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Math Interventions for Students With Autism Spectrum Disorder: A Best-Evidence Synthesis

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Abstract
Educators need evidence-based practices to assist students with disabilities in meeting increasingly rigorous standards in mathematics. Students with autism spectrum disorder (ASD) are increasingly expected to demonstrate learning of basic and advanced mathematical concepts. This review identifies math intervention studies involving children and adolescents with ASD and describes participant characteristics, methodological features, interventions, target behaviors, and related outcomes. Included studies met the design standards of the What Works Clearinghouse (2014). Studies focused on functional and computational skills for students with a comorbid diagnosis of intellectual disability (ID). Visual analysis confirmed a functional relation between evaluated interventions and mathematics outcomes in 71% of cases. Interventions generally yielded moderate to large effect sizes. Large confidence intervals were obtained across effects. More high-quality research including students with higher-functioning ASD is required to fully address the needs of this population.

The adoption of the Common Core State Standards in mathematics (CCSS-M; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) represents a concerted effort by states to provide students with the necessary skills for college and other career opportunities in science, technology, engineering, and mathematics (STEM) fields. Specifically, the CCSS-M places a greater focus on algebra, geometry, and conceptual understanding of math concepts than state standards or the National Assessment of Educational Progress (NAEP) Mathematics Framework (Hughes, Daro, Holtzman, & Middleton, 2013). In addition to improving educational outcomes, the CCSS-M are designed to improve the historically grim postsecondary outcomes for individuals with disabilities through the extension of new opportunities in higher education and employment (Kearns et al., 2010). Within the context of increased subgroup education accountability, the CCSS-M constitutes an unprecedented increase in the math performance expectations for all students, including students with disabilities.

Increased expectations have produced limited results (Wei, 2012). Students with disabilities in Grades 3 to 7 exhibit lower achievement and growth in mathematics than students without disabilities (Schulte & Stevens, 2015). Likewise, NAEP mathematics achievement levels of students with disabilities from 2007 to 2013 have remained flat, with approximately 80% of students scoring below proficiency (NAEP, n.d.). Narrowing the gap between the new expectations in mathematics (i.e., CCSS-M) and the actual performance of students with disabilities will require targeted remediation in mathematics and the development of new instructional

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approaches (Fuchs et al., 2015; Powell, Fuchs, & Fuchs, 2013).

Autism spectrum disorder (ASD) encompasses a range of developmental disabilities characterized by issues in communication, social interaction, and executive functioning (American Psychiatric Association, 2013). Children with ASD exhibit a highly variable functional and cognitive profile (Centers for Disease Control and Prevention [CDC], 2012). Intellectual disability (ID) is diagnosed in 30% of children with ASD; however, 46% have an average or above-average IQ (CDC, 2012). According to a report issued by the U.S. Department of Education (USDOE; 2014), ASD represents 7.6% of students receiving special education services and is the fastest-growing disability category identified under the Individuals With Disabilities Education Act (IDEA). Of children identified with ASD, approximately 40% receive the majority of their instruction (i.e., >80%) in the general education classroom setting.

Narrowing the gap between the new expectations in mathematics (i.e., CCSS-M) and the actual performance of students with disabilities will require targeted remediation in mathematics and the development of new instructional approaches.

The math achievement profile of students with ASD is—like the diagnosis itself—highly variable. Large-scale assessments of children with ASD have revealed patterns of both over- and underachievement in literacy and mathematics relative to general cognitive ability (Charman et al., 2011). An examination of growth trajectories of children receiving special education services suggested that students with ASD perform significantly worse than students with learning disabilities on calculation and applied mathematics problems (Wei, Lenz, & Blackorby, 2012). Although the majority of students with high-functioning ASD (HFASD) have average mathematical ability, many exhibit general deficits in mathematics relative to their intelligence (Chiang & Lin, 2007). A longitudinal analysis of children with ASD between the ages of 6 and 9 years conducted by Wei, Christiano, Yu, Wagner, and Spiker (2014) identified distinct profiles of mathematical performance, with 39% of children exhibiting average achievement across academic domains and 20% exhibiting average or above-average skill in mathematics while scoring below the national average on other tests of achievement. This variability continues well into adulthood, as individuals with ASD, upon attending college, are more likely to pursue majors in math yet remain at a high risk for unemployment and are less likely than other individuals with disabilities to attend college (Migliore, Timmons, Butterworth, & Lugas, 2012).

Purpose

Despite the emphasis on evaluating the efficacy of mathematics interventions for students with disabilities (e.g., Gersten et al., 2009), a synthesis of outcomes from high-quality research studies targeting students with ASD has yet to be published. Syntheses of academic interventions have the potential to guide the work of future researchers. In addition, students with ASD are a growing and heterogeneous population whose instructors would benefit from an overview of effective mathematics instruction. The range of mathematic achievement within ASD suggests that many students with ID may benefit from systematic prompting interventions used to teach functional skills for students with significant cognitive disabilities (Browder, Spooner, Ahlgrim-Delzell, Harris, & Wakeman, 2008). Students with HFASD, in contrast, generally possess average or above-average skills in numerical operations, counting, and number facts but often struggle with critical thinking and analytical skills required to solve higher-order problems (Siegel, Goldstein, & Minshew, 1996).

