Behavior analytic technologies mediated via augmented reality for autism: A systematic review

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Abstract

This review synthesizes the literature base evaluating the effects of behavior analytic interventions delivered via augmented reality (AR) technology for individuals with autism. We also conducted a quality review. We identified 14 studies with a majority of the studies (*n* = 11; 79%) utilizing single-case research design. Of the 14 studies, three met the quality criteria to be classified as "strong" and can offer evidence on the integration of AR technology into the practice of behavior analysis. All three studies taught a functional skill (i.e., tooth brushing and navigation). The remaining studies focused on skill acquisition with zero studies utilizing AR within the context of behavior assessment or behavior reduction interventions. This literature base is emerging with additional research required.

Full Text

Applied Behavior Analysis (ABA) as a practice is defined as the systematic application of behavior analytic principles to improve socially important behaviors (Baer et al., 1968; 1987). ABA-based interventions can target a range of skill sets including social communication, functional skills, and early interventions (e.g., naturalistic developmental behavioral interventions). Individuals with autism are often candidates for behavior analytic interventions to address their individual needs. Although ABA is not a practice specific to autism (Dillenberger & Keenan, 2009; Sigafoos & Schlosser, 2008), ABA-based interventions have been categorized as an empirically effective method for addressing individual needs of people with autism (Leef et al., 2021). There is a substantial body of literature related to ABA-based interventions for individuals with autism that utilize methods informed by ABA (e.g., prompting, reinforcement, task analysis), which have been classified as an evidence-based practices (Steinbrenner et al., 2020; Wong et al., 2015).

As the need for ABA-based services has continued to grow, the use of technology to support individuals with autism has also been an increasing trend. In particular, there has been continual development of new technologies that are often implemented as components within ABA-based individualized treatment programs. Along this line of progression, technology-aided instruction and intervention (TAII) are often utilized as a treatment component within the context of an individualized treatment plans (Barton et al., 2017). TAII is a broad term used to account for the use of technology-based interventions for individuals with autism and was classified as an evidence-based practice in 2014 (Steinbrenner et al., 2020; Wong et al., 2015). Within this category, there are many technologies included, such as computer-based instruction, video-based instruction, and more recently virtual reality (VR) and augmented reality (AR) platforms, some of which have been incorporated to ABA-based interventions. To date, the current trend in TAII involves the use of advanced technology that provides more immersion and interactivity, such VR and AR (Thai & Nathan-Roberts, 2018).

Both AR and VR require real-time display technology, commonly implemented with hand-held, projected, LCD screens, or head mounted displays. However, there are key differences between AR and VR in the stimulus and context presented to the user. In AR most sensory input is real, whereas in VR, sensory input is primarily computer generated. That is, AR is a live view of a physical, real-world environment, augmented by computer-generated sensory input, (e.g., sound, video, and graphics). Augmentations are typically displayed in semantic context with real-world environmental elements, such as a video animation of the characters in a book overlaid on a page of the real book (Chen et al., 2016). In contrast, VR is an immersive simulation that can increase the user's sense of being within an entirely computer-generated environment (Bailenson et al., 2008), such as being inside a fictional environment, originally described in a book. Historically, both AR and VR have been utilized as intervention platforms to teach a variety of skills ranging from social and emotional skills, like engaging in conversations or learning to identify facial expressions, to daily living skills, such as problem solving (Bailenson et al., 2008; Khowaja et al., 2020; Thai et al., 2018).

To gain an understanding of the depth of research and areas of need, systematic reviews have been conducted to evaluate specific technology use, such as VR (Mesa-Gresa et al., 2018; Thai & Nathan-Roberts, 2018). Both reviews indicated generally positive outcomes for the use of VR technology within intervention contests. However, one particularly valuable point of analysis discussed by Thai and Nathan-Robers (2018) was the need for consensus in measurement of the targeted skill (e.g., social skill) and participant measures used. Additionally, the authors highlighted the need for research incorporating AR technology as an alternative to VR. In some cases, the use of AR might provide an alternative that is more user-friendly via real world context, which requires less content creation (i.e., 3D modeling, animation) for practitioners to develop applications.

Recently, Marto and colleagues (2019) conducted a systematic review of the use of AR technology for individuals with autism. A total of 16 studies were analyzed in this review, which ranged across various skills (e.g., social skills, daily living, communication). This brief review provides a general overview of 16 studies and a summary related to the type of skills addressed, type of patient (e.g., child, adolescent) technology (e.g., smartphone, computer, video projector), number of participants, and findings. This review includes some general analysis of AR use within the context of social and adaptive skill interventions. However further investigation is warranted related to the AR technology and the various features used within the skill interventions.

Marto et al. (2019) also provide an indication of quality measure by using a modified version of the strengthening the reporting of observational studies in epidemiology (STROBE) research quality checklist (STROBE, 2021). However, this tool seems limited in that the measure does not incorporate many of the research quality standards that are applied within the field of autism research (see Riechow et al., 2008). Thus, a more rigorous measure that is specific to autism intervention research is needed to evaluate the quality of these studies. Also, the summary items provided are limited to broad categories rather than specific skills addressed (e.g., social skills, communication, cognitive skills). Furthermore, within the results section, limited coding information was provided for outcome ratings (i.e., studies were only coded as positive or not) without a specific reference to how this criterion was coded.

