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REVIEW PAPER

Mathematics Interventions for Individuals with Autism Spectrum Disorder: A Systematic Review

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Abstract This review provided a systematic analysis of mathematics interventions for individuals with autism. Using success estimates, strength of evidence ratings, and percentage of non-overlapping data (PND), we identified 13 studies that provided evidence of effective to very effective outcomes using mathematics accuracy measures for at least one intervention. Five studies with measurements related to engagement had 100 % success estimates with at least adequate evidence and had PND scores indicating very effective interventions for the majority of participants across studies. For accuracy-based outcomes, a majority of successful interventions included both behavioral and mathematical components. Although the combination of mathematical and behavioral components appears to be promising, differences in interventions and outcomes and limited details on participant characteristics limit conclusive clinical recommendations.

Keywords Applied behavior analysis · Autism spectrum disorder · Mathematics · Single-case research

Initial coding for this review was done while the first author was a graduate student at the University of Texas at Austin. The final study write-up was completed while she was an assistant professor at Manhattanville College

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Individuals with autism spectrum disorder (ASD) are increasingly held accountable to academic standards comparable to peers (Schaefer-Whitby 2013). Academic research focused on the ASD population is increasing, but in a review of evidence-based practices for ASD, only 12.7 % of studies involved academic outcomes (Wong et al. 2014). Research on the academic abilities of individuals with ASD underlines the importance of mathematics interventions. Although ASD may be associated with mathematics strengths (Baron Cohen et al. 2007; Chiang and Lin 2007) and average abilities (Chiang and Lin 2007; Titeca et al. 2014), around 25 % of individuals with ASD may have a mathematics learning disability (LD; Mayes and Calhoun 2003; Williams et al. 2008). Mathematics abilities likely vary with cognitive abilities (Mayes and Calhoun 2003; Wei et al. 2014), but Intelligence Quotient (IQ) alone might not fully predict mathematics achievement. Individuals with IQs of 80 or above (i.e., those with high-functioning autism (HFA); Bertrnd et al. 2001; Schaefer-Whitby et al. 2009) may show mathematics weaknesses in comparison to their IQ (Chiang and Lin 2007), or when compared to typically developing peers (Titeca et al. 2014). Students with HFA may particularly struggle with word problems due to difficulties with comprehension, memory, organization, and real-world reasoning (Donaldson and Zager 2010; Schaefer-Whitby et al. 2009).

Mathematics interventions for individuals with ASD could be patterned after interventions for individuals with similar cognitive profiles and/or mathematics weaknesses. For instance, systematic instructional packages with Applied Behavior Analysis (ABA) components (e.g., prompting, reinforcement), found to be effective among individuals with intellectual disability (ID) (Browder et al. 2008), could be appropriate for individuals with ASD and ID. Research with individuals with ID has, however, focused primarily on

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computation and/or functional skills (Browder et al. 2008). Instructional methods employed with individuals with LD may be appropriate for students with HFA (Donaldson and Zager 2010). Such methods include mathematics-based explicit, strategic instruction (e.g., steps for solving word problems), heuristics (generic approaches for word problems), visual representations, carefully constructed sequences of examples (e.g., concrete to more abstract problems), and verbalizations of problem solving steps and reasoning (Bryant et al. 2011; Gersten et al. 2009).

In addition to targeting mathematics performance, interventions may need to address instructional engagement. Researchers have reported that academic difficulties of individuals with ASD correlate with deficits applying social-attentional skills such as turn taking, switching attention between tasks, listening, and managing and organizing tasks (Blair and Razza 2007; May et al. 2013; McClelland et al. 2007). Repetitive and/or restricted behaviors or interests may also compete with engagement (Morrison and Rosales-Ruiz 1997).

To make recommendations for research and practice, it is necessary to critically analyze research aimed at improving mathematics accuracy and engagement for individuals with ASD. Two recent syntheses have reviewed mathematics interventions for this population. First, Spencer et al. (2014) reviewed interventions that focused on students with ASD and all academic content area instruction. Twenty-eight studies for academic content areas published between 2000 and 2012 were included, of which five examined mathematics only and one focused on mathematics and language arts. Second, Hart-Barnett and Cleary (2015) reviewed mathematics intervention studies for this population. The review included only 11 studies and analyzed intervention components such as the use of visual representations and cognitive strategies, but did not analyze the use of behavioral-based strategies common in ASD interventions. Neither review included a systematic approach for assessing quality of evidence or intervention success.

For the current review, attempts were made to identify additional studies, classify intervention components as either mathematics-based or behaviorally based, and provide success estimates, evidence ratings (Reichow and Volkmar 2010; Reichow et al. 2008), and percentage of non-overlapping data (PND) (Scruggs et al. 1988). Therefore, the purpose of the present review was to (a) identify the characteristics of participants, outcomes, and settings of mathematics interventions for individuals with ASD; (b) evaluate intervention effectiveness via an analysis of intervention results and quality indicators; (c) identify which intervention components are commonly used in effective interventions; and (d) offer recommendations for research and practice.

Method

Search Procedures

Two searches of the databases PsycINFO, Educational Resources in Education Clearinghouse (ERIC), and Education Full Text were conducted in June 2015. The first search used the terms (autis*, Asperger, or PDD) AND (mathematics OR math OR arithmetic OR numeracy OR geometry OR calculus OR algebra OR trigonometry). The second search replaced the second set of terms with "academic engagement." Searches were limited to peer-reviewed articles in English from 1980 to 2015. The year 1980 was used because that was the first year autism was a separate diagnostic category in the *Diagnostic and Statistical Manual of Mental Disorders* (DSM III; APA 1980). Abstract review led to 57 studies selected for further review. A co-author independently conducted the same searches and did not identify additional studies. References of included studies and related reviews (e.g., Hart-Barnett and Cleary 2015), and journals publishing included studies were searched for citations. Three additional studies were identified via journal and reference searches, leading to 60 studies selected for further review.