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As students with ASD increasingly receive instruction in the general education classroom setting, experimental inquiry must extend beyond the behavioral and social issues predominantly emphasized in extant research (Browder et al., 2008). The purpose of this review was to evaluate the characteristics (e.g., participants) and findings of mathematic interventions with sufficient methodological rigor to demonstrate effectiveness for students with ASD. Rigorous scientific research is increasingly viewed as the appropriate source for effective education practices (Cook & Odom, 2013). The What Works Clearinghouse (WWC; 2014), the primary research evaluation initiative established by the USDOE, developed a series of guidelines for evaluating experimental research. The WWC recommends excluding studies that do not meet essential methodological criteria from research syntheses. As research of limited quality can result in misplaced resources and instructional time, best-evidence syntheses of academic interventions for students with ASD will prove most beneficial to practitioners searching for effective teaching strategies and researchers attempting to make further contributions to the field (Slavin, 1995).

Research Questions

The research questions guiding this synthesis were: What are the features of high-quality empirical studies published in peer-reviewed journals in which the efficacy of math interventions was evaluated for students with ASD? Specifically, (a) what are the demographic characteristics of participants, (b) what methodological features have been used (e.g., generalization measures), (c) what types of interventions and target skills have been evaluated, and (d) how effective are the identified interventions in enhancing math outcomes for students with ASD?

Method

We addressed the research questions using a literature evaluation process consisting of multiple stages. First, we conducted a systematic search for research articles involving math interventions for students with ASD. As the inclusion of studies with insufficient methodological rigor that do not adequately control for the influence of confounding variables undermines conclusions of literature syntheses, we then evaluated the quality of studies identified in the initial search. Studies were included in the final sample after meeting minimum quality standards (WWC, 2014). Next, we coded the methodological features of articles with indicators adapted from previous reviews of research in math (e.g., Xin, Grasso, Dipipi-Hoy, & Jitendra, 2005; Xin & Jitendra, 1999). Finally, we summarized the effectiveness of the included studies.

Literature Search

Articles included in the initial sample were identified through a three-step process, including a database search, an ancestral search, and a hand search. Using PsycINFO, PsycARTICLES, and ERIC computer databases, we identified all peer-reviewed articles that included in the abstract (a) all possible truncations of *addition, arithmetic, basic facts, cardinality, count, decimals, division, fractions, geometry, math, measurement, money, multiplication, number conservation, number sense, numerals, percent, place value, algebra, problem solving, ration, seriation, subitizing, subtraction, symbol identification, telling time, word problems*, and *instruct, intervention, learn, teach*, or *train* and (b) all possible truncations of *autism* located anywhere in the article. The search generated 1,922 articles. The search record and, when necessary, full text were evaluated to determine if studies met the following inclusionary criteria:

1. Published in an English-language, peer-reviewed journal before May 2014.
2. Included participants explicitly identified as having a diagnosis of ASD (e.g., pervasive developmental disorder not otherwise specified [PDD-NOS]). Author report of the disability status of participants, rather than formal screening, was sufficient for inclusion.
3. Provided quantitative data directly related to the math skills of students with ASD. Case studies, task analyses featuring steps unrelated to mathematics

(e.g., Burton, Anderson, Prater, & Dyches, 2013), studies concerning compliance (e.g., Banda & Kubina, 2010), and research designs that did not disaggregate data for participants with ASD (e.g., Hua, Morgan, Kaldenberg, & Goo, 2012) were excluded. Single-case designs that included students without ASD or evaluated other skills in addition to math performance (i.e., using a multiple-baseline-across-behaviors design) were included, provided data pertaining to the performance of individual students with ASD on math tasks were presented.

4. Evaluated the efficacy or effectiveness of a mathematics intervention administered in the context of an experimental group or single-case design.

Of the 1,922 original articles, 21 satisfied the criteria for inclusion. An ancestral search of identified articles and relevant literature reviews (e.g., Browder et al., 2008; Hord & Bouck, 2012) identified three additional articles. One additional article was identified through a hand search of articles published between 2011 and 2014 in the following journals: *Education and Training in Autism and Developmental Disabilities, Education and Treatment of Children, Exceptional Children, Focus on Autism and Other Developmental Disabilities, Journal of Applied Behavior Analysis, Journal of Autism and Developmental Disorders*, and *Research in Autism Spectrum Disorders*. The three-step literature search resulted in the identification of 25 articles that met initial inclusionary criteria.

Evaluation of study quality. Two independent reviewers applied the quality indicators developed by the WWC (2014) to the initial sample of articles. Studies that did not meet minimum quality standards were excluded. The sole quasiexperimental group-design study identified in the initial search (Su, Lai, & Rivera, 2010) did not establish baseline equivalence in the characteristics of treatment and control groups and was removed from consideration.

To ensure that our synthesis included findings from experimental studies of sufficient rigor, we excluded studies that did not meet the pilot standards established by the WWC (see Figure 1). The WWC guidelines for single-case design identify the case as the individual participant or group of participants necessary to analyze the relationship between an independent variable and an outcome measure (e.g., a student in a reversal design; three students in a multiple-baseline-across-participants design). Per WWC guidelines, we applied quality indicators and codes of study features to individual cases (e.g., reversal design graphs) featured within articles. Thus, in articles that contained multiple cases, we coded only those cases that met minimum quality standards. Single-case designs with errors in graphical display—such as improperly aligned or mislabeled axes—that prevented accurate interpretations of findings were also eliminated.

Search procedures identified 57 cases across 24 articles. We excluded data from 29 cases reported across 10 articles due to a failure to meet minimum quality standards (Akmanoglu & Batu, 2004; Ault, Wolery, Gast, Doyle, & Eizenstat, 1988; Collins, Hager, & Galloway, 2011; Haring, Breen, Weiner, Kennedy, & Bednersh, 1995; Holifield, Goodman, Hazelkorn, & Heflin, 2010; Morrison & Rosales-Ruiz, 1997; Rapp et al., 2012; Tiger, Bouxsein, & Fisher, 2007; Waters & Boon, 2011; Whitby, 2013). Primary reasons for exclusion included insufficient number of experimental phases (i.e., fewer than three replications) and limited overlap of baseline and intervention data points in multiple-baseline designs. This resulted in a final sample of 28 total cases reported in 14 articles (see Table 1). Identified articles originally appeared in eight journals.

