Interventions Targeting Sensory Challenges in Autism Spectrum Disorder: A Systematic Review

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abstract

CONTEXT: Sensory challenges are common among children with autism spectrum disorder (ASD).

OBJECTIVE: To evaluate the effectiveness and safety of interventions targeting sensory challenges in ASD.

DATA SOURCES: Databases, including Medline and PsycINFO.

STUDY SELECTION: Two investigators independently screened studies against predetermined criteria.

DATA EXTRACTION: One investigator extracted data with review by a second. Investigators independently assessed risk of bias and strength of evidence (SOE), or confidence in the estimate of effects.

RESULTS: Twenty-four studies, including 20 randomized controlled trials (RCTs), were included. Only 3 studies had low risk of bias. Populations, interventions, and outcomes varied. Limited, short-term studies reported potential positive effects of several approaches in discrete skill domains. Specifically, sensory integration-based approaches improved sensory and motor skills-related measures (low SOE). Environmental enrichment improved nonverbal cognitive skills (low SOE). Studies of auditory integration-based approaches did not improve language (low SOE). Massage improved symptom severity and sensory challenges in studies with likely overlapping participants (low SOE). Music therapy studies evaluated different protocols and outcomes, precluding synthesis (insufficient SOE). Some positive effects were reported for other approaches, but findings were inconsistent (insufficient SOE).

LIMITATIONS: Studies were small and short-term, and few fully categorized populations.

CONCLUSIONS: Some interventions may yield modest short-term (<6 months) improvements in sensory- and ASD symptom severity-related outcomes; the evidence base is small, and the durability of the effects is unclear. Although some therapies may hold promise, substantial needs exist for continuing improvements in methodologic rigor.

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As defined by the *Diagnostic and Statistical Manual of Mental Disorders*, *Fifth Edition* (DSM-5), features of autism spectrum disorder (ASD) include deficits in social skills and communication; restricted and repetitive behaviors; excessive adherence to routine; intense interest patterns, and atypical sensory interests or responses.[1] Although challenging to operationalize and measure clinically, estimates indicate that 42% to 88% of people with ASD have impairments related to sensory processing that include both hyper- and hyporesponsiveness.[2–4] Sensory symptoms can involve both strong interests and aversions.

Sensory-focused interventions commonly target aversions/challenges, meeting needs for sensory input within adaptive frameworks, or may target perceived processing deficits, with the goal of improving people's abilities to interact with their environments. For example, a child with ASD may have difficulty tolerating bright lights, clothing or food textures, specific noises, daily living tasks, touch, or more idiosyncratic stimuli, such as certain colors. Alternatively, some children with may ASD may show a fascination with visually examining objects, seeking out certain textures to rub/touch (eg, clothing or hair), or experiencing the sound of certain objects/actions. These sensitivities and interests can interfere significantly with children's abilities to care for themselves, leave the home, participate in school, and be involved in social situations.

Although sensory challenges are common and impairing features of ASD for many, research examining the nature of sensory impairments across the life span has been lacking. Specifically, the field has historically lacked accepted frameworks for diagnosing sensory challenges (eg, sensory symptoms were not part of DSM diagnostic criteria until DSM-5) and developing responsive interventions.[2,3,5,6] Although an increasing number of interventions exist, their mechanisms and targets for change are not consistently defined. Broadly, interventions targeting sensory challenges involve the incorporation of sensory experiences (eg, sounds, texture, pressure, and so on) to affect a variety of outcomes. Consensus is also lacking regarding whether interventions work by acting on the underlying sensory processing differences commonly associated with ASD, how specific versus general these effects may be, and how generalizable any improvements may be over time to other situations that may tax sensory processing systems.

In the present review, a component of an Agency for Healthcare Research and Quality-commissioned update of a comparative effectiveness review of therapies for children with ASD conducted by the Vanderbilt Evidence-based Practice Center,[7] we examine the evidence specifically for interventions targeting sensory challenges in children with ASD. The full comparative effectiveness review update[8] and review protocol (PROSPERO registry number CRD42016033941) are available at www.effectivehealthcare.ahrq.gov.

TABLE 1 Inclusion Criteria

Category	Criteria
Study population	Children ages 2–12 y with ASD (mean age + SD is ≤12 y and 11 mo)
Publication languages	English only
Admissible evidence (study design and other criteria)	Admissible designs
	RCTs, prospective and retrospective cohort studies with comparison groups, and non-RCTs
	Other criteria
	Original research studies published from 2010 to present and not addressed in previous reviews
	Studies must have relevant population and ≥20 participants with ASD (non-RCTs) or at least 10 total participants (RCTs)
	Studies must address ≥1 of the following for ASD
	Outcomes of interest
	Treatment modality of interest
	Predictors or drivers of treatment outcomes (eg, biomarkers, clinical changes)
	Maintenance of outcomes across environments or contexts
	Sufficiently detailed methods and results to enable data extraction
	Reporting of outcome data by target population or intervention

METHODS

Search Strategy and Study Selection

We searched the Medline database via PubMed, Embase, and the Cochrane Library from January 2010 to September 2016 using a combination of controlled vocabulary and key terms related to ASD and sensory challenges (eg, autism, ASD, and sensory integration). We note that the original review,[9] which the current report updates, included studies from January 2000 to 2011. We also hand-searched the reference lists of included articles and recent reviews addressing ASD therapies to identify potentially relevant articles.