Inclusion and Exclusion Criteria

Included studies met the following criteria: (a) evaluated an intervention with at least one dependent measure of mathematics-related outcomes (e.g., accuracy with addition problems, latency to start a math assignment); (b) involved at least one participant with ASD; and (c) used an experimental design (e.g., single case, group experimental). Outcomes could focus on mathematics accuracy (e.g., percentage of correct problems), and/or engagement with mathematics instruction (e.g., latency to start math task, percentage of time on-task). Studies measuring "sitting," without attendance and/or interaction were excluded. Following the guidelines of the DSM-5 (APA 2013), participants with ASD could be described as being diagnosed with ASD, autism, Pervasive Developmental Disorder (PDD), or Asperger's syndrome. Mathematics outcomes needed to be disaggregated from non-mathematics outcomes (e.g., excluding mathematics data not disaggregated from reading or task completion data in which some steps were not mathematical), as well as from participants without ASD. Two authors applied criteria to the initial 60 articles and agreed upon the inclusion of 23 studies (most excluded due to lack of participants with ASD or non-disaggregated data).

Data Extraction and Coding

Information for each study was extracted across the following variables: participants, setting, mathematical outcomes, mathematics-based strategies or curricula, behavioral strategies, success estimates (Reichow and Volkmar 2010), strength of evidence ratings (Reichow et al. 2008), and PND (Scruggs et al. 1988; Scruggs and Mastropieri 1998). We coded participants in terms of the following: primary diagnosis, gender, age, IQ, ASD severity, and grade performance levels in mathematics. Asperger's was coded separately, due to the fact that although persons previously diagnosed as having Asperger's are now classified as having ASD (DSM-5; APA 2013), in the DSM-IV (APA 2000), one of the diagnostic criteria for Asperger's included a lack of cognitive delay. We coded IQ scores when available or descriptions of co-occurring ID, and estimated grade performance levels in mathematics and ASD severity (based upon reported use of autism rating scales); although these were often excluded from authors' descriptions of participants. Settings were coded in terms of the larger location (e.g., school), specific location (e.g., general education class), grouping format, and interventionist. Mathematics outcomes measuring accuracy or engagement were coded in terms of targeted skills (e.g., addition accuracy) and units of measurement (e.g., percentage correct). Mathematical-based intervention components included the use of mathematics strategies (e.g., counting-on, mnemonics for problem steps); visual representations (i.e., concrete, semi-concrete, or virtual materials used to represent mathematical concepts, including manipulatives); and/or a specific named mathematics curriculum. Behaviorally based intervention components (e.g., reinforcement, prompting, error correction, self-management) were procedures used commonly in the field of ABA, as evidenced by their inclusion in the text *Applied behavior analysis* (Cooper et al. 2007).

Data Analysis

As all included studies used single-case designs, we summarized results via methods that utilize visual analysis of graphed data. Specifically, we computed success estimates (Reichow and Volkmar 2010) and PND (Scruggs et al. 1988; Scruggs and Mastropieri 1998). These methods complement one another as success estimates take into consideration all changes to data that may indicate an effect (e.g., change in level, trend, variability) and provide an estimate of how often the intervention was successful (Reichow and Volkmar 2010) while PND provides an estimate of the extent of effects (Scruggs et al. 1988; Scruggs and Mastropieri 1998).

Success Estimates and Visual Analysis Success estimates (Reichow and Volkmar 2010) have been used in reviews of interventions for children with ASD (see Reichow and Volkmar 2010; Watkins et al. 2014). Visual analysis methods described by Kennedy (2005) and Kratochwill et al. (2010) were used to ascertain the number of successful implementations of the independent variable(s) (IV) to mathematics outcomes within or across participants (Reichow and Volkmar 2010). For each mathematics outcome, the coder examined the consistency of level, trend, and variability within baseline and intervention phases and considered immediacy of change and overlap between data. Based upon this analysis, the coder rated each implementation of the IV as either successful or unsuccessful and determined a ratio of successful implementations to total implementations. For instance, a multiple baseline design (MBD) across participants, demonstrating success for three of four participants, or an MBD across behaviors successful for three of four skills would both have success estimates of 75 %. Separate success estimates within a study were determined when there were two or more of the following: (a) interventions (e.g., in alternating treatment designs (ATDs)), (b) dependent variables (DV), or (c) distinct designs (Rapp et al. 2012).

Percent of Non-overlapping Data As success estimates do not fully describe the magnitude of intervention success as compared to baseline, an effect size measure (i.e., PND) was employed (Whalon et al. 2015) for each intervention (Scruggs et al. 1988; Scruggs and Mastropieri 1998). PND is used to document the extent to which scores achieved during intervention phases differ from those during baseline, and could be employed across a majority of designs utilized in reviewed studies. Although PND may be overly reliant on a single baseline score, utilizing it alongside a more qualitative approach to visual analysis (i.e., success estimates) allows for a richer understanding of results. According to Scruggs and Mastropieri (1998), PND scores above 90 represent *very effective* interventions, scores from 70 to 90 represent *effective* interventions, scores from 50 to 70 represent low or questionable effectiveness, and scores below 50 indicate ineffectiveness.

Evaluative Method for Determining Evidence-Based Practices in Autism The strength of evidence for each study was rated based on the Evaluative Method for Determining Evidence-Based Practices in Autism (Reichow et al. 2008). Although there are alternative methods for assessing quality indicators in single-case research (e.g., Kratochwill 2013), this method was developed specifically for interventions for individuals with ASD, has been shown to produce reliable and valid results (Cicchetti 2011), and has been used in systematic reviews (see Watkins et al. 2014; Whalon et al. 2015). To rate studies as having *strong*, *adequate*, or *weak* evidence, studies first received ratings on *primary* and *secondary* quality indicators. *High quality* ratings on primary indicators were given when (a) participant characteristics (age, gender, diagnosis) and interventionist characteristics were provided; (b) the IV was operationally defined with replicable precision; (c) the DV was operationally defined with replicable precision; (d) all baselines were operationally defined with replicable precision, appeared stable with no trend, and had at least three measurement points; (e) all relevant data for each participant showed a stable level and/or trend, contained less than 25 % overlap of data between adjacent conditions unless behavior was at floor or ceiling levels and showed a large shift in level or trend between adjacent conditions with the implementation or removal of the IV; and (f) there were at least three demonstrations of the effect (Reichow et al. 2008). The last two indicators may be concerned with intervention success, but are also indicators of experimental control, a key component of a well-designed, single-case study (Kennedy 2005; Kratochwill et al. 2010). As experimental control in ATDs and multielement designs involves differences between conditions, studies with such designs were rated as having high quality control if, in addition to other requirements, there was less than 25 % overlap between conditions. High quality ratings on secondary indicators included the assessment of (a) inter-observer agreement (IOA) for at least 20 % of sessions with reliability at or above 80 %, (b) procedural integrity at or above 80 %, (c) generalization and/or maintenance, and (d) social validity (Reichow et al. 2008).

