American Psychological Association · The Community for Psychologists in Independent Practice

Practice Innovations

ISSN: 2377-889X

2020, Vol. 5, No. 2, 150–164
http://dx.doi.org/10.1037/pri0000121

A Systematic Review of Remote Telehealth Assessments for Early Signs of Autism Spectrum Disorder: Video and Mobile Applications

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Autism spectrum disorder (ASD) impacts an individual's developmental trajectory across several domains, supporting the importance of early detection and identification, which is ultimately the first step toward treatment planning. Children should be exposed to an ASD screening at 18 and 24 months of age, but such services are not always available across demographic groups or accessible to underserved communities. Screenings can be especially limited in circumstances such as the COVID-19 pandemic or other situations dictating that people stay at home. Thus, it is important to expand the accessibility of assessment services that can provide accurate identification of ASD in young children through the use of technology such as video or mobile application platforms. This systematic review aimed to summarize the state of the literature as it relates to accessible telehealth assessments and screening tools for infants and toddlers suspected to have ASD in remote populations. Seven studies that utilized video or mobile applications to assess young children in underserved communities were found, including individuals within their first 3 years of life. Although some positive results were found regarding effectiveness, there is a need for more sustainable research for this age group, especially for those with limited access to services.

Clinical Impact Statement

This systematic review aimed to understand the current video- and mobile application-based assessments that have been used to assess infants and toddlers in remote areas who are suspected to have autism spectrum disorder. Findings suggest that there are a limited number of studies that utilize telehealth platforms in underserved communities. The seven studies found did reveal effectiveness of these telehealth assessment tools, but there is still a strong need for more research in this area.

Keywords: autism, technology, telehealth, assessment, remote

Supplemental materials: http://dx.doi.org/10.1037/pri0000121.supp

Autism spectrum disorder (ASD) is a neurodevelopmental disorder that is characterized by deficits in social communication and the presence of restricted and repetitive behaviors (American Psychiatric Association [APA], 2013). Early identification and intervention can improve functional outcomes for children with ASD (National Research Council, 2001), but access to such services is not comparable across all demographic groups, creating wide health disparities. This disparity in service access is especially problematic during unique situations such as the COVID-19 pandemic and other circumstances in which individuals are directed to stay at home. Rural and remote communities are at particular risk for experiencing health dispar-

This article was published Online First May 28, 2020.
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ities that may be exacerbated during a pandemic. Children in rural settings or who are at or below the poverty line receive ASD diagnoses at a much slower rate (Antezana, Scarpa, Valdespino, Albright, & Richey, 2017). Some studies have noted that children in these settings receive diagnoses half a year later relative to children in urban settings and a full year later for children at or below the poverty line (Mandell, Novak, & Zubritsky, 2005; Rhoades, Scarpa, & Salley, 2007). This may be due to significant challenges regarding the availability and adequacy of services for children with ASD, including economic challenges, geographic distance between families and providers, lack of professional resources, and cultural characteristics (Durkin et al., 2010; Janvier et al., 2016). Due to these limitations, there is great interest in the implementation of services remotely. As a result, it is crucial to understand the developing literature on efficient methods to deliver services, including technology-based approaches that incorporate video and mobile applications (Ashburner, Vickerstaff, Beetge, & Copley, 2016).

Early Development in Infancy and Toddlerhood

Although ASD can be diagnosed as early as 2 years of age, the median age of first diagnosis at the national level is 4 years 3 months (Maenner et al., 2020). Given the importance of early intervention for children with ASD, it is essential to examine what early signs can be identified to promote early detection and diagnosis, especially during infancy and toddlerhood (from ages 0 to 3 years), which is the focus of this review. For example, in early development, children with ASD fail to attend to and respond to social cues (Dawson et al., 2002; Dawson, Webb, & McPartland, 2005), which leads to impairments in areas such as joint attention, social orienting and imitation, and face processing (Dawson, 1991). Impairment in joint attention is a core social deficit in children with ASD and is often reported as one of the earliest indicators of ASD (Sullivan et al., 2007; Wetherby et al., 2004; Yoder, Stone, Walden, & Malesa, 2009). In addition to joint attention difficulties, children later diagnosed with ASD also show reduced attending to social aspects of an environment (e.g., name calling, clapping) and increased preference for nonsocial stimuli (e.g., rattle, music box, visual inspection of figures or objects), as well as poorer face processing, visual orienting, imitation, and emotion regulation during infancy than do their typically developing peers (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Dawson, Webb, Wijsman, et al., 2005; Elsabbagh et al., 2009; Farroni, Csibra, Simion, & Johnson, 2002; Hutman et al., 2010; Stone, Ousley, & Littleford, 1997; Zwaigenbaum et al., 2005).