Coding Procedures

We coded articles across a range of attributes. Codes pertained to demographic characteristics of participants and the methodological features of studies. Interventions and target skills were also evaluated. The detailed coding

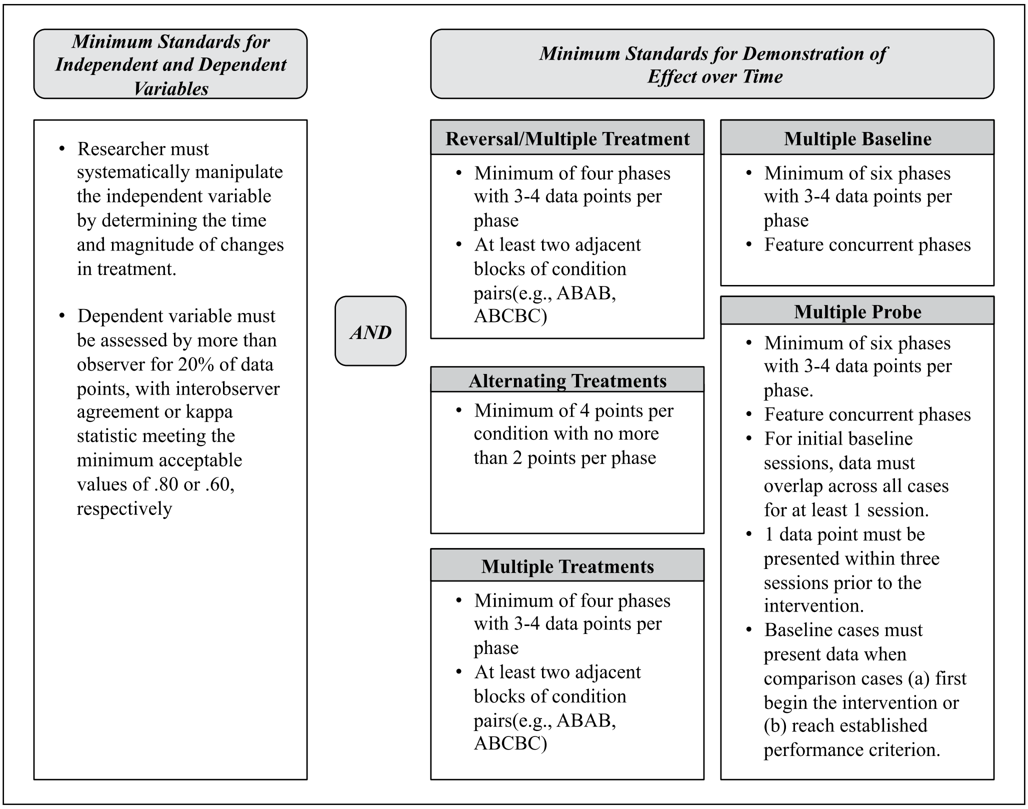

Figure 1. Overview of the What Works Clearinghouse design standards for single-case research.
Note. Adapted from What Works Clearinghouse (2014).

protocol with expanded definitions of terms is available from the first author.

Demographic characteristics. Demographic codes pertained to the age, gender, and primary ASD diagnosis of study participants. Additional diagnoses reported by the authors were also coded. ID status was determined through either author nomination or presentation of IQ scores. Participants under the age of 8 years were coded as having ID provided the authors reported (a) cognitive standard scores of less than 70 or (b) a cognitive mental-age-equivalent score more than 1 year lower than the participant's chronological age. The extent to which children participated in general education was coded based on the reported educational placement. Students who participated in the general education curriculum for more than 50% of the school day were categorized as participating in general education.

Methodological features. We coded the research design and other factors associated with the methodology of the identified studies. Research designs, including ABAB; multiple baseline or probe across participants, behaviors, or contexts; and alternating treatments, were categorized in accordance with descriptions provided by Gast and Ledford (2014). Additional codes described the extent to which authors reported social validity, procedural fidelity, and data related to the generalization and maintenance of targeted skills. Specifically, social validity codes indicated whether the author assessed the appropriateness of independent variables, targeted skills, and outcomes through surveys (e.g., questioning the teacher regarding student improvement), normative comparisons (e.g., placing participant performance in the context of typically developing peers), or blind coding of videos (e.g., blind observers

Table 1. Summary of Articles Concerning Mathematics Instruction for Children With Autism Spectrum Disorder.

Citation	Design	*n*	Mean age (*SD*)	Session duration/ frequency	Study duration	Skills	Intervention	Setting	Interventionist
Adcock & Cuvo (2009)[a]	MBB	3	8.3 (1.2)	20 min; 3–5 times per week	16–24 sessions (M = 19.3, SD = 3.4)	Addition, subtraction, multiplication, time, money (value)	Students received rewards and most-to-least prompting during measurement sessions; assignments featured interspersed tasks to increase student engagement	Resource room	Researcher
Bouck, Satsangi, Doughty, & Courtney (2014)	ATD	3	7.7 (1.7)	Not reported	30 sessions (approximate), plus pretraining	Subtraction	Instruction featuring least-to-most prompting in completing subtraction problems with concrete and computerized manipulatives	Clinic	Teacher
Cihak & Foust (2008)	ATD	3	7.3 (0.5)	5–20 min; 2 times per day	29–39 sessions (M = 33.7, SD = 4.1), plus pretraining	Addition	Instruction outside of the measurement context in completing addition problems using a number line and touch points; students received praise and least-to-most prompting during measurement sessions	Resource room	Teacher
Cihak & Grim (2008)	MPB	4	16 (0.8)	1–2 times per day	34–58 sessions (M = 45, SD = 5)	Money (purchasing)	Strategy instruction in producing specific monetary values using the counting-on strategy; students received least-to-most prompting and rewards for correct responses during measurement sessions	Classroom; community	Teacher