Studies rated as "strong" had high quality ratings on all primary indicators and three or more secondary quality indicators. Adequate studies, received high quality ratings on four or more primary indicators, with no unacceptable ratings, and at least two secondary indicators. Studies rated as "weak" had fewer than four high quality indicators or fewer than two secondary indicators. To determine the adequacy of evidence for mathematics outcomes for individuals with ASD, these ratings excluded non-mathematics data or data from participants without ASD.

Reliability of Coding

The first author coded all studies and developed initial summaries across all coded variables other than success estimates, PND, and evidence ratings (coded and checked separately). For each study, a co-author checked summaries against studies and marked data for each variable as "accurate" or detailed discrepancies. A combined inter-rater agreement (IRA) was calculated across 130 items (i.e., 26 studies with five variables per study). Initial agreement was obtained on 92.3 % of variables. For success estimates, two authors independently conducted visual analysis and determined success estimates according to procedures. A difference on any estimate within a study would lead to an overall disagreement for that study. Initial agreement was 92.3 %. For evidence ratings, two authors independently filled out a checklist with 11 primary and secondary quality indicators for each study. IRA was calculated across 286 items (i.e., 26 studies with 11 indicators per study) and was 98.6 %. Additionally, each coder determined an overall evidence rating for each study. IRA for evidence ratings was 92.3 %. In any case where IRA was not initially 100 %, all discrepancies were discussed until agreement between authors was reached. For the PND analysis, all studies were examined by two authors who independently computed PNDs. The researchers agreed on the PNDs 100 % of the time.

Results

Twenty-six studies were included. Table 1 provides information on studies involving mathematical accuracy (22 studies) and Table 2 describes studies involving mathematics engagement (7 studies). Information regarding participants and setting are reported across all studies, and mathematics outcomes, intervention components, success estimates, evidence ratings, and PND are reported separately for accuracy and engagement.

Participants and Settings

There were 53 participants (8 females, 45 males), with a mean age of 11.1 (range 5 to 19). Seventeen studies provided information on intellectual functioning. Twenty-eight participants across 16 studies were described as having IQs below 80 and/or as having ID. Seven participants were reported to have IQs above 80 (Burton et al. 2013; Cihak et al. 2010; Schaefer-Whitby 2013; Yakubova et al. 2015). Three participants without IQ information were reported to have Asperger's (Neely et al. 2013; Rapp et al. 2012; Tiger et al. 2007). Two studies provided grade-level mathematics equivalents, with most participants below grade level (Bouck et al. 2014; Waters and Boon 2011). Six studies reporting ASD severity ratings reported mild to moderate symptoms for a majority (Cihak and Foust 2008; Cihak and Grim 2008; Cihak et al. 2010; Fletcher et al. 2010; Holifield et al. 2010; Jowett et al. 2012; Polychronis et al. 2004).

Intervention occurred in schools for the majority of participants ($n = 42$). A majority of studies occurred in self-contained classes, resource, and/or separate rooms. Only three studies involved intervention in general education (Cihak et al. 2010; Levingston et al. 2009; Polychronis et al. 2004). Teachers or paraprofessionals were involved in interventions for 28 participants. Researchers were the primary interventionists for 21 participants. All instruction occurred either one-on-one, in the context of independent practice, or within a group. Two studies occurred outside of the USA (Akmanoğlu and Batu 2004; Jowett et al. 2012).

Mathematics Outcomes

Accuracy Twenty-two studies with accuracy measures commonly targeted one or more of the following skills: addition (Cihak and Foust 2008; Fletcher et al. 2010; Leaf et al. 2010; McEvoy and Brady 1988; Rapp et al. 2012; Rockwell et al.