In addition to social and communicative delays, restricted and repetitive behaviors (RRBs) may also be an early indicator of risk for ASD. RRBs can include preoccupation with specific interests, adherence to nonfunctional routines or rituals, repetitive body or motor movements, and persistent preoccupation with parts of objects (APA, 2013). At younger ages, RRBs are not exclusively present in children with ASD. However, some studies have noted that RRBs have been present in infants as young as 8 months who were later diagnosed with ASD. Parents have noted more severe RRBs at these early ages, compared to those who are not diagnosed with ASD (Watson et al., 2007). Additionally, the presence of RRBs at 12 months of age (e.g., spinning, visual peering) has been shown to relate to development of additional ASD symptoms and diagnosis (Ozonoff, Heung, Byrd, Hansen, & Hertz-Picciotto, 2008). It is clear from the literature that a number of early ASD behaviors in both the social communication and RRB domains can be identified in children as young as infancy. Assessing for these difficulties as early as possible can help identify an infant or toddler who may be at risk for ASD. Thus, the current review synthesizes the evidence regarding remote assessment practices that may aid in the detection of these early signs of ASD.

Current ASD Assessments in Early Childhood

Currently, the gold-standard protocol for an ASD diagnostic assessment includes a structured interview with caregivers regarding the child's medical and developmental history and current behaviors and abilities (e.g., Autism Diagnostic Interview—Revised [ADI−R]; Lord, Rutter, & Le Couteur, 1994) and direct observation of the child for behaviors consistent with a diagnosis of ASD (e.g., Autism Diagnostic Observation Schedule, Second Edition [ADOS-2]; Lord et al., 2012). Measures of cognitive functioning and language abilities are also recommended as part of an ASD assessment (Ozonoff, Goodlin-Jones, & Solomon, 2005), as are parent-report measures of adaptive functioning and comorbid behavior problems. Many interdisciplinary evaluations also include medical assessments, audiology consultations, teacher reports, and home or daycare observations (Huerta & Lord, 2012).

This assessment protocol can take several hours of direct contact and requires a substantial amount of training to administer and interpret reliably. Furthermore, there can be bias inherent in an ASD diagnostic decision, with the gold-standard assessment battery correctly diagnosing 80% of all cases and ASD screeners used by primary care physicians correctly diagnosing around 50% (Singer, 2013). As a result, it is crucial to find diagnostic instruments that reduce time, cost, and subjectivity and promote easier implementation across various populations. Additionally, the American Academy of Pediatrics recommends that children be screened for developmental delays as early as 9 months of age, in addition to ASD-specific screenings at 18 and 24 months of age (Zwaigenbaum et al., 2015).

Applying efficient tools such as technology has the potential to streamline the diagnostic process. Several forms of technology, such as videoconferencing, video analysis, and mobile or web applications that facilitate remote assessment, can be used in assessing individuals with ASD. Assessing these behaviors remotely through a teleconference or video observation setting offers the advantage of capturing behaviors in a naturalistic setting, which can provide a unique perspective on the presentation of the child with ASD.

Videoconferencing and Video Analysis

Videoconferencing has been used as a viable method for ASD diagnostic assessments in toddlers. Reese et al. (2013) studied the difference in diagnostic accuracy between in person (InP) and an interactive videoconferencing (IVC) assessment by evaluating children with ASD who ranged from 3 to 5 years of age. Using the ADOS-2 and ADI−R, Reese and colleagues assessed children either InP or via IVC. Through IVC, parents were instructed on how to administer the ADOS-2 social bids that are designed to elicit behaviors in certain contexts. Results indicated no difference between InP and IVC for the observations during the ADOS-2, ratings on the ADI−R, diagnostic accuracy, and overall parental satisfaction. This indicates a need for further investigation on using technology-based assessments to provide families in remote areas with the ability to detect early signs of ASD and obtain a diagnosis during early development.

Buchter and Riggleman (2018) also discussed the benefits of using teleconferencing. This form of communication is an effective alternative to traveling, for both the families and the providers, and it increases productivity because it allows more families to gain access to assessments in a shorter amount of time. Additionally, the ability for the providers to videoconference live with the family and their child with ASD, as well as analyze recorded videos of the child, allows for behavioral observations in a naturalistic setting without the possibility of interference caused by the provider's presence in the home. Families are also able to use teleconferencing to access a variety of professionals with diverse training backgrounds who can cater to particular needs depending on the child with ASD.

Mobile or Web Applications

Ecological momentary assessment (EMA; Shiffman, Stone, & Hufford, 2008) through mobile or wed applications is another approach for more intensive measurement of behavior. This methodology involves participants' completing ratings at various times throughout the day when prompted. When assessments are delivered via phone messaging or websites, parents or children who only have access to a cellular phone can complete an EMA relatively easily and quickly. The assessments can include current self-report measures of symptomology in their natural environment. These frequent in-the-moment assessments offer many advantages, because they provide a unique perspective of the parent's or child's experiences over time. By capturing momentary states that are often responses to certain events, EMA allows for the assessment of dynamic symptoms that may vary on a day-to-day or hour-to-hour basis, demonstrating the trajectory and patterns of these outcomes.