More recently, Khowaja et al. (2020) provided a more in-depth review of the AR intervention literature from 2005 to 2018 related to children and adolescents with autism. A total of 30 studies were included and were evaluated across eight research questions. Specifically, the authors evaluated demographic information across countries conducting the research, targeted skills taught, evaluation parameters, outcomes, participants' diagnosis, technology used, research design, data collection measurements, settings, and outcomes. One important component of this review was the analysis of publication trends of the studies. Specifically, the last year within the search parameter yielded the greatest number of studies (n = 12), which may indicate the need for continued evaluation and synthesis of this area of research. Further, although the authors provide some preliminary analysis of the studies included (e.g., demographic, learning skill, participants); a more rigorous quality evaluation of these studies would be useful. A more in-depth analysis across intervention components is also warranted given that in this review only AR-related components were summarized, rather than the other non-technology components of the interventions, such as prompting and reinforcement. Additionally, a more in-depth analysis of outcome measurements would also be helpful to guide future directions for AR research and clinical applications.

Similarly, Berenguer et al. (2020) also conducted a systematic review that aimed to evaluate the evidence-base for AR-based interventions for children and adolescents with autism., concluding that there is currently a lack of empirical studies that meet the quality standards to be classified as an evidence-based practice (EBP). This review seems to be evaluating the literature on the assumption that the use of AR is an intervention, rather than the notion that the use of AR technology may only be associated with the materials used to provide an intervention. In most cases, use of AR is embedded into an intervention to present material and learning opportunities. For example, Chen et al. (2016) provided instructions by a therapist on how to operate the AR technology (either a story book or table) during the intervention phase. After the participant either watched the video clip or read the story, they were tested to mimic the targeted facial expressions. If their response was incorrect, they were instructed to re-watch/re-read the content and the therapist asked the child to identify the relevant social signals that represented the corresponding facial expression. When evaluating the components of this intervention, the use of the AR technology provided targeted stimuli to help teach the facial expressions/emotions. Additionally, the therapist provided an error correction for incorrect responses, which is also an important component to these intervention procedures. As such, the previous reviews on this topic are limited in their analysis since AR was conceptualized as the intervention, rather than including all relevant intervention components (e.g., prompting, reinforcement, error-correction), which is essential when evaluating EBPs.

Finally, a meta-analysis by Denizli-Gulboy and colleagues (2021) was conducted on the single-case research utilizing AR-embedded interventions for individuals with autism. In this meta-analysis, nine studies were evaluated based on their effect size strength and summarized by descriptive characteristics (e.g., participant characteristics, dependent and independent variables, experimental control). In terms of strength, four of the studies were categorized as strong, four were categorized as adequate, and one was rated as empirically weak. The summarized findings of this meta-analysis classified AR as a promising intervention for teaching targeted behaviors/skills to individuals with autism. Although these findings are consistent with previous reviews (e.g., Berenguer et al., 2020), this meta-analysis is also limited in its analysis since AR was conceptualized as an intervention, rather than a treatment component within a multiple-component intervention.

As this area of research has evolved, and with advances in technology, syntheses of specific technology-aided ABA-based interventions are needed to further investigate this area of research and its evidence base. Thus, the current review aims to evaluate the effects of ABA-based interventions delivered via AR technology for individuals with autism. Secondarily, we also aim to analyze the quality of the literature to help guide future research and practical application for the use of AR. As individuals with autism have known sensitivities to wearable items (Kyriacou et al., 2021), we will focus this review on the non-wearable AR technologies (e.g., excluding head-worn displays like Microsoft HoloLens 2 and Google Glass®), as wearables introduce another dimension of feasibility.

Method

Literature Search Procedures

The researchers conducted this literature search as part of a larger literature search looking to identify all articles utilizing AR and VR in the treatment of ASD. For the purpose of this review, the researchers extracted the articles specifically utilizing AR at the end of the search through the inclusion and exclusion review. Two researchers conducted a systematic search in the following databases: *PsychINFO, Medline, Psychology and Behavioral Sciences Collection,* and *ERIC.* The researchers conducted the searches by combining a term to describe ASD (i.e., “Autis*,” “Developmental disab*,” “Asperger,” “ASD”) with a term to describe AR/VR (“augmented reality,” “virtual reality”). The original search was conducted in February 2021 and yielded 1083 articles after the removal of duplicates. Figure 1 presents the PRISMA search graphic results. Following the initial database search, the authors screened all articles by their title and abstract and excluded any articles that did not mention the use of AR or VR and ASD (n = 924). Then, all remaining articles (n = 159) were screened by their full text using the inclusion criteria below and 88 were excluded with a total of 71 articles meeting inclusion criteria.

Next, an ancestral and forward search of the included articles was conducted. For the ancestral search, the references of the included articles were reviewed and extracted if titles contained any of the key search terms (provided above). For the forward search, Google Scholar was used to search the record of included articles by selecting the “cited by” button. Relevant articles citing the included article were reviewed for possible inclusion. Finally, the references of three reviews were hand searched (Berenguer et al. 2020; Khowaja et al., 2020; Marto et al., 2019). All relevant articles were extracted from the ancestral and citation search into a Microsoft Excel™ spreadsheet. These articles then underwent the full inclusion review. The researchers conducted this iterative process and retrieved a total of 19 additional articles from the ancestral and forward search. The final part of the search process focused on separating studies that integrated non-wearable AR technology from those utilizing VR technology or wearable AR technology (e.g., smart glasses). A total of 90 articles (71 from the initial search and 19 from the extended search) were screened and 76 were excluded for a total of 14 articles included in this review.