Table 1 Coding variables for studies including mathematical accuracy outcomes

Study	Participants	Setting	Mathematical-related outcomes	Mathematical intervention components	Behavioral-based intervention components	Success estimates and strength of evidence rating	PND
Akmanoğlu and Batu (2004)	2 males (12, 17) and one female (6) with ASD and ID	1-1 with researcher in special education class (2); in university classroom (1)	Receptive numeral identification (pointing to named numeral): percentage correct	X	Prompting, errorless learning, reinforcement	100 % adequate evidence	S1 (I) 100 % (M) 100 % S2 (I) 100 % (M) 100 % S3 (I) 100 % (M) 100 %
Bouck et al. (2014)	3 males with ASD (6, 7, 10)	1-1 in room of clinic with therapist	Subtraction accuracy: percentage correct	Concrete and virtual base-10 cube blocks	Prompting and error correction	Virtual 100 % adequate evidence	S1 (I) 100 % (M) 100 % (G) 100 % S2 (I) 100 % (M) 100 % (G) 100 % S3 (I) 100 % (M) 100 % (G) 67 %
						Concrete 100 % adequate evidence	S1 (I) 100 % (M) 100 % (G) 100 % S2 (I) 100 % (M) 100 % (G) 100 % S3 (I) 100 % (M) 100 % (G) 100 %
Burton et al. (2013)	3 males with ASD (13, 14, 15); IQs of 85, 76, and 61	1-1 with teacher or para-professional in self-contained classroom	Money word problems: percentage of accurate steps on task analysis	Bills, cash register	Video self-modeling, task analysis, and reinforcement	100 % strong evidence	S1 (I) 100 % (M) 100 % S2 (I) 100 % (M) 100 % S3 (I) 100 % (M) 100 %
Cihak and Foust (2008)	1 male 2 females with ASD (7, 7, 8); IQs of 45, 50, and 40	1-1 with special ed. teacher in resource room	Accuracy single digit addition: percent correct	TouchMath; number lines	Prompting, reinforcement, modeling	TouchMath 100 % adequate evidence	S1 (I) 91 % (R) 100 % S2 (I) 100 % (R) 100 % S3 (I) 100 % (R) 100 %
						Number lines 100 % adequate evidence	S1 (I) 0 %[a] S2 (I) 60 % S3 (I) 80 %
Cihak and Grim (2008)	2 males, 2 females with ASD (16, 17, 16, 15); IQS of 50, 45, 47, and 35	1-1 in resource room with teacher and with teacher at local store	Independent purchasing: observed percent of independent responses	Counting-on	Modeling, praise (reinforcement), prompting, time delay	100 % strong evidence	S1 (I) 100 % (M) 100 % S2 (I) 100 % (M) 100 % S3 (I) 100 % (M) 100 % S4 (I) 100 % (M) 100 %
Collins et al. (2011)	1 male with ASD (14); IQ of 47	1-1 with special ed. teacher or para-professional in resource room	Accuracy computing sales tax: percentage correct	X	Constant time delay, prompting, differential reinforcement, error correction	0 % weak evidence[b]	S1 (I) 25 % (M) 0 %
Fletcher et al. (2010)	2 males with ASD (13, 14); IQs of 54 and 45	1-1 with special ed. teacher or para-professional in self-contained class	Accuracy single digit addition: percentage correct	TouchMath; number lines	Prompting, reinforcement, modeling	TouchMath 100 % adequate evidence[b]	S1 (I) 100 % (M) 100 % S2 (I) 100 % (M) 100 %
						Number lines 0 % adequate evidence[b]	S1 (I) 85 % S2 (I) 86 %
Holifield, et al. (2010)	2 males ASD (10, 9); IQs of 70 and 39	Independent practice in self-contained classroom with teacher	Accuracy one-digit multiplication or subtraction without regrouping: percentage correct	X	Self-monitoring, vocal cueing, reinforcement	100 % weak evidence	S1 (I) 100 % S2 (I) 0 %[a]

Table 1 (continued)

Study	Participants	Setting	Mathematical-related outcomes	Mathematical intervention components	Behavioral-based intervention components	Success estimates and strength of evidence rating	PND
Jimenez and Kemmery (2013)	2 males with ASD (4, 4) and ID	1-1 or in group of two with special ed. teacher in self-contained classroom	Numeracy skills with 1–10: percentage of skills mastered on *The Early Numeracy Curriculum Assessment*	The *Early Numeracy Curriculum* (theme-based math stories, graphic organizers, manipulatives)	Prompting, reinforcement, corrective feedback, modeling, time delay	100 % weak evidence[b]	S1 (I) 40 % S2 (I) 100 %
Jowett, et al. (2012)	1 male with ASD (5); IQ of 72	1-1 with researcher in home or in classroom (generalization)	Identification, writing of 1–7: total number of correct marks using rating scale	X	Video modeling, prompts fading, chaining, reinforcement	100 % strong evidence	(I) 99 % (M) 100 %
Kamps et al. (1987)	2 males with ASD (9, 11); IQs of 50	1-1 with peer tutor in special education classroom	Accuracy of coin and value identification: frequency of correct probes	X	Reinforcement models, prompting, feedback via peer tutors	100 % weak evidence	S1 (I) 91 % S2 (I) 91 %
Leaf, et al. (2010)	1 male with ASD (5)	1-1 in research setting	Accuracy identifying sums of addition problems: percent correct on probes	X	No-no prompting (correction), Simultaneous prompting (errorless), token economy (reinforcement)	No-no 100 % adequate evidence Simultaneous 25 % adequate evidence	(I) 79 % (I) 56 %
Levingston et al. (2009)	1 male with ASD (10)	1-1 with teacher in general education class	Accuracy of component skills and total solution of multiplication/ division word problems: percentage correct	Breaking down word problems to component math skills; solve and check	Modeling, prompting, error correction, reinforcement	Component skills 100 % adequate evidence Full solution 0 % weak evidence	(I) 100 % (G) 100 % (I) 00 %[a]
McEvoy and Brady (1988)	2 females with ASD (9, 7) and one with co-occurring ID	Independent practice in special education class with teacher and researcher	Fluency on single digit addition and matching numerals to sets: rate of correct problems	X	Contingent reinforcement	100 % weak evidence	S1 (I) 78 % S2 (I) 94 %
Morrison and Rosales-Ruiz (1997)	1 male with autism (5); IQ 36	1-1 in room in home with researcher	Counting objects: percentage of correct responses	High and low preferred Counting objects	Preference assessment, prompting, reinforcement	Preferred 100 % weak evidence Low preferred 0 % weak evidence	NA
Polychronis et al. (2004)	1 male with ASD (7)	1-1 trials during natural opportunities of group lesson; by gen ed. teacher or researcher	Telling time: percentage correct on test trials (and trials to criterion) and percentage correct on naturalistic probes	Cardboard clock	Discrete trials time delay, modeling, errorless learning, error correction, reinforcement	30-min schedule 100 % adequate evidence 120-min schedule 100 % adequate evidence	(I) 100 % (I) 100 %
Rapp et al. (2012)	2 males ASD 1 male		Accuracy of addition facts, multiplication facts, or	X	Reinforcement prompting and error		S1 (I) 100 % S2 (I) 100 %

Table 1 (continued)