Specific Aims of the Current Review

By systematically reviewing the currently available empirical research, this review aimed to (a) examine remote telehealth assessments delivered through video or mobile applications that can provide an ASD diagnosis or detect early signs of ASD from 0 to 3 years of age, (b) understand how these technologies may improve early diagnostic assessment in ASD and if they can be comparable to or more effective than face-to-face assessments, and (c) discuss and suggest implications for future development of remote diagnostic assessments for early childhood that may improve access to care.

Method

Search Methods

A systematic review of the literature was conducted using three electronic databases—EBSCOhost, PsycINFO, and PubMed—during November and December 2019. Specific search terms involved a combination of autism terms (e.g., *autis**, *ASD, Asperger*) and phrases to capture underserved populations (e.g., *rural, remote, underserve*, low-income, low SES*), specific early signs of ASD phrases (e.g., *joint attention, early sign, social orienting, stereotyp**), assessment terms (e.g., *assessment, diagnosis, screening, evaluation*), and technology terms (e.g., *telehealth, mobile, video, app*). The PsycINFO search permitted filtering out by age, so only articles that examined participants at the neonatal (birth to 1 month), infancy (2–23 months), and preschool (2–5 years) stages were included. Exact search terms are presented in the online supplemental materials. This search yielded 551 articles overall (PubMed = 459, EBSCOHost = 102, PsycINFO = 90).

Selection Criteria

Resulting articles were screened to eliminate duplicates as well as any review papers, conference posters, presentations, study protocols, and dissertations or theses. Abstracts and full-text articles of the resulting studies were then screened to determine whether they met inclusion criteria. Studies included in this review must have (a) been published in English in a peer reviewed journal; (b) excluded single-subject designs; (c) included a study population of children from infancy to toddlerhood (ages 0–3 years); (d) included participants who were suspected to have a neurodevelopmental delay or disability (e.g., ASD), (e) used some form of technology to assess participants remotely, such as mobile devices or videos; (f) examined early signs of ASD; and (g) examined the use of technology in underserved and remote populations (e.g., rural, low-income areas). The reference lists of these articles were searched for any additional articles that may be included, resulting in a total of seven studies included in this review. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher, Liberati, Tetzlaff, Altman, & the PRISMA Group 2009) guidelines were used to determine study inclusion (see Figure 1 for the full PRISMA diagram). The final seven studies were reviewed in terms of the following features: (a) participant demographics; (b) technology, assessment modality, and study features; (c) early signs that were examined; and (d) study outcomes (e.g., reliability, accuracy, sensitivity or specificity).

Results

Participant Demographics

Across all seven reviewed studies, a total of 851 children suspected of a developmental delay and/or ASD were assessed. Only one study reported separate demographics for the 0–3 age range (Tariq et al., 2019), with M_{age} = 30 months (60% male). Three of the remaining studies did not report the mean age (Ciccia, Whitford, Krumm, & McNeal, 2011; Duda, Daniels, & Wall, 2016; Maleka, Van Der Line, Page Glascoe, & Swanepoel, 2016), whereas the other three studies reported only the mean age and gender breakdown of all participants, including those who were over 3 years old (Obeid, Beekman, Roizen, Ciccia,

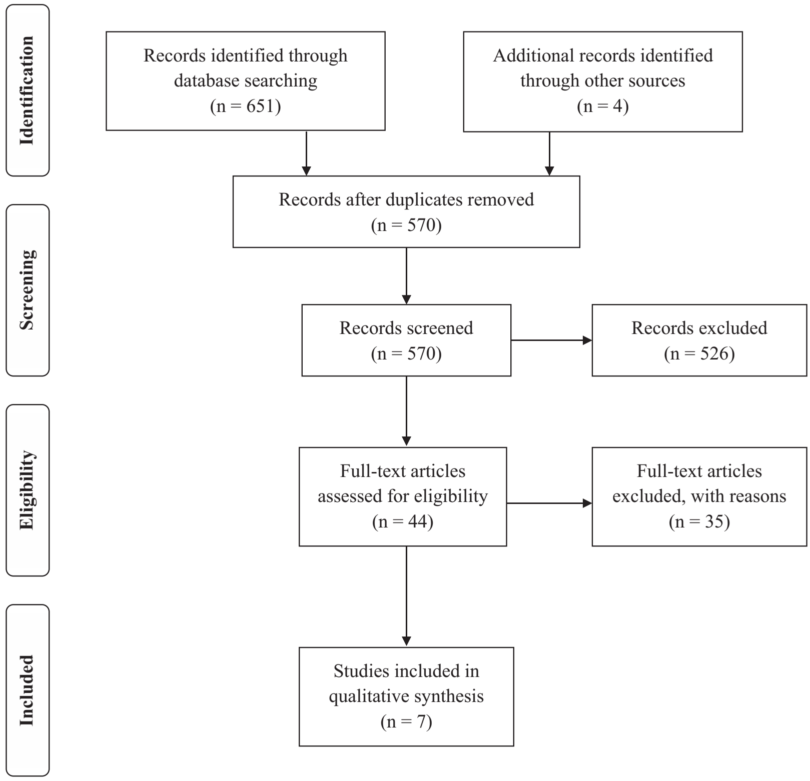

Figure 1. PRISMA flow diagram for determining study inclusion.