Inclusion Criteria

To be included in this review, articles had to meet the following criteria: (a) be peer-reviewed and published in English, (b) include at least one participant with ASD, (c) implement a behavior analytic assessment or intervention designed to establish/increase appropriate behavior or decrease interfering behaviors, (d) utilize an experimental design to evaluate the effects of the intervention on the target behaviors, (e) use a form of non-wearable AR to facilitate the therapeutic intervention, and (f) provide quantitative data pertaining to the participant’s acquisition of the target behaviors. Studies that did not collect data on target behaviors such as social-communication, problem behavior, or functional living skills, or did not include a therapeutic intervention as the independent variable were excluded. For example, McMahon et al. (2016) conducted a study that looked at use of AR during an intervention to teach science vocabulary which was excluded because it taught an academic skill. For this review, the researchers included any study utilizing a quasi-experimental, group comparison experimental, or single-case experimental design. Studies evaluating the validity of AR interventions or participants’ perspectives on using the technology were excluded. For example, Keshav and colleagues (2017) investigated a social skills coaching tool delivered via AR smart glasses and collected qualitative data regarding the usability and practicality of the intervention but did not collect quantitative data regarding effects of the intervention. Finally, any study that discussed the development of technologies or the architecture of the technologies but did not provide quantitative data on the effects of the intervention on the target dependent variables was excluded. For example, Trepagnier et al. (2005) discussed multiple computer-based and virtual environment technologies that are in development but did not utilize those technologies in an experiment. After application of the inclusion criteria, a total of 14 articles were included in the current review.

Descriptive Synthesis

The lead author trained two graduate students, who were completing their master's programs in educational psychology, to conduct the data synthesis for included articles. The raters first trained on two articles until they reached 100% reliability. The raters then coded the remaining articles according to the following variables: (a) dependent variable; (b) independent variable, and (c) technology utilized (description of the AR technology). Raters provided a narrative description of the dependent variables, independent variables, and technology used. The two lead authors then sorted the articles into groups based on whether the independent variable was (1) behavior assessment, (2) intervention designed to reduce behavior, or (3) intervention designed to establish or increase behavior. For example, if an article included a functional analysis and functional communication training, the article was sorted into the behavior assessment category and intervention designed to reduce behavior category. For each intervention study, the two lead authors prepared a descriptive synthesis of the intervention components following the ABA three term contingency: antecedent – behavior – consequence. For example, if the study utilized AR to embed participant preference (e.g., the participant's love of cats was integrated into the intervention via cat projections providing prompting), the intervention would be coded as an antecedent intervention.

Application of Reichow Evaluative Method

The two lead authors first grouped the articles based on the experimental design (i.e., single-case research versus group experimental/quasi-experimental) to facilitate the quality evaluation. We evaluated each study according to single-case research rubric or group-experimental research rubric depending on how the authors identified their design. For example, Escobedo et al. (2014), identified they utilized single-subject research design but then reported assessing three times (pre-experiment, during-experiment, and post-experiment). This design most closely matches a pre/post experimental group research design rather than a single-case research design, but we evaluated using the single-case rubric as that was how they identified their research design.

The lead authors rated the quality of the articles using the Reichow evaluative method (Reichow et al., 2008). Reichow's evaluative method was chosen as it includes procedures to evaluate both single-case and group experimental research, includes internal and external validity measures, and was specifically developed for the autism population. It also allows for raters to identify methodological strengths and weakness of a literature base and determine if the literature supporting a practice meets the rigorous standards for the practice to be considered evidence-based.

Establishing Interrater Reliability (IRR)

Search and Inclusion Criteria. Two raters conducted each phase of the search to establish reliability. For the initial title and abstract review, two raters coded 100% of the articles (*n* =1083. For the full inclusion review, two raters coded 100% of the articles (*n* = 159). IRR was calculated using the percent agreement method for each phase of the review by dividing the total number of agreements by the total number of agreements plus disagreements and then multiplying by 100 to obtain a percentage. For the initial title and abstract search, IRR was established at 96%. For the full inclusion review (*n* = 14), IRR was established at 89%. During each stage of the review, the two raters reviewed any disagreements and discussed until agreement was established for a final IRR of 100%.

Descriptive Synthesis. Two raters independently coded nine of the 14 articles (64%) to establish IRR. There were three categories within each article for a total of 27 items for which reliability was evaluated (9 articles with three categories each). The lead author evaluated the two data summaries to decide whether the summaries agreed. Agreement was established on 26 of the items. The lead researcher calculated IRR by taking the total number of items with agreement and dividing by the total number of items and then multiplying by 100 to obtain a percentage. The initial IRR was 96% and raters discussed disagreements for a final IRR of 100%. The lead researcher then checked all of the ratings to ensure accuracy of the table.

Quality Review. The two lead authors independently rated seven of the 14 articles (50%) to establish IRR. The seven articles included three group experimental/quasi-experimental design studies and four single-case research studies. There were 12 indicators per article for a total of 84 items for which reliability was evaluated. Agreement was established on 82 of the 84 items (98%). The two authors discussed the two disagreements and formed a consensus for a final IRR of 100%.

Results

Of the 14 articles included in this review, none of the articles utilized AR technology for behavior assessment or behavior reduction programs. All of the resulting articles utilized AR technology to facilitate interventions designed to establish or increase behavior. Table 1 presents the data summaries for the 14 included articles.

Dependent variables targeted

Of the 14 studies, 11 studies (79%) evaluated the effects of the AR mediated intervention on social skills. Of the 11 studies, one study also included problem behavior as a dependent variable (Chung et al., 2015). The 11 studies targeted play (n =1 ; Bai et al., 2015), identification of facial expressions (n=3; Chen et al., 2015; Chen et al., 2016; Weyden et al., 2021), duration of attention or time spent on task (n=2; Escobedo et al., 2014; Tentori et al., 2015), social greetings (n= 3; Lee et al., 2018; Lee et al., 2019; Lee et al., 2020), and general social behavior such as joint attention and reciprocal communication (n=2; Chung et al., 2015; Lorenzo et al., 2019). The remaining three studies (21%) all targeted functional living skills. One study focused on tooth brushing (Cihak et al., 2016) and the other two studies targeted navigational skills (McMahon et al., 2015a; McMahon et al., 2015b).