(continued)

Table 1. (continued)

Citation	Design	*n*	Mean age (*SD*)	Session duration/ frequency	Study duration	Skills	Intervention	Setting	Interventionist
Fletcher, Boon, & Cihak (2010)	ATD	2	13.5 (0.5)	5–15 min; 2 times per day	24–28 sessions (*M* = 26, *SD* = 2), plus pretraining	Addition	Instruction in completing addition problems using a number line and touch points (i.e., TouchMath); students received praise and least-to-most prompting	Self-contained	Teacher
Gardill & Browder (1995)[b]	MBP	1	12	Not reported	39 sessions	Money (purchasing)	Student received faded stimulus prompts, praise, and constant-time delay prompting during measurement sessions	Classroom; community	Not reported
Jimenez & Kemmery (2013)[b]	MPP	2	Not reported	Not reported	13 biweekly assessment sessions (*M* = 11.5, *SD* = 1.5)	Rote and object counting (1–10), symbol use, calendar skills, cardinality, addition with objects, measurement	Students received story-based math lessons involving praise, number lines, constant-time delay prompting, and manipulatives	Self-contained	Teacher
Jowett, Moore, & Anderson (2012)	MPB	1	5.5	Not reported	65 sessions	Number and quantity identification (1–7)	Video modeling and prompting	Home; classroom	Researcher
Kamps, Locke, Delquadri, & Hall (1989)[a]	MPB	1	9	20 min; 3 times per week	61 sessions	Money (value)	Students received peer mediated instruction featuring modeling, prompting, and praise	Self-contained	Teacher; peer

(continued)

Table 1. (continued)

Citation	Design	*n*	Mean age (*SD*)	Session duration/ frequency	Study duration	Skills	Intervention	Setting	Interventionist
Levingston, Neef, & Cihon (2009)	MBB	1	10	10-15 min; 5 times per week	14 probe sessions, plus training	Word problems, steps in identifying operation, and calculating answer (multiplication and division)	Strategy instruction involving use of specific steps in solving word problems; students received modeling and prompting outside of the measurement context	Inclusive classroom	Researcher
McEvoy & Brady (1988)	ABAB	2	8 (1)	10 min	47–51 session (*M* = 49, *SD* = 2)	Fluency: addition and quantity identification (one to two pictures, correct and incorrect)	Contingent access to toys following independent completion of math problems	Self-contained	Teacher
Polychronis, McDonnell, Johnson, Risen, & Jameson (2004)	ATD	1	7	Average 4 trials distributed over 30- and 120-min instructional periods	10 sessions; 7 weeks	Telling time	Strategy instruction consisting of constant-time delay prompting and contingent praise; compared training trials ($n \approx 4$) distributed within 30-min and 120-min period	Inclusive classroom	Teacher

(continued)

Table 1. (continued)

Citation	Design	*n*	Mean age (*SD*)	Session duration/ frequency	Study duration	Skills	Intervention	Setting	Interventionist
Rockwell, Griffin, & Jones (2011)	MPB	1	10.25	45 min; 4 times per week	8 weeks	Word problems (addition/ subtraction)	Strategy instruction in identifying and completing word problems featuring modeling, prompting, graphic organizers, and a heuristic for memorizing steps	Clinical	Researcher
Weng & Bouck (2014)	MPP	3	15.7 (0.9)	Not reported	21 sessions	Money (value); selecting inexpensive items	Student received video prompts and most-to-least prompting	School; community	Researcher

Note. ABAB = reversal design; ATD = alternating treatment design; MBB = multiple baseline across behaviors; MBP = multiple baseline across participants; MPB = multiple probe across behaviors; MPP = multiple probe across participants.
[a]Indicates design included nonmath behaviors. [b]Indicates design included participants without ASD.

rate significance of recorded depictions of participant behavior). Fidelity codes were used to indicate the presence or absence of data related to implementation integrity of the independent variable (e.g., checklists, direct counts of treatment behaviors; Ledford & Wolery, 2013). Generalization codes were assigned to studies in which the target skills were applied to tasks or within settings in which the participants had received no training. Maintenance codes referred to studies in which outcomes were measured in the absence of all elements of the intervention.

Intervention and target skills. Intervention codes pertained to both the instructional techniques and delivery mechanisms employed exclusively within the intervention conditions of the identified studies. We also categorized the general skill targeted for intervention in each of the studies in accordance with categories featured in previous reviews (e.g., Gersten et al., 2009; Jitendra & Xin, 1997). Descriptions of the codes used for instructional techniques and targeted skills appear in Table 2.

Analysis of Treatment Outcomes

Single-case design typically relies on visual analysis and graphical display, prompting various researchers to find fault in both parametric (e.g., Shadish, Hedges, & Pustejovsky, 2014) and nonparametric (e.g., Wolery, Busick, Reichow, & Barton, 2010) effect sizes for single-case research. Regardless, the WWC (2014) has expressed an interest in ultimately establishing a quantitative measure of single-case effects. Due to the uncertainty surrounding the quantification of single-case design, multiple estimates of treatment effect were calculated for each study. Maintenance and generalization data were excluded from effect size calculations.