Study	Participants	Setting	Mathematical-related outcomes	Mathematical intervention components	Behavioral-based intervention components	Success estimates and strength of evidence rating	PND
	Asperger's and EBD (9, 8, 7) .	1-1 in training room at school with researcher	addition and subtraction: percentage correct		correction with response repetition	MBD participants 100 % weak evidence MBD behaviors 66 % weak evidence	S3 (I) 88 % S1 (I) 94 % S2 (I) 53 % S3 (I) 89 %
Rockwell et al. (2011)	1 female ASD (10); IQ of 79	1-1 in researcher's home	Addition and subtraction word problems: percentage correct	Schema-based instruction; mnemonics, and organizers	Direct instruction with modeling, feedback	100 % strong evidence	(I) 97 % M (100 %) (G) 89 %
Schaefer-Whitby (2013)	2 males ASD, 1 male Asperger's (14, 13, 13); IQs 90, 94, and 107	1-1 in separate classroom with researcher; generalization in general education	Accuracy of word problems: percentage correct on problems from curriculum and state math test	Solve It! Problem Solving Routine (cognitive strategies)	Modeling, prompting, error correction	100 % strong Evidence	S1 (I) 100 % (M) 67 % S2 (I) 100 % (M) 67 % S3 (I) 100 % (M) 00 %
Tiger et al. (2007)	1 male with Asperger's (19)	1-1 in therapy room with therapist in residential day center	Responding on questions of different difficulty (e.g., addition, calculus) percentage correct	X	Differential reinforcement (DR) of shorter response time or of correct responding; token economy	DR Short: 0 % for all questions weak evidence DR Correct compared to DR Short for medium questions: 100 % weak evidence	All questions: (I) 0 %[a] (ceiling levels in baseline for easy and medium) Medium questions (I) 44 %[a] compared to DR short adjacent conditions (ceiling level in 1 of 2 adjacent conditions)
Waters and Boon (2011)	1 male with ASD, 1 male with Asperger's (15, 16); IQs 64 and 64	1-1 with teacher in self-contained classroom	Subtraction 3-digit money problems with regrouping: percentage correct	TouchMath	Modeling; verbal cueing, positive verbal corrective feedback	100 % strong evidence	S1 (I) 100 % (M) 100 % S2 (I) 100 % (M) 100 %
Yakubova et al. (2015)	3 males with ASD (17, 18, 19); IQs 71, 70, 82	1-1 with researcher in separate classroom	Subtraction fraction word problems: percentage correct	Checklist of problem solving steps	Video model of problem solving; self-management	100 % strong evidence	S1 (I) 100 % (M) 100 % S2 (I) 100 % (M) 100 % S3 (I) 100 % (M) 100 %

I intervention, *M* maintenance, *G* generalization, *R* replication, *S1* subject one

[a] Perfect score at least once in baseline

[b] Overall evidence rating would have been higher if including participants without ASD and/or non-mathematics outcomes

Table 2 Coding variables for studies including mathematical engagement outcomes

Study	Participants	Setting	Mathematical-related outcomes	Mathematical-based intervention components	Behavioral-based intervention components	Success estimates and strength of evidence rating	PND
Banda and Kubina (2010)	1 male with ASD (13)	1-1 in resource room with researcher	Mathematics problem initiation: observed latency (s) to starting missing addend problems	X	Behavior momentum: low probability after high probability	100 % adequate evidence	(I) 100 %
Bouck, et al. (2014)	3 males with ASD (6, 7, 10)	1-1 in office or computer room of clinic with therapist	Subtraction problem step completion: percentage of independently completed steps	Concrete base-10 cube blocks and virtual base-10 blocks	Prompting and error correction	Virtual 100 % Adequate evidence	S1 (I) 100 % (M) 100 % (G) 100 % S2 (I) 100 % (M) 100 % (G) 100 % S3 (I) 100 % (M) 100 % (G) 100 %
						Concrete: 100 % adequate evidence	S1 (I) 100 % (M) 100 % (G) 100 % S2 (I) 100 % (M) 100 % (G) 100 % S3 (I) 100 % (M) 100 % (G) 67 %
Cihak et al. (2010)	3 males with ASD (11, 11, 13); IQs of 108, 72, 105	1-1 instruction of device with teacher in general education class; engagement data during whole class lesson	Task engagement (in seat, looking at materials or teacher, writing related to task, complying with instructions within 4 s): percentage of 15-s partial intervals for mathematics lesson	X	Self-modeling picture prompts and self-management via handheld device, modeling, prompting	100 % strong evidence	S1 (I) 100 % S2 (I) 100 % S3 (I) 100 %
Holifield et al. (2010)	2 males ASD (10, 9); IQs of 70 and 39	During independent practice in self-contained classroom with teacher	Attending to task (reading or writing on worksheet, counting, erasing an answer, following directive, or asking or answering a task-related question: percentage of intervals on task with momentary time sampling (10 s) during multiplication or subtraction practice	X	Self-monitoring, vocal cueing, reinforcement	100 % weak evidence	S1 (I) 82 % S2 (I) 100 %
Legge et al. (2010)	2 males ASD (11, 13)	Independent work time in self-contained classroom with math instruction from teacher and self-monitoring training from experimenter	On-task behavior (sitting, looking at assignment, manipulating materials): percentage of intervals on task using momentary time sampling every 2 min during independent math work	X	MotivAider® vibrating reminder, self-monitoring, modeling, feedback, reinforcement, fading	100 % adequate evidence	S1 (I) 100 % (M) 100 % S2 (I) 0 % (M) 100 %

Table 2 (continued)

Study	Participants	Setting	Mathematical-related outcomes	Mathematical-based intervention components	Behavioral-based intervention components	Success estimates and strength of evidence rating	PND
Neely et al. (2013)	1 male with Aspergers (7)	One-on-one in room in participant's home with researcher	Task engagement (looking at assignment, responding to questions or engaging in demand-related conversation): percentage of 10-s whole intervals with engagement while working on double-digit subtraction	X	Least-to-most prompting, reinforcement to complete learning activities using iPad writing application	100 % adequate evidence	S1 (I) 100 %[a] S2 (I) 100 %[a]
Tiger et al. (2007)	1 male with Aspergers (19)	One-on-one in therapy room with therapist in residential day center	Latency to responding to mathematics problems levels (e.g., simple addition, calculus) observed time (s) to answer question	X	Differential reinforcement (DR) of shorter time to respond or correct responding; token economy	DR Short for all questions 100 % weak evidence DR Correct for medium questions 0 % compared to DR short weak evidence	DR Short for all questions (I) 100 % Medium questions: N/A compared to DR Short; all latency measures in DR Short at "0 s"; PND would indicate that 89 % of DR correct data points were "worse than" (i.e., had longer latencies than) adjacent DR Short data