Intervention components facilitated via AR

Of the 14 studies, 13 (93%) utilized AR to facilitate antecedent interventions. The most common form of antecedent intervention facilitated via AR was stimulus prompting with eight of the 14 studies using AR for this purpose (57%; Bai et al., Chen et al., 2016; Escobedo et al., 2014; Lee et al., 2018; Lee et al., 2019; McMahon et al., 2015a; McMahon et al., 2015b; Tentori et al., 2015). The second most common use of AR in this literature base (4 studies, 29%) was to facilitate modeling or video modeling (Chen et al., 2016, Cihak et al., 2016; Lee et al., 2018; Lee et al., 2019). While not explicitly testing preference, 3 of the 14 studies (21%) mentioned the AR modality may have been preferred by the participants and served as an embedded preference intervention (Chung et al., 2015; Lorenzo et al., 2019; Weyden et al., 2021). Two of the 14 studies (14%; Lee et al., 2018; Lee et al., 2019) used AR to facilitate verbal and written instructions. Finally, one of the 14 studies (7%; Chen et al., 2016) utilized AR to facilitate social stories and one of the 14 studies utilized AR to facilitate role-play (7%; Lee et al., 2020).

A smaller number of studies, three of the 14 (21%), utilized AR to facilitate consequence interventions. All three of the studies utilized the AR system to provide feedback to the user following a response (Chen et al., 2015; Escobedo et al., 2014; Lee et al., 2020). For example, Chen et al. (2015) embedded an icon indicating an error while Escobedo and colleagues (2014) embedded audio feedback indicating a correct response. Although not experimentally demonstrated in any of the studies, this feedback potentially could have served to reinforce the target behaviors.

Other intervention components

Notably, 12 of the 14 articles (86%) included other intervention components outside of the intervention components facilitated via AR. The other intervention components primarily involved prompting by the experimenter (n = 3; Bai et al., 2015; Cihak et al., 2016; Weyden et al., 2021) or error correction by experimenter (n = 5; Chen et al., 2015; Chen et al., 2016; McMahon et al. 2015a; McMahon et al., 2015b;; Weyden et al., 2021). Other intervention components included direct instruction, (n = 3; Cihak et al., 2016; Lee et al., 2018; Weyden et al., 2020), cues to engage with the system (n = 1; Lee et al., 2020), role-play with interventionist (n = 3; Lee et al., 2018; Lee et al., 2019; Lee et al., 2020), modeling by the therapist (n =1; Lorenzo et al., 2019), and social praise by the therapist (n =1; Lorenzo et al., 2019). Finally, Tentori and colleagues (2015) describe an “awareness intervention” for a problem separate from the AR intervention, although details were not provided.

Technology utilized

Six out of 14 studies (43%) adopted an existing AR application, such as Aurasma, Layar, Quiver Vision, and Vuforia. Five of the 6 studies were implemented on mobile devices (Chen et al., 2016; Cihak et al., 2016; Lee at al., 2019; Lorenzo et al., 2019; McMahon et al., 2019) while one study (Chen et al., 2015) utilized a Vuforia platform to develop an AR-based self-facial modeling (ARSFM) learning system in a PC and 52-inch LCD monitor. Two studies from a single research group utilized a mobile AR application the group developed (Escobedo et al., 2014; Tentori et al., 2015). Lee et al. (2018) combined Microsoft Kinect and Unity to implement real time action binding in their intervention. Similarly, Weyden at al. (2021) designed AR applications using Unity and Microsoft Kinect for Xbox One to utilize the skeleton tracking system. A study by Bai et al. (2015) used a marker-based AR system as a child played with wooden blocks while viewing corresponding virtual objects projected on a computer monitor. Chung et al. (2019) examined the effectiveness of AR-based video games as a social behavior intervention using commercially available games. Lee et al. (2018) used their own platform to display a virtual map on a computer monitor where each participant practices social interactions while navigating in the virtual “mini-theater” through AR in their mobile device. McMahon, Smith et al. (2015) used location-based AR to implement a Navigator Heads Up Display application in iPhone.

Results of quality ratings and evidence evaluation

Of the three group experimental design studies, none of them met the criteria to be classified as “strong” or “adequate” and, therefore, cannot offer any evidence towards the use of AR to facilitate therapy based on the principles of ABA. Of the 11 single-case experimental design studies, eight included an “unacceptable” rating for at least one of the primary indicators and was thus classified as “weak”. The resulting three studies (Cihak et al., 2016; McMahon et al., 2015b; McMahon et al., 2015a) met all of the primary indicators with “high” ratings and showed evidence of three secondary indicators. Therefore, all three studies are classified as “strong” and can offer evidence of the integration of AR into therapy based on the principles of ABA. The three studies were conducted by two different research teams, at two different locations, with 14 different participants and meet the qualifications to be considered a promising practice.

Discussion

The purpose of this review was to synthesize the literature base evaluating the effects of behavior analytic interventions delivered via AR technology for individuals with autism. We also conducted a quality review to help inform future research and practice. We identified 14 studies, all of which targeted skill acquisition. Zero studies focused on behavior assessment or behavior reduction. Of the 14 studies, three met the quality criteria to be classified as “strong” and can offer evidence on the integration of AR technology into the practice of behavior analysis. All three studies taught a functional skill (i.e., tooth brushing and navigation).