& Short, 2019; Smith et al., 2017; Tariq et al., 2018).

In terms of ethnicity, four studies reported a breakdown of ethnicities. Maleka et al. (2016) and Obeid et al. (2019) examined a majority of African or African American participants (>93%), whereas Smith et al. (2017) examined a majority of Caucasian (41%) and Hispanic (43%) participants. Tariq et al. (2019) examined only Bangladeshi participants, who were located in a primarily urban location (92.7%). Further, four studies were conducted in a community-based setting for minority, low-income communities, whereas the other three studies utilized a clinical sample to test the feasibility of the specific technology. Tariq et al. (2018) initially tested the technology-based assessment in a clinical U.S. sample before applying the tool to a low-resource sample in Bangladesh (Tariq et al., 2019). Minimal caregiver information was provided, with only one study (Obeid et al., 2019) reporting a primarily female sample (92%), whose education level was mostly high school or below (62%) or either some college or a college degree (33%). See Table 1 for the breakdown of the aforementioned demographic data.

Technology and Assessment Modality

The final seven articles were grouped by type of technology used to assess or screen for early signs of neurodevelopmental delays or disabilities. This included four articles examining videoconferencing or video analysis (Ciccia et al., 2011; Smith et al., 2017; Tariq et al., 2018, 2019) and three articles examining mobile or web applications (Duda et al., 2016; Maleka et al., 2016; Obeid et al., 2019). The reviewed studies included both screening and assessment tools, with four articles implementing a technology-based developmental delay and/or ASD screener and three articles implementing a technology-based

Table 1
Demographic Variables of Infant and Toddler Participants and Their Caregivers

Study	N^a	M_{age} (months)[a]	Gender (% M)[a]	Location	Race or ethnicity (%)	Caregiver	
						Gender (%)	Education (%)
Ciccia et al. (2011)	263	—	—	Cleveland, OH	—	—	—
Duda et al. (2016)	38	—	76.1 (Total)	Massachusetts	—	—	—
Maleka et al. (2016)	207	—	—	South Africa	A (99.9); other (.5)	—	—
Obeid et al. (2019)	49	39 (Total)	49 (Total)	Cleveland, OH	AA (93) Total	F(92)Total	High school (62), some college or degree (33)
Smith et al. (2017)	51 (Total)	50.6 (Total)	70.6 (Total)	Southwestern U.S.	C (21), H (22), AA (4), other (4)	—	—
Tariq et al. (2018)	93	52 (Total)	70.4 (Total)	California	—	—	—
Tariq et al. (2019)	150 (Total)	30	60	Bangladesh	Bangladeshi: urban (92.7), semiurban (5.3), rural (2)	—	—

Note. Dashes indicate that data were not reported. M = male; A = African; AA = African American; F = female; C = Caucasian; H = Hispanic.
[a] Children were limited to ages 0–3 years unless noted as "Total."

assessment for ASD diagnosis. See Table 2 for details of each study reviewed for each assessment type.

Videoconferencing or Video Analysis

Naturalistic Observation Diagnostic Assessment (NODA; Smith et al., 2017). A previous study (Smith, Oberleitner, Treulich, McIntosh, & Melmed, 2009) noted that parents have the ability to collect appropriate home videos of their child that would provide sufficient behavioral examples and developmental information necessary to meet diagnostic criteria for ASD. To compare this to the typical gold-standard IPA, Smith and colleagues (2017) explored a novel telehealth approach to diagnosis using home video recordings provided by parents of children suspected with ASD, known as NODA. Participants consisted of a total of 51 children (ranging from ages 18 months to 83 months) with at least one parent, including 40 children suspected to have ASD (M_{age} = 52.78, SD = 17.58) and 11 typically developing children (M_{age} = 42.55, SD = 11.07).

Ten qualified clinicians with at least 10 years of ASD assessment experience were trained to rate the NODA videos. All participants completed the IPA during their first visit. For children under 69 months, the battery included the ADI−R (Lord et al., 1994), the ADOS-2 (Lord et al., 2012), the Mullen Scales for Early Learning (Mullen, 1995), and the Vineland Adaptive Behavior Scale, Third Edition (Sparrow, Cicchetti, & Saulnier, 2016).