Treatment efficacy was initially assessed through visual analysis of individual cases (Gast & Ledford, 2014). We then applied nonparametric procedures due to their frequent use in meta-analyses of single-case research and applicability across a range of single-case designs (e.g., Vannest, Davis, Davis, Mason, & Burke, 2010). Data were extracted from graphs in accordance with procedures described by Parker, Hagan-Burke, and Vannest (2007). In order to determine the consistency of findings, three nonoverlap effect sizes (Parker, Vannest, & Davis, 2011) were calculated, specifically, percentage of nonoverlapping data (PND), improvement rate difference (IRD), and Tau-U. A Pearson product-moment correlation coefficient was computed to assess the relationship between outcome variables.

Visual analysis. We visually analyzed the phases (e.g., baseline, treatment) from each case to code the presence or absence of a functional relation. A functional relation was defined as a consistent change in the dependent variable across a minimum of three applications of the independent variable. We evaluated within-phase factors related to observed and expected level of performance, such as data level, trend, and variability (see Gast & Ledford, 2014; WWC, 2014). Additional factors, such as the immediacy of change following the introduction of the independent variable, the proportion data overlap between phases, and consistency of data patterns within conditions, were also evaluated.

PND. Although subject to a range of issues, PND—the proportion of treatment values that surpass the highest baseline data point—was selected due to its close alignment with visual analysis and historic association with single-case research (Gast & Ledford, 2014). PND for reversal and multiple-baseline designs was calculated using extracted values by (a) evaluating the range of baseline values, (b) counting the number of intervention data points outside of the range of baseline values, and (c) dividing these data points by the total number of data points in intervention and multiplying by 100. For alternating-treatment designs, PND was derived through individual comparisons of each data point across conditions. Large, moderate, and negligible effect sizes are associated with PND values of >70%, 50% to 70%, and <50%, respectively.

IRD. Adapted from risk reduction or risk difference calculations used in medicine, IRD

Table 2. Description of Coding Categories.

Category	Description
Instructional techniques	
Prompting	The provision of verbal, gestural, or physical assistance designed to produce correct responding delivered in a systematic (e.g., constant-time delay) or unspecified manner
Representational	Tangible or electronic manipulatives, number lines, graphic organizers, or figures used to demonstrate mathematical concepts
Video based	The use of video media to teach math skills
Computer assisted	Computers used for any purposes other than video recording and playback
Modeling	The demonstration of a math skill to a participant prior to task assignment that does not occur as part of a prompting hierarchy
Consequence	The provision of contingent feedback, correction, or rewards
Antecedent	The arrangement of environmental factors unrelated to math content (e.g., duration of sessions, preferred materials) prior to instruction
Strategy instruction	Explicit instruction in a discrete procedure designed to derive a solution
Peer mediated	Interventions involving the delivery of instruction by peers
Instructional mechanism	
Setting	Data collection venues, including home, school, clinic (e.g., university program or treatment center), or community (e.g., local store
Arrangement	The groupings in which instruction was delivered, including 1:1 (implementer and child), small group (two to five children), large group (six or more children), or independent (two or more children work without assistance within a group of indefinite size)
Length of treatment	The overall duration of the study, including short (less than or equal to 1 week or seven training sessions), intermediate (more than 1 week and fewer than 30 sessions), or long (more than 1 month and more than 30 sessions).
Session duration	Average duration of instructional sessions, in minutes
Implementer	Individuals responsible for delivering the intervention, including researchers, peers (e.g., siblings), or teachers (e.g., general educators, therapists, special educators)
Target skills	
Early numeracy	Skills such as number identification and counting
Fluency	Involves improving the rate and reducing latency of responses in mathematics
Algebra	Basic algebra problems
Fractions	Concepts such as comparison of quantity or representations of fractions
Problem solving	Involves the completion of word problems
Functional skills	Life skills, such as telling time and purchasing
Computation	Operations such as addition, subtraction, multiplication, and division

possesses advantages over alternative non-overlap indices of effect, including high correlation with common effect sizes (e.g., Cramer's V) and easily calculated confidence intervals (Parker, Vannest, & Brown, 2009). Improvement rate is calculated by dividing the number of improved data points by the total number of data points within each phase. Improved baseline data points are more consistent with a therapeutic effect (e.g., increase in appropriate behavior) than any of the values recorded during treatment. Likewise, improved treatment data points exceed all those in the baseline condition. IRD represents the difference between the improvement rates of treatment and baseline phases. IRD scores that exceed .70 indicate large treatment effects, scores ranging from .50 to .70 indicate moderate treatment effects, and scores below .50 suggest small or negligible effects. We identified improved data points for each phase using a web-based application (Vannest, Parker, & Gonen, 2011) and obtained IRD and 95% continuity-corrected confidence intervals with freely available statistical software (Lowry, 2014).

Tau-U. Nonoverlap effect sizes generally do not account for therapeutic trends that emerge during baseline (Parker, Vannest, & Davis, 2011). Tau-U combines the Mann-Whitney *U* index of nonoverlap with Kendall's rank correlation, a percentage of data pairs measuring improvement over time that provides a conservative means of correcting for monotonic baseline trends (Parker, Vannest, Davis, & Sauber, 2011). Mann-Whitney *U* statistically compares the combined scores from baseline and treatment phases, producing a proportion of pairwise comparisons that improve from baseline to treatment. Tau-U scores less than .5, ranging between .50 and .69, or that range between 0.70 and 1 are associated with small, moderate, or large treatment effects, respectively (Crutchfield, Mason, Chambers, Wills, & Mason, 2014).

We calculated Tau-U using a web-based application developed by Vannest and colleagues (2011). Baseline trends were examined prior to phase comparisons. Data with a trend level of 0.4 in the direction associated with treatment were corrected (Parker, Vannest, Davis, et al., 2011). We then conducted phase contrasts between the baseline and treatment conditions within each case and computed 95% confidence intervals.