I intervention, *M* maintenance, *G* generalization

[a] Traditional materials phase was considered to be baseline

2011; Tiger et al. 2007), subtraction (Bouck et al. 2014; Holifield et al. 2010; Rapp et al. 2012; Rockwell et al. 2011; Waters and Boon 2011; Yakubova et al. 2015), money or purchasing (Burton et al. 2013; Cihak and Grim 2008; Collins et al. 2011; Kamps, et al. 1987; Waters and Boon 2011), word problems (Burton et al. 2013; Levingston et al. 2009; Rockwell et al. 2011; Schaefer-Whitby 2013; Yakubova et al. 2015), numeracy (Akmanoğlu and Batu 2004; Jimenez and Kemmery 2013; Jowett et al. 2012; Morrison and Rosales-Ruiz 1997), and multiplication and/or division (Holifield et al. 2010; Levingston et al. 2009; Rapp et al. 2012; Tiger et al. 2007). One study involved time (Polychronis et al. 2004), one fractions (Yakubova et al. 2015), and one included problems related to calculus, trigonometry, geometry, and exponential powers (Tiger et al. 2007).

Engagement Seven studies measured engagement. Four measured percentages of intervals in which participants were attending to and/or engaging with lessons and/or materials (Cihak et al. 2010; Holifield et al. 2010; Legge, et al. 2010; Neely et al. 2013). Banda and Kubina (2010) and Tiger et al. (2007) measured latency to start mathematics tasks. Bouck et al. (2014) reported the percentage of completed steps (regardless of accuracy) in problems.

Success Estimates, Strength of Evidence Ratings, and PND

Individual study information can be found in Tables 1 and 2. A list of quality indicators for individual studies is available upon request.

Accuracy Studies Seven studies had success estimates of 100 % for all accuracy outcomes and interventions with strong evidence ratings (Burton et al. 2013; Cihak and Grim 2008; Jowett et al. 2012; Rockwell et al. 2011; Schaefer-Whitby 2013; Waters and Boon 2011; Yakubova et al. 2015), and three had success estimates of 100 % for all outcomes and interventions with adequate ratings (Akmanoğlu and Batu 2004; Bouck et al. 2014; Polychronis et al. 2004). The median PND for these 10 studies was 100 % (range 97 to 100 %), with all results in the "very effective" range (Scruggs and Mastropieri 1998). An additional three studies had adequate ratings and showed 100 % success estimates with one intervention, with a second intervention demonstrating success ratios of 0 to 66 % (Cihak and Foust 2008; Fletcher et al. 2010; Leaf et al. 2010). The median PND for the interventions with 100 % success estimates in these three studies was 100 % (range 79 to 100 %; effective to very effective), and those without 100 % success estimates had a median PND of 70 (range 0 to 86 %; ineffective to effective). Levingston et al. (2009) had an adequate rating with a 75 % success estimate for problem component skills (PND of 100 %), and 0 % success estimated for the full solution (PND of 0 %). "Unsuccessful" implementations were due to increases in baseline prior to intervention that could have been the result of generalization/facilitation effects (Horner and Baer 1978) from learning component skills. We gave adequate ratings primarily because studies did not receive high quality ratings on one to two primary indicators. For instance, Fletcher et al. (2010) was rated as adequate due to the presence of only two demonstrations of the effect for participants with ASD (strong evidence if including participant without ASD).

Eight studies were given weak ratings (Collins et al. 2011; Holifield et al. 2010; Jimenez and Kemmery 2013; Kamps et al. 1987; McEvoy and Brady 1988; Morrison and Rosales-Ruiz 1997; Rapp et al. 2012; Tiger et al. 2007). The median PND for these studies (excluding Morrison and Rosales-Ruiz 1997) was 90 % (range 0–100 %), indicating results ranging from *ineffective* to very effective. Success estimates were either 100 % (Holifield et al. 2010; Jimenez and Kemmery 2013; Kamps et al. 1987; McEvoy and Brady 1988), 0 % (Collins et al. 2011; Morrison and Rosales-Ruiz 1997) or differed based upon intervention or design (100 and 66 % for different designs in Rapp et al. 2012; 100 % for one form of differential reinforcement of correct responding and 0 % for differential reinforcement of shorter response time in Tiger et al. 2007). Studies rated as "weak" had only one secondary indicator (Holifield et al. 2010; Kamps et al. 1987; McEvoy and Brady 1988; Morrison and Rosales-Ruiz 1997; Tiger et al. 2007) and/or were rated as "high quality" on fewer than four primary indicators (Collins et al. 2011; Jimenez and Kemmery 2013; Kamps et al. 1987; Morrison and Rosales-Ruiz 1997; Rapp et al. 2012; Tiger et al. 2007). Six of these studies (excluding Collins et al. 2011; Jimenez and Kemmery 2013) lacked procedural integrity measures, and five (excluding Collins et al. 2011; Jimenez and Kemmery 2013; Rapp et al. 2012) did not measure generalization, maintenance, or social validity. Jimenez and Kemmery (2013) were rated as having weak evidence for two participants with ASD (including participants without ASD, the study would have adequate evidence). Collins et al. (2011) included participants without ASD, but an effect for mathematics outcomes was only demonstrated for one of these participants.