Of the three articles that met quality criteria, two projected augmented graphics over real world scenes, potentially allowing the graphics to serve as stimulus prompts (McMahon et al., 2015a; McMahon et al., 2015b). This application is one of the most obvious benefits of AR applications within behavior analysis. The ability to project stimulus prompts in an environment where behavior would naturally occur can reduce the overall dependency on a therapist and increase independence for the individual receiving services. This might also facilitate scaling of interventions with reduced resources, and increasingly important goal for low-resource settings.

Another potential benefit of AR might be the use of AR to facilitate generalization of skills across settings, people, or time (i.e., maintenance of skills). In particular, AR can allow for teaching of skills within the real world environment and programming of common stimuli, two of the generalization strategies identified by Stokes and Baer (1977). It might also allow for teaching of skills that are difficult to simulate, for example, social skills. Rather than adults role-playing as a child, AR can simulate a peer, allowing the child participant to engage with a confederate similar to what they would experience in the real world environment (Lee, 2020).

While there are many potential benefits to AR, it is recommended that practitioners consider conducting cost-benefit analyses to evaluate whether there is benefit of facilitating the specific interventions or components of intervention under consideration with AR. Notably, in some of the research included in this review, there was still a reliance on the therapist to prompt or provide error correction. This begets the question of whether the integration of AR would lead to more effective and efficient interventions. For example, in Cihak et al. (2016), the therapists prompted using least-to-most prompting on top of the AR application with embedded video models for tooth brushing. Similarly, in Lee et al. (2018, 2019), participants did not demonstrate immediate improvements from baseline to intervention indicating that perhaps the error correction and role-play provided by the therapist or experimenter may have been the active component of the intervention.

It is also possible that there may be lower tech solutions that achieve similar results to those found from AR. For example, Chen et al. (2015) utilized AR to provide response prompting to teach emotional matching to social situations. However, it is unclear if this was necessary as the results may be achieved with lower tech solutions (e.g., flashcards) or the error correction procedures utilized by the therapists may have been the active component of the intervention. Alternatively, Chen et al. (2016) did note improvements for four of their six participants with just the AR facilitated intervention. Two of the six participants required additional consequence-based interventions. Therefore, it might be useful to identify the characteristics of the individuals for which AR technologies are most beneficial (e.g., cognitive ability, physical ability, etc.).

While AR might be a promising technology to integrate into aspects of ABA, there are notable directions for future research. First, only three articles met the quality standards. With such a small sample size, it makes it difficult to draw conclusions about which aspects of AR might facilitate interventions that are more effective and efficient. For example, it is possible that both augmented graphics over real world scenes and three dimensional AR models might both produce interventions that are more effective. If both are equally effective, the practitioner might consider which of the two is more cost and time efficient. Future researchers might also compare behavior analytic interventions delivered via AR versus traditional materials.

Second, as all of the studies targeted skill acquisition, zero studies utilized AR in the context of behavior assessment or behavior reduction. Therefore, future research might consider evaluating AR as a modality to facilitate behavior assessment or behavior reduction programs. Finally, although there is a strong possibility that AR might facilitate generalization of learned skills, few of the included studies systematically evaluated generalization. Future research should evaluate generalization to the real world environment and evaluate if interventions facilitated via AR result in improved generalization of skills.

Some limitations must also be noted for the review. First, we only included peer-reviewed articles in our search. This excluded a number of potentially relevant articles in grey literature or conference papers. Second, we did not include wearable technologies. As individuals with autism report sensory sensitivities (Kyriacou et al., 2021), we decided to separate wearable versus non-wearable technologies as wearable technologies introduce additional feasibility questions. Finally, we chose to apply the Reichow quality indicators to the literature base (Reichow et al., 2008). This excluded a number of the studies from our final synthesis. However, as we aim to provide recommendations for researchers and practitioners, it is important to consider the quality of the studies. Future researchers should aim to meet quality standards in the design of their research.

Implications For Practice And Conclusion

For practitioners, the researchers recommend first relying on EBPs. If considering AR technologies to facilitate behavior analytic interventions, the researchers recommend practitioners carefully evaluate the pre-requisite skills necessary for the child to engage meaningfully with the AR technology. For example, a majority of the studies included in this review trained the participants how to use the technology prior to implementing the intervention (e.g., Chen et al., 2015). Practitioners might also create scaffolding and learning plans for natural change agents (e.g., caregivers and educators) to implement the AR interventions to facilitate generalization to the real world environment. Ultimately, the use of AR technology to facilitate behavior analytic assessments and interventions are not evidence-based as the literature base is still emerging. There are still many unknowns, and future research is needed to create a clear framework for technology-related decision making within intervention frameworks. That is, additional research is warranted to identify when to use technology-related intervention components (such as AR) and for whom technology-facilitated intervention is best suited.