Interobserver Agreement (IOA)

Two authors independently coded IOA for the review of abstracts, the evaluation of study quality, and the application of study codes. The authors received training using practice materials until adequate agreement (i.e., >90%) was demonstrated. IOA was calculated by dividing the number of agreements by the total number of agreements plus disagreements and multiplying by 100. Scoring discrepancies were discussed until a consensus was reached. For 100% of abstracts identified in the initial search, agreement was defined as both reviewers agreeing on the inclusion or exclusion of an abstract. IOA for the abstract review was 99%. IOA for all studies evaluated with WWC design standards was 92%. For codes pertaining to demographic and study features, agreement was defined as both reviewers recording the same code for a single category. Average IOA across 20% of studies for all codes was 97% (*SD* = 2.5, range = 94%–100%), including visual analysis (100%).

Results

Identified cases ($n = 28$) featured a total of 28 participants. A one-to-one correspondence between cases and participants was not observed as the number of participants required to establish a functional relation varies by design. Participants were predominantly male (71%; $n = 20$) and ranged in age from 5 to 17 years ($M = 10$). Information regarding the age of two elementary-level participants was not reported. Approximately 46% of participants ($n = 13$) were early elementary school age (6–9 years). An additional 28% of participants ($n = 8$) were high school age (14–17 years). Preschoolers (1–5 years) and middle school–age students (10–13 years) composed a relatively smaller portion of the sample with approximately 4% ($n = 1$) and 21% ($n = 6$) of participants respectively.

In terms of disability status, the authors identified 71% of participants as having autism ($n = 20$). Fewer participants were described as having the more general ASD (21%; $n = 6$) or more specific subcategories, such as PDD-NOS ($n = 1$) or Asperger's syndrome ($n = 1$). Authors identified 60% of participants ($n = 17$) as having ID. No information regarding cognitive functioning was provided for 32% of participants ($n = 9$), with only two participants being specifically identified as not having ID (6%). Notwithstanding ID, 17% of participants ($n = 5$) were identified as having secondary disabilities, including attention deficit hyperactivity disorder (*n* = 2), hearing impairment (*n* = 2), emotional-behavior disturbance (*n* = 1), or language impairment (*n* = 1). School placement was not reported for 35% of participants (*n* = 10). Approximately 39% of participants (*n* = 11) and 25% (*n* = 7) received education services through special or general education, respectively.

Methodological Features

The most common research designs featured in the identified cases were alternating treatment (36%; *n* = 10) and multiple-probe- or multiple-baseline-across-behaviors designs (39%; *n* = 11). Comparatively fewer cases featured multiple-probe- or multiple-baseline-across-participants (11%; *n* = 3) or ABAB designs (14%; *n* = 4). Authors reported data related to social validity in five articles, or 29% of cases (*n* = 8). Data reflected the results of consumer satisfaction surveys in all cases. Reports regarding fidelity of implementation were more common, with authors providing some measure of fidelity in 10 articles, or 68% of cases (*n* = 19). Generalization and maintenance of targeted skills was assessed in a minority of cases, or 43% (*n* = 12) and 36% (*n* = 10), respectively.

Intervention and Target Skills

Researchers applied a combination of instructional approaches within each study. Interventions in a majority of cases included consequences, such as contingent praise (61%; *n* = 17) and prompting (68%; *n* = 19). The least-to-most prompting procedure used by Bouck, Satsangi, Doughty, and Courtney (2014), for example, involved providing verbal instructions if students did not correctly complete subtraction problems. Further errors in responding resulted in a physical demonstration of the appropriate response by the instructor. Jimenez and Kemmery (2013) used a constant-time delay prompting early numeracy skills (e.g., number identification). Teachers initially conducted errorless sessions, in which students asked to name a number were immediately provided with the correct answer. Thereafter, students received 5 s to identify a number, after which time teachers provided error correction (e.g., "This is 2"). Representation techniques (39%; *n* =11), strategy instruction (21%; *n* = 6), and antecedent interventions (21%; *n* = 6) were featured less frequently. Techniques used in three or fewer cases included computer-assisted (11%; *n* = 3), modeling (11%; *n* = 3), video-based (7%; *n* = 2), and peer-mediated (4%; *n* = 1) instruction. Jowett, Moore, and Anderson (2012) showed the participant video clips modeling the correct completion of number identification tasks (i.e., writing numbers and identifying quantities). The researchers then asked the participant to demonstrate the modeled behaviors.

Instruction was generally consistent in terms of setting, arrangement, and the personnel responsible for implementation. Procedures typically occurred in school settings (86%; *n* = 24). Home (4%; *n* = 1), community (21%; *n* = 6), and clinical settings (14%; *n* = 4) were relatively less common. Of the total number of cases, 21% (*n* = 6) were conducted in more than one setting. For example, using a school-based instructional program, Cihak and Grim (2008) initially taught participating students (*n* = 4) a skill-purchasing strategy involving "counting on," or adding sums beginning from the larger or smaller addend (e.g., 3 + 2 = 3, 4, 5) rather than counting all addends (e.g., 3 + 2 = 1, 2, 3, 4, 5). After meeting mastery criteria (i.e., three independent purchases over three consecutive sessions) in two school settings, the participants demonstrated the strategy in a community department store.

