reviewers based in the same global region. It is therefore possible that reviewers brought limited perspectives and their own biases that may have influenced overall feasibility ratings. However, reviewers represented three different professional groups, all had experience of working in multiple countries (across HIC and LMIC), all had expertise in technology and technology development for health applications, and weighted kappa values showed substantial agreement between raters and consensus. It would be very valuable for future studies to include stakeholders from diverse (but particularly LMIC) contexts. We further acknowledge that categorical ratings were performed without operationalised criteria. At present there are no global criteria for feasibility ratings of health technologies. For this reason, we included narrative comments to 'motivate' consensus ratings. Given the importance of the feasibility of technology, it may be helpful to develop a shared evaluation framework for technology in ASD, akin to the evaluation framework developed for parent education and training in ASD (Dawson-Squibb & de Vries, 2019). Notwithstanding these limitations, this was the first study to our knowledge to perform feasibility rating of ASD technologies. We hope

that our approach may stimulate reflection about these constructs in research.

Conclusion

Evidence-based technologies for ASD can play a tremendous role to ensure that the majority of people living in under-served areas have timely access to appropriate services and support. Digital technologies may therefore have utility for identification, diagnostic procedures, intervention, training and research in HIC and LMIC settings. Here we reflected on the feasibility of six examples of such technologies in LMIC contexts. Our findings suggest that feasibility of the use of such technologies in LMIC will depend on the fundamental principles of affordability, accessibility, acceptability and cultural appropriateness. These will determine the likely scale-up (increasing the reach in the community of interest) and scale-out (expanding the reach to new or different communities) (Aarons et al., 2017), and will ensure that we do not inadvertently exacerbate the pre-exisiting digital disparities between HIC and LMIC contexts.

Given the widespread usage of mobile and smartphones and the increasing availability of affordable high-speed mobile internet access in the majority of LMIC, mHealth has the greatest potential to increase access to ASD screening, diagnosis and treatment globally. However, the evidence-base for mobile technologies in LMIC settings remains extremely limited. For instance, there are almost no Apps for ASD to date that have been evaluated specifically for a LMIC context. To address this knowledge gap careful and nuanced research will be required to establish the feasibility of using mobile applications to provide access to quality health, educational and other services and care to the culturally, linguistic, socio-economically and geographically diverse global ASD community.

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