The NODA procedure included both developmental history and video data. Through an online account and a NODA application that was installed on a mobile device, parents first completed a brief developmental history interview, and the data were stored on this account. Then, the application instructed parents to record 10-min videos of their child's behaviors in four settings: (a) family meal time, (b) playtime with others, (c) playtime alone, and (d) parent concerns. The first three situations allowed the child to demonstrate any social-communication and play skills. The application provided instructions to parents on how to introduce specific social presses to their child (e.g., interact with them playfully; say their name to get their attention; ask them where something is in the room; give them time to initiate or respond;

Table 2
Description of Methodology, Technology, Assessment Modality, Early Signs, and Outcomes

Study	Early signs of ASD	Assessment or screening tool?	Technology used	Assessment modality or type	Sample type	Study design features	Outcomes	Findings
Ciccia et al. (2011)	Speech, expressive and receptive language, play, social behavior	Screening tool	Videoconferencing (INvesT)	(a) Parent interview, (b) REEL-3, (c) PLS-4 (abbreviated version)	Community-based urban health clinic for minority, low-income families	Evaluation of satisfaction of technology screener compared to in person	(a) Family satisfaction with videoconferencing screener, (b) reliability of the speech and language screener	(a) High satisfaction with quality of technology and use of videoconferencing overall, (b) reliability of speech and language screening was 100% ($n = 10$)
Duda et al. (2016)	Communication, social skills, play behaviors	Screening tool	Web application (MARA)	MARA (7-item parent questionnaire)	Clinical sample	Evaluation of MARA tool to determine future ASD diagnosis	(a) Ability of MARA to detect children likely to receive an ASD diagnosis, (b) sensitivity and specificity of MARA	(a) $n = 25$ received an ASD diagnosis; (b) sensitivity: 89.9%, specificity: 79.7%
Maleka et al. (2016)	Expressive and receptive language; fine and gross motor skills, self-help, academics; social−emotional health	Screening tool	Web application (PEDS and PEDS-DM)	PEDS and PEDS-DM	Community-based PHC clinic	Evaluation of paper versus smartphone method for PEDS	(a) Correspondence and agreement between paper (SLP) and smartphone (CHWs) methods, (b) interrater reliability between SLP and CHWs	(a) 99% correspondence, (b) $\kappa = .960$
Obeid et al. (2019)	Social skills, speech, symbolic play, language, play performance	Screening tool	Web application (INvesT)	(a) Risk assessment, (b) ITC, (c) MCHAT, (d) CARS-2, (e) PLS-4, (f) affect in play task, (g) parent interview	Community-based urban health clinic for minority, low-income families	Double-blinded, placebo-controlled RCT (telehealth vs. in-person)	(a) Primary developmental concern across age groups, (b) risk of developmental delays	(a) $n = 6$ with overall developmental concerns, (b) $n = 26$ with overall high risk for developmental delay, (c) $n = 18$ with category-specific high risk for developmental delay

Table 2 (*continued*)

Study	Early signs of ASD	Assessment or screening tool?	Technology used	Assessment modality or type	Sample type	Study design features	Outcomes	Findings
Smith et al. (2017)	Social impairment; verbal and nonverbal impairment; repetitive, sensory, and stereotyped behaviors	Assessment	Video analysis (NODA)	(a) For IPA: ADI−R; ADOS-2; VABS-3 (Mullen, 1995); (b) NODA: developmental history and 4 prerecorded 10-min videos of the child in different situations (submitted by parents)	Clinical sample	Evaluation of IPA versus NODA	(a) Diagnostic agreement between IPA and NODA, (b) sensitivity and specificity of NODA	(a) 88.2%; κ = .75; (b) sensitivity: 84.9%, specificity: 94.4%
Tariq et al. (2018)	30 signs of ASD from all ADOS-2, Modules 1–3	Assessment	Video analysis (via mobile web portal)	8 machine-learning models generated from modules of the ADOS-2 and ADI−R to analyze a brief 2-min video of the child (submitted by parents)	Clinical sample	Blinded raters: machine-learning analysis	(a) Test accuracy, (b) sensitivity and specificity, (c) top classifier	(a) Above 90%; (b) sensitivity: >94.5%, specificity: only 3 of 8 models > 50%
Tariq et al. (2019)	30 signs of ASD from all ADOS-2, Modules 1–3	Assessment	Video analysis (via mobile web portal)	(a) MCHAT and ADOS-2 for IPA, (b) 8 machine-learning models generated from modules of the ADOS-2 and ADI−R to analyze a brief 2- to 5-min video of the child (submitted by parents)	Low-resource sample	Blinded raters: machine-learning analysis	(a) Test accuracy, (b) sensitivity and specificity	(a) 85%; (b) sensitivity: 76%, specificity: 77%

Note. ASD = autism spectrum disorder; REEL-3 = Receptive-Expressive Emergent Language Test, Third Edition; PLS-4 = Preschool Language Scale, Fourth Edition; MARA = Mobile Autism Risk Assessment; PEDS = Parents Evaluation Developmental Status; PEDS-DM = PEDS: Developmental Milestones; PHC = primary health care; SLP = speech–language pathologist; CHWs = community health workers; ITC = Infant Toddler Checklist for Autism; MCHAT = Modified Checklist for Autism in Toddlers; CARS-2 = Childhood Autism Rating Scale, Second Edition; PLS-4 = Preschool Language Scale, Fourth Edition; RCT = randomized control trial; NODA = Naturalistic Observation Diagnostic Assessment; IPA = in-person assessment; ADI−R = Autism Diagnostic Interview—Revised; ADOS-2 = Autism Diagnostic Observation Schedule, Second Edition; VABS-3 = Vineland Adaptive Behavior Scale, Third Edition.

point at something and direct their attention to it). The fourth situation instructed the parents to record any behaviors that were concerning to them.