Declarations

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tables

Table 1.
Descriptive Synthesis

Citation	Dependent Variable	Intervention	Technology
Bai et al. (2015)	Pretend play, constructive play, relational play, simple play, and no play defined by the researchers and based on the categories outlined by Smilansky (1968). Measured play using rate (frequency/minute) and duration.	Intervention involved a child sitting in front of an AR mirror or control set up. The AR mirror super imposed stimuli into the play **Antecedent Intervention via AR:** Visual prompting by overlaying visuals on the physical props (AR system) **Other Intervention Components:** Verbal prompting by experimenter	Goblin XNA and the ALVAR tracking library. Marker-based tracking with 24" monitor and webcam facing the user and the markers
Chen et al. (2015)	Identification of the 6 basic facial expressions (happiness, sadness, fear disgust, surprise, and anger) as measured by percentage of opportunities correct (termed correct assessment rate)	Therapist instructed the participants on how to operate the system and perceive cues. The participants read a scenario script and referenced at the corresponding illustrations on the monitor screen. They then selected a mask to wear on their face (6 total emotions). **Consequence Intervention via AR:** Visual error correction with the mask cueing a 3-D model of a head with the selected emotion on the display **Other Intervention Components.** When an answer was incorrect, the therapist utilized *error correction* by asking the participant to determine what each mask represented and why the appropriate mask should be selected in the scenario.	AR-based self-facial modeling Vuforia™ (Qualcomm, San Diego, CA) platform with Unity Extension Application Program Interface (API) A 52" LCD monitor and web cam facing the user
Chen et al. (2016)	Mimicking of the 6 basic facial expressions (happiness, sadness, fear disgust, surprise, and anger) as measured by percentage of opportunities correct (termed correct assessment rate)	Therapist instructed the participants on how to operate the system and perceive cues. The participants watched an AR-based video-model with storybook including video clips. They then selected a mask to wear on their face (6 total emotions). Finally, the researcher asked the participant to imitate the emotion. **Antecedent Intervention via AR**: Stimulus prompting highlighting the relevant stimuli; social stories; video modeling **Other Intervention Components**: When an answer was incorrect, the Therapist utilized *error correction* by asking the participant to determine what each mask represented and why the appropriate mask should be selected in the scenario.	Vuforia™ (Qualcomm, San Diego, CA) platform with Unity Extension Application Program Interface (API) to develop the AR-based video-modeling with storybook Augmented dynamic video layer: virtual visual hints via video clips overlaid on a tablet PC based on the storybook and extended social stimulation.
Chung et al. 2015	Joint positive effect, reciprocal conversation, and aggression as measured using partial interval recording and reported as percentage of time	The participants played video games consisting of either: (1) sedentary video game, (2) active video game, and (3) active video game via AR **Other Intervention components**: No purposeful intervention components although the AR video game was reported to be preferred over the other two types of video games. Best categorized as embedded preferences (antecedent intervention)	AR video games consisted of "Fruit Ninja Kinect" (by Half Brick Studios) and "Kinect Party" (by Double Fine Productions)
Cihak et al. (2016)	Steps to brushing teeth as measured by steps performed independently	Intervention consisted of scanning a picture in the visual schedule using an iPod which initiated a first person view video-modeling of teeth brushing.	iPod touch fourth generation, Aurasma AR application, marker-based augmented reality picture prompt.

		Antecedent Intervention via AR: Video model of tooth brushing (62s total) **Other Intervention Components:** Verbal instruction and a gesture prompt to scan the picture and brush their teeth. Least-to-most prompting was used to complete each step of the task.	
Escobedo et al. (2014)	Selective attention (staying on task when distraction present), sustained attention (ability to stay on task for an extended period of time during a continuous or repetitive activity), and total time spent on task. All measured using time in minutes	**Antecedent and Consequence Intervention via AR:** Discrete trial teaching with textual/visual prompting and rewards that potentially served as reinforcers provided by AR system	Mobile Object Identification System (Mobis) allows teachers to superimpose text, audio, and visual shapes on top of physical objects.
Lee(2020)	(1) Knowledge of appropriate social greetings as measured by correct responding to social scenarios to identify which body greeting (out of an array of six options) is appropriate for the scenario and (2) implementation of the selected social body gestures evaluated using a 5-point Likert scale rubric.	Therapist instructed the participants on how to operate the system and perceive cues. In room 1, the trainer manipulated the 3-D virtual characters to role-play a social scenario. In room 2, the participant stood in front of the monitor and a question appeared below the virtual character asking the participant to select which greeting is appropriate for the scenario presented. The participant then role-played the social greeting selected. A wrong response resulted in visual stimuli indicating the selection is incorrect (e.g., a red fork). A correct response resulted in visual stimuli indicating the selection is correct (e.g., a green circle). **Antecedent and Consequence Intervention via AR:** Role-play simulations of social scenarios with feedback provided by the system for correct/incorrect responses **Other Intervention Components**: Cued by therapist to stand in front of the system and look at the screen. Therapist also prompted child to follow the corresponding body greetings/social gestures. After the AR session, the therapist prompted the participant to engage in repeated practice of target responses.	Kinect Skeletal Tracking System: 3-D virtual characters (classmates, teachers, neighbors, and salesclerks) animated by the trainers in 3-D contextual backgrounds on a screen. All the physical movements of these 3-D virtual characters were created by the trainers using their own bodies with movements captured using Xbox Kinect^{TM}. 3-D virtual characters were projected into 3-D contextual backgrounds in a separate room where a child with ASD interacts with the virtual characters.
Lee et al. (2018)	(1) Knowledge of appropriate social greetings as measured by correct responding to social scenarios to identify which social greeting (out of an array of six options) is appropriate for the scenario and (2) implementation of the selected social greeting evaluated using a 5-point Likert scale rubric.	Therapist instructed the participants how to use the social map and how to use the AR-based concept map training system (ARCM) system. The participants used their hand to manipulate the ARCM system and selected one of 20 scenarios. Each scenario consisted of a 3D AR animation with dialogue. Social stories were stratified based on level of relation (e.g., intimate relations, close relations, alienated relations) and embedded into the ARCM. The participant was presented a question following the animation. A wrong response resulted in error correction (i.e., direct instruction by the Therapist and representation of the trial). A correct response results in the 3-D avatar responding to the social greeting. **Antecedent intervention via AR**: Stimulus prompt highlighting the relevant stimuli; verbal and written instruction; modeling with the AR application	ARCM was described as a mini-theater on a table where participants role-play through their avatar. ARCM includes: (1) physical environment maps, (2) tangible avatar cards, (3) 3-D avatar models, (4) question marks with avatar indicator arrow, and (5) 3-D virtual animation of the greeting with dialogue.