Engagement Studies Two studies had 100 % success estimates, intervention PND scores of 100 %, and strong ratings (Banda and Kubina 2010; Cihak et al. 2010). Three had 100 % estimates and adequate ratings (Bouck et al. 2014; Legge et al. 2010; Neely et al. 2013) with two also having 100 % PND scores for all intervention phases (Bouck et al. 2014; Neely et al. 2013). For Legge et al. (2010), although visual analyses indicated that the intervention was effective for two participants, PND scores were 0 and 100 %. Holifield et al. (2010)) was rated as having weak evidence of a 100 % success ratio and PND scores of 82 and 100 %. Tiger et al. (2007) was rated as having weak evidence with a 100 % success estimate for differential reinforcement of shorter response time (PND of 100 %) and 0 % for differential reinforcement of correct responding (PND was not applicable; see Table 2) for decreasing latency to start a task. Adequate ratings were given because studies did not have high quality ratings on all primary indicators. Studies with weak evidence had only one secondary indicator.

Intervention Components of Accuracy Studies

Thirteen studies described mathematics-based intervention components. Studies utilized visual representations such as "touch points" from Bullock, Pierce, and McClellan's (1989) TouchMath© currricula (Cihak and Foust 2008; Fletcher et al. 2010; Waters and Boon 2011), number lines (Cihak and Foust 2008; Fletcher et al. 2010), and skill-specific manipulatives such as base-ten blocks, dollar bills, counting objects, and cardboard clocks (Bouck et al. 2014; Burton et al. 2013; Jimenez and Kemmery 2013; Morrison and Rosales-Ruiz 1997; Polychronis et al. 2004). Strategy instruction included counting-on (Cihak and Grim 2008) and methods for breaking down word problems (e.g., mnemonics, organizers, recognition of component steps; Levingston et al. 2009; Rockwell et al. 2011; Schaefer-Whitby 2013; Yakubova et al. 2015). Schaefer-Whitby (2013) used problem solving strategies derived from Montague's (2003) *Solve It! Problem Solving Routine curriculum*. Jimenez and Kemmery (2013) utilized a scripted curriculum *The Early Numeracy Curriculum* (Jimenez et al. 2013). In contrast, all 22 studies utilized one or more identified behavioral strategy. Common methods included reinforcement ($n=17$ studies), prompting ($n=13$ studies), modeling or video modeling ($n=12$ studies), error correction ($n=9$ studies), and time delay ($n=4$ studies). Additional methods (e.g., self-management, errorless learning) can be found in Table 1.

Most of the studies (i.e., 10 of 13) with strong or adequate evidence, 100 % success estimates, and PND scores in the effective to very effective range for at least one intervention utilized a combination of behavioral and mathematical components. For instance, successful studies combined behavioral strategies such as prompting and reinforcement with skill-specific manipulatives (Bouck et al. 2014; Burton et al. 2013; Polychronis et al. 2004), TouchMath© representations (Cihak and Foust 2008; Fletcher et al. 2010; Waters and Boon 2011), and mathematics strategy instruction (Cihak and Grim 2008; Rockwell et al. 2011; Schaefer-Whitby 2013). Two interventions using only behavioral strategies were supported by 100 % success estimates and adequate or strong ratings for early numeracy skills (Akmanoğlu and Batu 2004; Jowett et al. 2012). Leaf et al. (2010) had an adequate rating and a 100 % success estimate for using error correction to teach sum identification, but errorless learning had only a 25 % estimate.

Intervention Components of Engagement Studies

Of the seven studies that included engagement measures, only one (with adequate evidence, 100 % success estimates and PND score of 100 %) included mathematics-specific intervention components (base-ten blocks) combined with behavioral strategies (Bouck et al. 2014). The remaining six studies used behavioral strategies alone (with four studies having 100 % success estimates and adequate to strong evidence, and two studies having weak evidence). Common behavioral strategies included prompting ($n=4$ studies) reinforcement ($n=3$ studies), self-management ($n=2$ studies), and modeling ($n=2$ studies).

Discussion

Results of this review indicate that the majority of successful mathematics accuracy interventions included both behavioral and academic components, and some interventions with behavioral-only components were successful for increasing engagement or early numeracy skills. Several conclusions can be drawn based on the specific research aims of this review. First, in terms of participant characteristics, many studies failed to report on intellectual abilities of all participants, and the vast majority of studies failed to report information on grade-level mathematics performance. Examining cases where information on intellectual functioning was reported, it appeared that the majority of research has focused on teaching targeted foundational mathematics skills and concepts to participants with ASD and co-occurring ID. A more limited amount of research has focused on individuals with HFA and/or examining more complex mathematics skills (e.g., word problems). Across the majority of participants and studies, interventions tended to occur in restricted contexts (e.g., one-on-one instruction, self-contained classrooms).

In terms of intervention success, 13 of the 22 studies with accuracy outcomes had 100 % success estimates for at least one intervention, PND scores in the effective to very effective range, and evidence ratings of at least adequate. Five studies with engagement outcomes had 100 % success estimates and at least adequate evidence, and PND scores indicating very effective interventions for the majority of participants. Regarding intervention components, all 26 studies included behavioral intervention components and only 13 included mathematics-specific components. However, successful interventions for accuracy with at least adequate evidence most commonly incorporated both behavioral and mathematics instructional components (i.e., 10 of the 13 studies with 100 % success estimates, effective to very effective PND scores, and at least adequate evidence). Although some interventions using only behavioral strategies provided adequate to strong evidence of positive results for numeracy outcomes, the majority of studies using behavioral strategies alone for accuracy had weak evidence ratings. For engagement, however, four studies using behavioral methods alone had 100 % success estimates with at least adequate evidence. Despite review limitations (e.g., evidence ratings discounted participants without ASD, additional components such as use of technology not synthesized), these conclusions provide important implications for both practice and research (as discussed in the following section).