To assist with the efficiency of using the NODA application at home, we gave parents suggestions on how to best capture each situation, such as mounting the mobile device to set up ahead of time (e.g., using a tripod) and arranging essential objects and individuals so that they were in the camera frame (e.g., the child's face, toys). Additionally, to ensure that all videos were equal in length, the app automatically stopped recording after the 10-min period was completed. Parents were also able to view the video before uploading or rerecording if needed.

Following the parent's completion of the online history form and the four videos, the trained raters reviewed the materials through an online assessment system that allowed them to complete a *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM–5;* APA, 2013) checklist for ASD, and provide the final diagnostic decision (either ASD or non-ASD). The online video reviewer interface allowed raters to make note of examples of behaviors characteristic of ASD by pausing the video and selecting a term or "tag" from a predefined list of descriptors (e.g., no social response, no eye contact). Each tag was automatically mapped to the *DSM–5* criteria for ASD, which assisted with the rater's review of the developmental history form and the completion of the *DSM–5* checklist.

Mobile home video portal (Tariq et al., 2018, 2019). Tariq and colleagues (2018) echoed Smith et al.'s (2017) concerns about the lack of efficient methods for diagnosing ASD, especially in younger children, because the diagnostic process can be long and taxing on both the child and the clinician and can delay the age at which a diagnosis is provided. Because of the importance of early diagnosis of ASD, Tariq and colleagues (2018) created a mobile web application (similar to the Smith et al., 2017, model) that could extend to more families, especially in remote and underserved areas. As in Smith et al., the mobile portal allowed raters to view home videos of children while using "tags" to note the presence of specific behaviors in each video clip. However, the focus was to assess for up to 30 behavioral examples and possible early signs (e.g., social orienting and smiling, eye gaze) that may or may not be characteristic of ASD, rather than just provide a diagnostic decision.

Whereas Smith and colleagues (2017) utilized 10-min videos in four settings per child, Tariq et al. (2018) aimed to review brief videos of children to test the possibility of quickly and reliably detecting ASD via a mobile application at a more accelerated speed. In the Tariq et al. study, participants consisted of 116 children with ASD (M_{age} = 48 months, SD = 27 months) and 46 typically developing children (M_{age} = 35 months, SD = 14 months). Eight machine-learning models were used to identify developmentally appropriate features. These models were generated from modules utilized in the administration of the typical gold-standard instruments (e.g., the ADOS-2 or the ADI−R) and were categorized by language level.

Following the Tariq and colleagues (2018) study, Tariq and colleagues (2019) expanded their findings on machine learning in home videos of children in the United States and utilized the same method on videos of children with developmental delays in Bangladesh. Raters used two models of classification: (a) distinguishing typical versus atypical behavior and (b) distinguishing ASD versus non-ASD.

Videoconferencing INvesT model (Ciccia et al., 2011). Ciccia and colleagues (2011) also tested the feasibility of videoconferencing as a method to screen for neurodevelopmental disabilities (e.g., ASD) in children as young as 12 months, specifically examining speech and language outcomes, known as the INvesT model. Through this method, clinicians used a videoconferencing platform to administer a parent interview and a speech and language screener to children at 3 years of age or younger. The clinicians then conducted the Receptive-Expressive Emergent Language Test, Third Edition (Proger, 1971) and an abbreviated Preschool Language Scale, Fourth Edition (PLS-4; Zimmerman, Pond, & Steiner, 2002) with the children to assess speech articulation abilities.

Mobile or Web Applications

Mobile Autism Risk Assessment (MARA; Duda et al., 2016). Duda and colleagues (2016) examined the MARA, a parent-report mobile screening tool that is scored automatically, and could determine whether a child is at risk for ASD. The MARA consists of seven items (e.g., "Can your child have a back-and-forth conversation with you?" or "Does your child engage in imaginative or pretend play?") that ask about a child's communication, social skills, and behaviors and can be used on any device connected to the Internet. Each item is followed by four–five answer choices that can help the parent answer the question. The answers are compiled and run through a machine-learning model that uses an alternating decision tree (similar to the case in Tariq et al., 2018, 2019) that can calculate answers and detect the presence of typical versus atypical development.

Mobile Parents Evaluation of Developmental Status Tool (PEDS; Maleka et al., 2016). Maleka and colleagues (2016) also emphasized the importance of applying developmental screenings to low-income and underserved countries. Specifically, in South Africa, there is a lack of comprehensive developmental screening tools that can aid in the early detection of children, especially due to understaffing of professionals and limited resources. The Parents Evaluation Developmental Status (PEDS) tool was used as a validated screening measure in a mobile form and can be implemented by community health workers (CHWs) who work with children in South Africa with developmental concerns. Three CHWs were trained on a smart-phone version of the PEDS screener via an hourlong session that reviewed administration and scoring procedures. This screener included both the PEDS tool and the PEDS: Developmental Milestones to collect data on parent-reported concerns about their child's behaviors and development skills. A total of 207 families with children ages 6–18 months (N = 142) and 19–26 months (N = 65) were assessed for this study at a primary health care clinic. The CHWs interviewed caregivers using the PEDS application while a speech−language pathologist scored the measure simultaneously (via either paper or the smartphone app).