		Other Interventions: Role play with the Therapist and direct instruction in response to an error.	
Lee(2019)	(1) Knowledge of appropriate social greetings as measured by correct responding to social scenarios to identify which social greeting (out of an array of six options) is appropriate for the scenario and (2) implementation of the selected social greeting evaluated using a 5-point Likert scale rubric.	The Therapist taught the participant to use the system. They then read the social story with the participant and discussed the story. The child was asked to color the picture with blanks strategically placed to highlight the relevant stimuli (e.g., expressions). After coloring the holds the tablet in front of the picture with the Quiver™ AR app open. Quiver™ then runs the application to present the virtual 3D animation. After the animation, the child was asked to role-play the social situation presented in the story. **Antecedent Intervention via AR**: Stimulus prompt highlighting the relevant stimuli; verbal and written instruction; modeling with the AR application **Other interventions**: Role play with the experimenter	Redesigned Quiver™ 3D AR coloring app to create the targeted social situations. The QuiverTM app animated the scenes depicted in the coloring pages used during intervention.
Lorenzo et al. (2019)	Social skills measured using the *Autism Spectrum Inventory*	AR application was used to deliver the S^D during direct instruction for the experimental group. Tasks for the test group were completed with traditional materials. Two sessions per week lasting 15 minutes for 20 weeks. Participants were taught how to use the AR prior to beginning the experiment. **Antecedent intervention via AR**: Although it wasn't tested, it is possible that the AR was preferred and served as an embedded preference intervention. **Other interventions:** Modeling by the therapist and social praise delivered by the therapist	Quiver Vision application for Android smartphones. Application had a variety of social situations.
McMahon et al. (2015)	Independent navigation of a city to access employment opportunities as measured by the number of correct navigational checks during navigation to an unknown business location.	The Therapist taught the use of the devices using "model-lead-test". Three experiment then consisted of three conditions: (1) navigation using a paper map, (2) navigation using google maps, or (3) navigation using the AR app. All of the experimental conditions included prompting by the Therapist after three consecutive errors. **Antecedent Intervention via AR:** Stimulus prompts highlighting relevant directional and location information **Other intervention components:** Error correction using verbal and gestural prompts by experimenter	Layar AR application displayed on a mobile device -- iPhone 4s. Layar uses location-based AR display to show selected content and visual prompts (e.g., distance and location name).
McMahon, Smith et al. (2015)	Independent navigation of a college campus as measured by the number of correct navigational checks during navigation to an unknown location.	The Therapist taught the use of the devices using "model-lead-test". Three experiment then consisted of three conditions: (1) navigation using a paper map, (2) navigation using google maps, or (3) navigation using the AR app. All of the experimental conditions included gestural prompting by the Therapist after 4s of an incorrect or no response. **Antecedent Intervention via AR**: Stimulus prompts highlighting relevant directional and location information **Other intervention components:** Gestural prompting if no responding to the stimulus prompts	Navigator Heads Up Display uses location based AR display to show selected content and visual prompts (e.g., distance and location name)
Tentori et al. (2015)	Attention measured in minutes	The researchers installed the Mobis prototype in the classroom and teachers utilized the	Mobile Object Identification System (Mobis) allows teachers

		technology in their instruction. No additional details provided. **Antecedent Intervention via AR**: Stimulus prompts (text, audio-recorded messages, visual shapes) highlighting relevant information **Other intervention components:** The authors included an "awareness intervention" for PB separate from the AR intervention. It was unclear what the intervention entailed	to superimpose text, audio, and visual shapes on top of physical objects.
Weyden et al. (2021)	Identification of six facial expressions (happiness, sadness, surprise, fear, disgust, and anger) as measured by number of correct responses	The researchers first taught participants to use the application. They also provided instruction regarding the expressions and faces. Caregivers prompted correct responses. Upon instance of an incorrect response, the trial was re-presented. **Antecedent intervention via AR**: Although it wasn't tested, it is possible that the AR was preferred and served as an embedded preference intervention **Other intervention components:** Researcher taught the participants the expressions and faces prior to the intervention. Intervention included visual and gestural prompting provided by the caregiver, re-testing of the same emotions, and error correction.	Hardware: Microsoft Kinect for Xbox One Software: AR application designed using Unity. The app included three sets of the six facial expressions: (1) graphical depiction, (2) real photo for person one, and (3) real photo for person two.