Practical Implications

Given differences in interventions and outcomes, it is difficult to recommend one specific intervention for use across individuals with ASD (similar to findings from Wong et al. 2014). Interventions supported by adequate to strong evidence with 100 % success estimates and PND scores indicating effective to very effective interventions, should be considered for practical use, with individualized modifications as necessary. These methods included combining behavioral strategies such as prompting, reinforcement, modeling, and error correction with skill-specific manipulatives (e.g., base-ten blocks), touch points from TouchMath©, and mathematics strategy instruction (e.g., counting-on, methods for remembering word problem steps). Behavioral methods alone (e.g., modeling with prompting and reinforcement) may be useful for simple numeracy skills. Behavioral methods such as self-management may, in some cases, also be successful for promoting engagement.

As predicted, behavioral intervention components utilized with individuals with ID were also included in successful interventions for individuals with ASD and ID. Similarly, strategies used for individuals with LD (e.g., strategy instruction) were often included in successful interventions for individuals with HFA. More importantly, however, combinations of these strategies appeared to be the most effective across participants with ID and HFA, suggesting important implications for how interventions are designed for individuals with ASD and a range of intellectual abilities. Additionally, findings from this review suggest that explicit, systematic one-on-one interventions that target specific skill mathematics areas for individuals are often effective. Intervention procedures in reviewed studies also suggest that repeated practice and rehearsal with these specific targeted skills are recommended. In the absence of more specific recommendations, practitioners should utilize evidence-based mathematics practices (e.g., manipulatives, strategy instruction), and, as needed, modify utilizing evidence-based practices for ASD (see Wong et al. 2014).

Recommendations for Future Research

In terms of participant characteristics, limited information on intellectual and academic functioning, and ASD severity of participants, makes it difficult to determine whether different methods are necessary for individuals with different characteristics. Efforts should be made to provide more information on these variables. Similar to findings of Browder et al. (2008), studies with participants identified with ID, or IQs within the ID range, were often taught basic computation, numeracy, and/or functional skills. Although interventions combining behavioral-based components and mathematics components (and some with behavioral components alone) were successful for this population, research is needed to replicate findings for specific interventions and mathematics outcomes, and to explore interventions teaching more complex skills to this population. A smaller number of studies involved individuals with HFA or individuals with an IQ in a borderline range (IQs 75–79). Of note, all of these studies that included accuracy outcomes, involved word problems (an area of concern for this population; Donaldson and Zager 2010; Schaefer- Whitby et al. 2009). Although strategies found to be effective for individuals with learning disabilities (e.g., visual representations, strategy instruction, Gersten et al. 2009) also had evidence of success with individuals with ASD and IQs of 75 and above (Burton et al. 2013; Rockwell et al. 2011; Schaefer-Whitby 2013) the small number of participants limits recommendations. Future researchers should recruit participants with HFA and assess a variety of mathematics skills.

Information garnered on settings suggests the need for intervention research that can be easily adapted to general education settings, as a majority of school-based studies were conducted in a one-on-one instructional context in a self-contained class or separate room. There was limited research utilizing comprehensive curricular programs common to general education and group contexts. Thus, although research supports targeted one-on-one interventions, future researchers should evaluate small and/or large group interventions in inclusive settings.

In addition to the need for research examining more complex math skills, given the paucity of studies examining mathematics engagement, future research in this area is needed. Although studies excluded from this review have measured engagement across multiple academic areas, to understand the effects on specific areas, disaggregated data is needed. The lack of studies including mathematics intervention components for engagement outcomes also limits the knowledge base. For instance, it is possible that manipulatives could increase engagement with certain tasks. Further examination of how behavioral methods might differentially effect accuracy and task initiation are also necessary (Tiger et al. 2007).

In terms of the evidence-based mathematics interventions for individuals with ASD, although it is promising that a majority of studies were effective and rated as having adequate to strong evidence, weak evidence ratings for eight studies demonstrates a need for researchers in this area to include more quality indicators. It should be noted, however, that some studies rated as “weak” would have had stronger ratings if participants without ASD were included in the ratings. Although it is important to demonstrate the utility of interventions across individuals with varying disabilities, given the unique characteristics of ASD, it is also necessary to demonstrate whether intervention effects can be replicated within this specific population. Additionally, although aspects of Reichow et al.'s (2008) rating criteria may be stringent, the system provides a rigorous assessment of intervention research for individuals with ASD. Perhaps unsurprisingly, therefore, studies with adequate to strong evidence consistently had positive success estimates and PND scores in the effective to very effective range; success ratios and PND were more variable across studies with weak evidence. The majority of studies rated as having weak evidence did not include measures of procedural integrity, generalization, maintenance, and social validity. These are areas that future researchers should assess.

The use of ABA components (in particular prompting, modeling, error correction, and reinforcement) in effective academic interventions supports findings by Wong et al. (2014). Such methods appeared to be particularly successful when combined with evidence-based mathematics instructional components such as the use of manipulatives and explicit strategy instruction. Unfortunately, however, as discussed earlier, the current body of research may limit generality of results to individuals with a variety of characteristics, to a variety of mathematics outcomes, or to group and/or inclusive interventions. Additionally, current research does not delineate critical components of successful interventions. Although many academic interventions and curricula inherently include behavioral components such as modeling and error correction, it is not clear whether more individualized methods (prompting, learner specific reinforcement) would be needed in all cases. Furthermore, interventions that included behavioral methods and certain mathematics-based strategies (e.g., number lines; Cihak and Foust 2008; Fletcher et al. 2010) were not universally successful. Component analyses (e.g., introducing an intervention with mathematics-only components and systematically introducing and/or removing behavioral strategies to isolate effects) are necessary. As many studies rated as having weak evidence examined behavioral strategies alone, evaluations of such interventions with stronger methods are needed. Finally, additional procedural information from authors may aid in the ability to accurately identify/confirm the validity of behavioral intervention components. For instance, some studies that described using "reinforcement" (and were coded as such) did not describe whether preference and/or reinforcer assessments were conducted.

Ultimately, continued single subject research exploring targeted mathematics interventions for individuals with ASD will allow for more extensive practical recommendations for a variety of individuals and outcomes. Additionally, the evaluation of comprehensive mathematics programs for individuals with ASD (utilizing single subject designs as well as group design methodologies) is an important next step in determining inclusive evidence-based practices.

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