Personnel responsible for implementation conducted sessions in one-to-one sessions in 71% of cases (*n* = 20). Small-group or independent arrangements appeared in 4% (*n* = 1) and 14% (*n* = 4) of cases, respectively. Authors did not describe the instructional arrangements featured in 14% of cases (*n* = 4). Teachers implemented instruction in 71% (*n* = 20) of cases. Researchers generally administered intervention procedures in the remaining cases (25%; *n* = 7). Peers delivered instruction alongside teachers in 4% of cases (*n* =1). For example, Kamps, Locke, Delquadri, and Hall (1989) provided peer tutors with training involving autism and various instructional techniques (see Table 1). The implementation agent was not described in 4% of cases ($n = 1$).

Intervention packages exhibited little variability in terms of overall treatment length and session duration. Treatments of intermediate duration (i.e., >1 week and <30 sessions) were applied in 79% of cases ($n = 22$). Long-term treatments exceeding 1 month were applied in 19% of cases ($n = 5$). Researchers reported using short-term interventions (i.e., ≤1 week or seven sessions) in 4% ($n = 4$) of cases. Session duration was reported in 54% ($n = 15$) of cases. Average session duration was 16 min ($SD = 9$, range = 10–45).

Interventions targeted a relatively narrow range of skills. Most interventions involved computation ($n = 11$; 39%) or functional skills ($n = 11$; 39%). Researchers targeted fluency in 14% of cases ($n = 4$). Early numeracy and problem solving were each targeted in 7% of cases ($n = 2$). For the cases involving problem solving, Levingston, Neef, and Cihon (2009) provided a student with training in specific behaviors needed to solve word problems involving multiplication or division (e.g., identification of the operation, identifying the larger number). Rockwell, Griffin, and Jones (2011) trained a student to identify specific forms of addition and subtraction problems and to sort numbers from the problem into a diagram corresponding with the problem format.

Outcomes

Reviewers identified a functional relation in 71% of cases ($n = 20$). Functional relations were not observed in studies involving antecedent factors (i.e., length of instructional session), tangible reinforcement, or computerized manipulatives—compared to tactile manipulatives—as the sole intervention component. Notwithstanding the limited available evidence concerning intervention packages and target variables, relationships between specific instructional strategies and positive outcomes were evident. Prompting—particularly, systematic prompting (e.g., constant-time delay), combined in most cases with positive consequences and manipulatives—generally improved students' responding in cases featuring addition, multiplication ($n = 7$), or purchasing skills ($n = 7$). Featured in only 7% of cases ($n = 2$), interventions featuring strategy instruction, word problems, and modeling nonetheless resulted in positive effects for students on measures of word problems.

Effect size calculations were consistent with the results of visual analysis; cases that did not demonstrate a functional relationship generally had negligible effects (effect sizes for individual cases are available from the first author). Average PND, Tau-U, and IRD outcome measures were consistent with moderate treatment effects, at 72.1 ($SD = 34.19$, range = 0–100), 0.62 ($SD = 0.53$, range = –0.75–1), and 0.76 ($SD = 0.34$, range = 0–1), respectively. Adjustments for baseline trend prior to the calculation of Tau-U were necessary in 14% of cases ($n = 4$). A Pearson analysis of treatment effect intercorrelation revealed robust relationships between IRD and PND ($r = .964$, $n = 28$, $p < .0001$), PND and Tau-U ($r = .851$, $n = 28$, $p < .0001$), and Tau-U and IRD ($r = .79$, $n = 28$, $p < .0001$). The range of confidence intervals for IRD ($M = .21$, $SD = .26$) and Tau-U ($M = .63$, $SD = .39$), however, indicated a low level of certainty regarding treatment outcomes.

Discussion

The purpose of this review was to identify methodologically rigorous, peer-reviewed research studies which evaluated the efficacy of math interventions for students with ASD. Specific questions addressed (a) participant characteristics, (b) methodological features, (c) intervention components and targeted skills, and (d) reported outcomes. Studies featured an equitable proportion of students from elementary and secondary settings. The majority of participants were identified as having ID, with authors reporting that participants did not have ID in a small portion of cases. Information regarding treatment integrity was reported in the majority of studies. Maintenance and generalization measures appeared less frequently (30% of studies). Of the various interventions and instructional arrangements, prompting and contingent consequences delivered by teachers in one-to-one sessions appeared most frequently. Computation and functional skills were targeted in approximately 80% of interventions. Visual analysis identified a functional relation in 71% ($n = 20$) of identified cases. Effect size calculations indicate that the interventions were moderately effective; however, large confidence intervals potentially undermine conclusions regarding the efficacy of instruction (Parker et al., 2009).

The WWC standards supersede alternative methods of evaluating experimental design developed within the research community, despite the omission of criteria related to several notable features of experimentation.

Results of the coding process were largely consistent with previous best-evidence syntheses of single-case research (e.g., Fallon, Collier-Meek, Maggin, Sanetti, & Johnson, 2015; Maggin, Briesch, & Chafouleas, 2013). Application of the WWC criteria resulted in the exclusion of 42% of studies involving mathematics instruction for students with ASD. Per WWC guidelines, interventions must produce an effect in 20 cases over five separate studies before being considered evidence based. Although we observed positive findings across the majority of cases, none of the identified math interventions may be considered evidence-based practices for students with ASD. The absence of three or more replications of effect represented the most common reason for exclusion. One point of departure from previous reviews was the extent to which multiple-baseline studies were excluded based on issues with data in multiple-baseline designs. Specifically, data either did not overlap during initial baseline sessions or did not verify the absence of experimental effect in baseline at appropriate instances during the treatment condition (see Figure 1). Further clarification regarding these criteria may be necessary in order to prevent the unnecessary exclusion of evidence (Maggin et al., 2013).