Web Application of the INvesT model (Obeid et al., 2019). Obeid and colleagues (2019) created a web application modeled after the original INvesT model (Ciccia et al., 2011) and specifically categorized risk of ASD in children from 12 to 36 months of age using a risk assessment that provides developmental areas in which parents can choose whether there is a presence of specific developmental concerns (e.g., behavioral problems, emotion regulation, RRBs).

Early Signs

The early signs of ASD that were assessed in all seven studies were somewhat similar, with the two articles on machine-learning models including a range of up to 30 features that directly correlated with modules of the gold-standard assessments of ASD (Tariq et al., 2018, 2019). The videoconferencing model, screening tools, and web application assessed speech and play behaviors in the form of expressive and receptive language, social skills, and symbolic play, which are all vital signs to examine in infancy and toddlerhood. Smith et al. (2017) assessed for similar behaviors in addition to repetitive, sensory, and stereotyped behaviors. Additionally, the PEDS tool screened for information on self-help, academics, and motor skills.

Study Outcomes

Five of the reviewed studies provided outcome data on agreement, sensitivity, and specificity on the technology-based approach that was tested. In the Smith et al. (2017) study, the NODA and IPA approach were examined via calculated percentage of agreement; kappa, sensitivity and specificity were calculated for both the full sample ($N = 51$) and for the subsample of children suspected to have ASD ($N = 40$). Diagnostic agreement was 88.2% ($\kappa = 0.75$) in the full sample and 85% ($\kappa = 0.58$) in the ASD-only sample. Sensitivity was 84.9% in both, whereas specificity was 94.4% in the full sample and 85.7% in the ASD-only sample. In the study by Duda et al. (2016) on the MARA screening tool, a total of 222 children were assessed, with 38 participants' being below the age of 3 years. Of these children, 25 were diagnosed with ASD. Sensitivity was reported at 89.9%, and specificity was reported at 79.7%. In a similar way, high agreement was found between the paper-based PEDS tools and the smartphone application PEDS tool in the Maleka et al. (2016) study, especially in the 6- to 18-month age group. High interrater agreement was noted to be $\kappa = 0.960$ at a 99% correspondence.

The Tariq et al. (2018, 2019) studies in both the United States and Bangladesh resulted in high test accuracy in addition to some positive sensitivity and specificity. In the clinical U.S. sample, the test accuracy was rated above 90% across all eight machine-learning classifiers, with sensitivity at or above 94.5% for each model. However, the specificity was noted as low, with only three out of the eight classifiers at or above 50%. In the Bangladeshi study (Tariq et al., 2019), the test accuracy was also high (85%), with a sensitivity of 76% and specificity of 77%.

Ciccia et al. (2011) noted a 100% reliability of the speech and language screening tool in a smaller sample ($n = 10$) via the INvesT videoconferencing model, in addition to high family satisfaction with the quality of the technology and use of videoconferencing overall. Obeid et al. (2019) used the INvesT model to compare the web application to an InP assessment that included a variety of well-established ASD screeners. The outcomes noted that of the 49 children assessed (between 12 and 36 months), six were flagged with some overall developmental concerns, 26 were categorized as high risk for developmental delays, and 18 were categorized as high risk for specific areas of developmental delays.

Discussion

The goal of this systematic review was to better understand how technology such as video and mobile application approaches could improve the current assessment of early signs of ASD to inform early diagnosis in underserved populations. Much of the current research on this topic has focused primarily on technology-based assessment tools for school-age children and does not always address the limitation of accessibility of services, which is especially relevant when circumstances create barriers for families to leave home or to travel long distances. Thus, the present review's focus on novel assessment approaches for children under 3 years of age in low-income, underserved communities significantly advances the literature in this area. To diagnose ASD, professionals are recommended to complete a developmental history interview with parents as well as direct observation of the child. However, most clinicians use only one of these approaches to diagnose ASD due to the lack of efficiency, cost, and training on both interview and observational methods (Rice et al., 2014). Using technology either in the form of videoconferencing or video analysis or via a mobile or web application can provide a more efficient method to collect naturalistic observations that are vital for an accurate assessment. Further, this can be a more viable option for families who are located in remote areas, because this will decrease travel time to a clinic and likely result in a more timely diagnosis (Oberleitner, Laxminarayan, Suri, Harrington, & Bradstreet, 2014). Additionally, because there is such a high prevalence rate of ASD, the use of screening tools can create a streamlined process to detect high-risk children who would benefit from an immediate comprehensive evaluation to confirm the presence of an ASD diagnosis and thus lead to quicker access to evidence-based services and treatments than can improve functional outcomes (Dawson et al., 2010).