Table 2

Quality Indicator Ratings for Group Experimental and Quasi-experimental Research

	Lorenzo et al. (2019)	Tentori et al. (2015)	Weyden et al. (2021)
Primary Indicators			
Participant information	H	U	H
Independent variable	A	U	A
Control condition	H	U	H
Dependent variable	U	U	A
Link Between Research Question and Data Analysis	A	U	H
Use of Statistical Tests	A	U	U
Secondary Indicators			
Random assignment	0	0	0
Interobserver agreement	0	0	0
Blind raters	0	0	0
Fidelity	0	0	0
Attrition	1	0	0
Generalization or maintenance	0	0	0
Effect size	1	0	0
Social validity	0	0	1

[1] Codes for quality ratings for primary indicators are as follows: H = high quality, A = acceptable, and U = unacceptable

[2] Codes for quality ratings for secondary indicators are as follows: 1 = criteria met, 0 = criteria not me

Table 3

Quality Indicator Ratings for Single-case Research

	Bai et al. (2015)	Chen et al. (2015)	Chen et al. (2016)	Chung et al. (2015)	Cihak at el. (2016)	Escobedo et al. (2014)	Lee et al. (2020)	Lee et al. (2018)	Lee et al. (2019)	McMahon et al. (2015)	McMahon, Smith, et al. (2015)
Primary Indicators											
Participant information	H	H	H	A	H	U	H	H	H	H	H
Independent variable	H	A	H	A	H	A	H	A	A	H	H
Dependent variable	A	U	U	H	H	H	U	U	U	H	H
Baseline	U	H	H	A	H	U	H	A	A	H	H
Visual analysis	U	H	H	U	H	U	H	H	H	H	H
Experimental control	U	H	H	U	H	U	H	H	H	H	H
Secondary Indicators											
Interobserver agreement	0	0	0	1	1	1	0	0	0	1	1
Kappa	0	0	0	0	0	0	0	0	0	0	0
Blind raters	1	0	0	0	0	0	0	0	0	0	0
Fidelity	0	0	0	0	0	0	0	0	0	1	1
Generalization or maintenance	0	1	1	0	1	0	1	1	1	0	0
Social validity	0	0	0	1	1	0	1	0	0	1	1

[1] Codes for quality ratings for primary indicators are as follows: H = high quality, A = acceptable, and U = unacceptable

[2] Codes for quality ratings for secondary indicators are as follows: 1 = criteria met, 0 = criteria not met

Figures

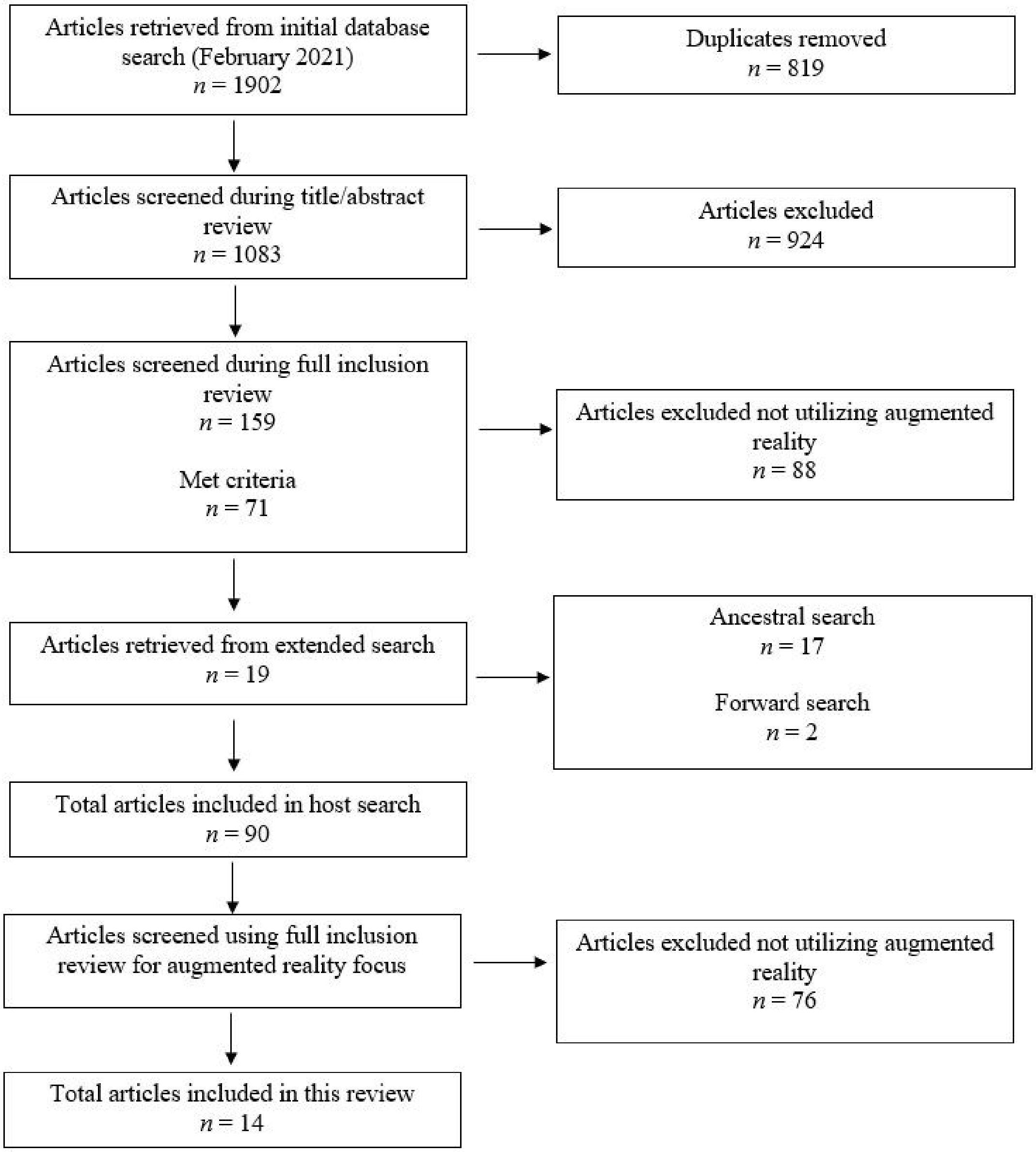

Figure 1

Search Graphic