Despite the various mathematical issues facing children with ASD (e.g., Wei et al., 2014; Siegel, Goldstein, & Minshew, 1996), identified studies generally targeted computational or functional skills for students with ID. Such interventions do not address the range of challenges encountered by students with HFASD (i.e., without ID) who may require assistance with advanced mathematical concepts emphasized within the CCSS-M. Notwithstanding the equitable distribution of participants who received services in special and general education settings, the majority of intervention featured one-to-one instructional arrangements that may not be feasible in general education classroom settings. The components of the interventions further reflect the extent to which research has not addressed the needs of students with HFASD. Interventions prominently featured the prompting and consequence-based procedures used in mathematics instruction for individuals with severe cognitive disabilities (Browder et al., 2008). Approaches associated with achievement gains in students with higher levels of functioning (e.g., specific learning disabilities), such as representation techniques, appeared in fewer cases (Gersten et al., 2009).

The design standards disseminated by the WWC (2014) are linked to funding and federal recognition of qualifying interventions as an evidence-based practice. Consequently, the WWC standards supersede alternative methods of evaluating experimental design developed within the research community, despite the omission of criteria related to several notable features of experimentation (e.g., external validity; Maggin et al., 2013). Studies reported data regarding discretionary aspects of methodology to varying degrees. Although intervention fidelity was assessed in the majority of studies, authors provided far less information concerning the maintenance and generalization of the skills addressed in the interventions. Thus, the extent to which the interventions resulted in long-term gains across a variety of math skills remains uncertain.

Of greater concern is the lack of information concerning social validity. The WWC does not require studies to report social validity despite general acknowledgement of the importance of such data among researchers (e.g., Horner et al., 2005). As many single-case designs intentionally eschew statistical methods of ascertaining significance (see Baer, 1977), an adequate interpretation of findings requires an alternative means of attesting to the importance of student performance. Limited insight into the feasibility of interventions, combined with the omission of objective information such as instructional time, reduces the utility of research findings for practitioners. Given the lack of social validity in many areas of the education research (Hudson, Lewis, Stichter, & Johnson, 2011), the inclusion of guidelines related to social validity in the WWC standards may warrant consideration.

The technical compromise reflected in the WWC guidelines, in which cases are subject to visual analysis prior to the calculation of treatment effects, does not address features of single cases resistant to quantification. Specifically, alternating-treatment and multiple-baseline- or multiple-probe-across-behavior designs present a series of issues for the quantitative analysis recommended by the WWC. Parker and colleagues (2009) noted that "obtaining [confidence intervals] in single-case research can be humbling" (p. 142) given the uncertainty they engender regarding effect sizes. The number of data points permitted under current guidelines for alternating treatment designs (Figure 1), though consistent with traditional visual analysis (Gast & Ledford, 2014), do not produce acceptable confidence intervals. Aggregated effect assessment of multiple-baseline- or multiple-probe-across-behavior phases may be misleading in instances when treatment is applied across disparate (i.e., nonmath) behaviors or students. Published examinations of single-case effect sizes featuring reversal or multiple-baseline-across-participants designs provide limited insight into the wider range of single-case designs (e.g., Parker et al., 2009). Greater inquiry into the range of designs is required should the WWC continue to emphasize the derivation of effect sizes.

Limitations

This review has two notable limitations. First, it is possible that our search, though extensive, did not identify all of the relevant studies pertaining to mathematics for students with ASD. The inclusion of students with ASD in studies ostensibly targeting intellectual or developmental disability impedes the location of studies concerning this population. In addition, our review exclusively featured work published in peer-reviewed journals. Dissertations, theses, or other "gray literature" were not reviewed. Second, cases that satisfied WWC design standards yet failed to demonstrate a functional relation were not excluded, as the removal of ineffective methodologically sound studies may overstate treatment effectiveness (Maggin et al., 2013).

Limited insight into the feasibility of interventions, combined with the omission of objective information such as instructional time, reduces the utility of research findings for practitioners.

Implications for Practice

Regardless of its limitations, research regarding mathematics instruction for students with ASD does provide some guidance for practitioners. Explicit instruction consisting of prompts and supplemented with positive consequences remains the standard for addressing the needs of students with disabilities (Browder et al., 2008). Instruction enhanced with video modeling, computer equipment, and peer tutoring—though promising—is relatively absent from the literature. Practitioners may refrain from using techniques that strain resources in favor of simpler, validated forms of instruction. The few studies involving word problems suggest that students with ASD are amenable to instruction in these areas. Practitioners will nonetheless require further guidance in targeting the problem solving skills of this population.

Implications for Research

Few studies exist regarding mathematics instruction for students with ASD. Fewer meet standards of quality recommended by the WWC. A need for increased quality in single-case and group-design research is clearly evident. Beyond incorporating standard quality features (e.g., three replications of effect, random assignment), we advise researchers to directly consult the WWC standards during the development stages of future studies. Such measures may be particularly important in single-case research, where the WWC guidelines do not encompass historically adequate designs (e.g., multiple-baseline design across conditions; Akmanoglu & Batu, 2004; Gast & Ledford, 2014). Further suggestions for improving research quality involve the inclusion of discretionary aspects of quality, including fidelity, maintenance, and generalization.

It is important for research in applied disciplines, such as education, to remain relevant given current changes in policy and demographics. The influx of students with ASD into inclusive settings, coupled with the CCSS-M standards, will require researchers to extend their focus to the full range of individuals with ASD. Further replication of the intervention packages identified in this review is required in order to satisfy the minimum standards of evidence-based practices. An explicit emphasis on word problems would address the demand of the CCSS-M and documented language deficits in students with ASD. Likewise, the limited number of cases involving peer tutoring constitutes a missed opportunity given social challenges encountered by this population. The research identified in this review nonetheless provides starting points for important areas of inquiry for students across the autism spectrum.

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