Of the seven studies included in this review, four studies utilized a videoconferencing or video analysis method to administer an assessment, and three studies utilized a mobile- or web-based application as a screening tool. All studies revealed positive outcomes in a variety of domains, including high satisfaction with the technology (Ciccia et al., 2011), sensitivity and specificity of ASD diagnosis (Duda et al., 2016), range of developmental risk classifications (Obeid et al., 2019), and interrater agreement between administration methods of the tool (Maleka et al., 2016). For example, the NODA observation (Smith et al., 2017) resulted in high sensitivity and specificity, in addition to a positive diagnostic agreement rate when compared to the InP protocol, suggesting that this approach has potential as a supplement or alternative to traditional InP diagnostic evaluations. Moreover, the machine-learning model implemented by Tariq et al. (2018) in the United States and later examined in a Bangladeshi population (Tariq et al., 2019) noted a positive test accuracy across both settings in all classifiers, although the specificity differed depending on the classifier used, suggesting the need for further research into how to best use these tools to discriminate ASD from other diagnoses. Additionally, it would be interesting for future research to consider how variation in video length (anywhere from 2 to 5 min) affects the accuracy and psychometric qualities of these tools.

Of the current studies, methods involving video analysis proved to have positive outcomes, extending prior work in this area. Previous research analyzing natural home videos of infants and toddlers have shown that home videos are effective at analyzing a variety of symptoms associated with ASD in children 24 months and younger (Clifford & Dissanayake, 2008; Clifford, Young, & Williamson, 2007; Maestro, Muratori, Cavallaro, et al., 2005; Maestro, Muratori, Cesari, et al., 2005). Furthermore, studies looking at infants ages 0–12 months have found that behaviors associated with ASD are both more frequent and more severe in the 7- to 12-month age range than the 0- to 6-month range (Maestro, Muratori, Cavallaro, et al., 2005; Maestro, Muratori, Cesari, et al., 2005). This finding that ASD-related characteristics are more prevalent in slightly older infants highlights the importance of testing video analysis methods at various age ranges throughout early development. Overall, it appears that early signs of ASD can be effectively analyzed using natural home videos. However, this has not yet been examined in children of low-income, underserved areas.

Limitations and Future Directions

The reviewed literature found limited research on accessible remote telehealth assessment tools to detect early signs of ASD in infants and toddlers (ages 0−3 years), which limits the generalizability of the current findings. Although the seven reviewed articles did provide many positive results and innovative ideas, the sample was limited and often did not focus solely on the younger age range that the current review aimed to examine. As such, it is not possible to determine any one methodology that can be used for a population of infants and toddlers specifically from low-income, underserved communities. Another limitation of the articles reviewed was the limited demographic information provided. There was little to no data provided on the family background, including parent education, age, gender, caregiver type, and ethnicity. Additionally, only one article (Tariq et al., 2019) provided a breakdown of information on the different age groups, which resulted in no data on mean age and gender of each age group, specifically the children who were from 0 to 3 years of age. Comprehensive reporting of demographic information is essential for future studies.

Additionally, only two studies reviewed compared the technology-based assessment to a face-to-face approach (Obeid et al., 2019; Smith et al., 2017). It is vital to utilize a randomized control trial method to accurately test the effectiveness of a new assessment tool, especially for a diagnosis that is rooted in a gold-standard assessment protocol that is widely used. Specifically, these larger scale controlled designs can better evaluate the efficacy of an implemented assessment in comparison to active controls to confirm the efficacy evidenced by these preliminary studies. Further, for replication purposes, detail of the full procedure is essential for future researchers to follow the protocol correctly. Some reviewed studies did provide information on the reliability and training procedures of the clinicians, but not all of them included detailed instruction. The feasibility of an assessment would be improved if the protocols were accessible to other providers. The PEDS tool used by Maleka and colleagues (2016) included CHWs and speech−language pathologists who were already working in the clinic and were not part of the research team. By developing tools that can be implemented by non-ASD specialists, as done in this latter study, the tool can likely be sustainable for future use.

Conclusion

Overall, there are few studies examining telehealth assessments that are accessible via video or mobile applications to assess young children who are suspected of having ASD or other developmental delays. The literature reviewed showed some promising results and indicates that some of these methods may be feasible, but this should be further examined in more rigorous designs to determine whether the technology-based format is comparable to the standardized face-to-face assessments, specifically using larger and well-characterized samples and randomized controlled studies. Future studies should continue to implement these novel approaches with effective training protocols that can be used for a wider range of areas and professionals. Because comprehensive assessments are costly and are less available, the need for accessible assessments is crucial. These findings suggest that there is still a need for early diagnostic services for children during their first 3 years of life to implement intervention as early as possible and improve their developmental trajectory. Additionally, to inform ongoing and rapid developments of accessible services, particularly during the time of a pandemic or other situations that force people to stay at home, it is essential to understand the effectiveness, strengths, and weaknesses of existing approaches in the literature.

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Received April 9, 2020
Revision received April 28, 2020
Accepted April 29, 2020 ■