We developed inclusion criteria in consultation with an expert panel of clinicians and researchers (Table 1). We included comparative study designs (eg, randomized controlled trials [RCTs] and prospective or retrospective cohort studies) and studies published in English. We required that eligible RCTs have a total minimum sample size of 10. We required a higher minimum sample size (n = 20) for other comparative studies because they typically have fewer controls for bias than RCTs.

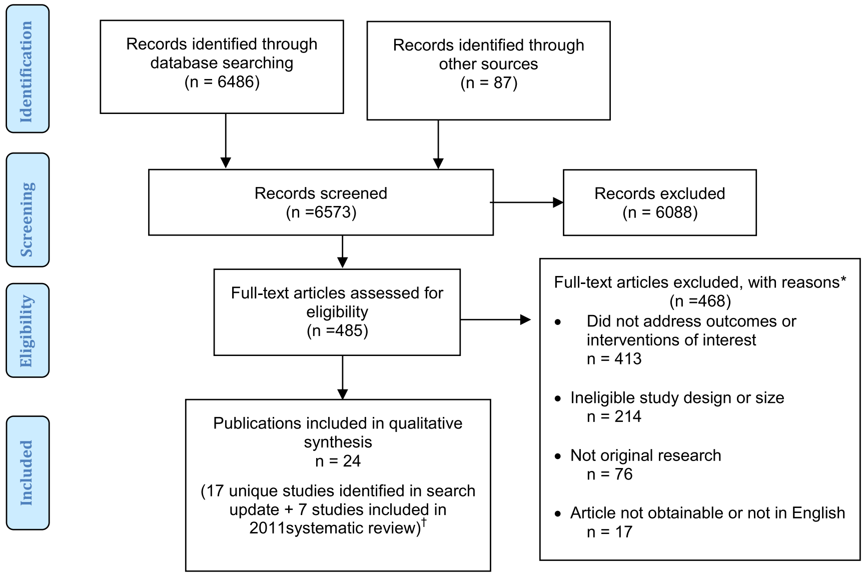

FIGURE 1
Disposition of studies identified for this review. * Numbers do not tally because studies could be excluded for multiple reasons. † One paper reports 2 separate trials. We also include analysis of 7 comparative studies reported in our 2011 review of therapies for children with ASD; thus, we describe a total of 24 studies.

Data Extraction and Analysis

One investigator extracted data regarding study design; descriptions of study populations, intervention, and comparison groups; and baseline and outcome data. A second investigator independently verified the accuracy of the extraction and made revisions as needed. Significant heterogeneity in interventions and outcomes reported precluded meta-analysis; thus, we synthesized studies qualitatively and report descriptive statistics in tables (Tables 2 and 3).

Assessment of Study Risk of Bias and Strength of Evidence

Two investigators independently evaluated the overall methodologic risk of bias of individual studies using the ASD-specific assessment approach developed and used in previous reviews of interventions for ASD.[7,10,11] Senior reviewers resolved discrepancies in risk-of-bias assessment, and we used an approach described in the full review[8] to determine low, moderate, or high risk-of-bias ratings.

Assessment of the strength of the evidence (SOE) reflects the confidence that we have in the stability of treatment effects in the face of future research. The degree of confidence that the observed effect of an intervention is unlikely to change in additional research, the SOE, is presented as insufficient, low, moderate, or high. Assessments are based on consideration of study limitations, consistency in the direction of the effect, directness in measuring intended outcomes, the precision of the effect, and reporting bias.[12] We determined the SOE separately for major intervention-outcome pairs using a prespecified approach, which is described in detail in the full review.[8]

RESULTS

Our searches (conducted for the broader systematic review update[8]) identified 6573 citations, of which 24 (reported in multiple publications) met the inclusion criteria (Fig 1). Seventeen of these studies were published after the completion of our initial review of therapies for children with ASD,[7] and 7[13–19] were included in the previous review. The studies included 20 RCTs,[13–32] 1 nonrandomized trial,[33] and 3 retrospective cohort studies.[34–36] Three studies had low risk of bias,[21,23,30] 10 had moderate risk of bias,[14,15,19,20,22,24,25,27,29,31,32] and 11 (including 1 publication[26] reporting 2 unique RCTs) had high risk of bias.[13,16–18,26,28,33–36] Table 2 outlines the study characteristics and risk of bias assessments.

We categorized interventions addressed in the included studies based on the core strategies used in each intervention. In some cases, this approach grouped together interventions that may have used specific, manualized techniques with others that used only a subset of those techniques (eg, "Ayres-based" sensory integration and sensory integration models that may have used some Ayres strategies). We note that no alternative approaches would have substantially changed our overall findings in terms of SOE.

Based on the literature meeting criteria for this review, we categorized interventions as:

- sensory integration-based (interventions using combinations of sensory and kinetic components, such as materials with different textures, touch/massage, swinging and trampoline exercises, and balance and muscle resistance exercises to ameliorate sensory challenges);
- environmental enrichment-based (interventions incorporating targeted exposure to sensory stimuli to promote tolerance of stimuli in other contexts);
- auditory integration-based (interventions incorporating auditory components, such as filtered sound to ameliorate sensory processing challenges via theorized retraining of aural pathways);

TABLE 2 Overview of Studies Addressing Interventions Targeting Sensory Challenges

Characteristic	RCTs (n = 20)	Nonrandomized Trials (n = 1)	Retrospective Cohort Studies (n = 3)	Total Literature
Intervention category				
Sensory integration-based approaches	3	0	1	4
Environmental enrichment-based approaches	2	0	0	2
Auditory integration-based approaches	4	0	0	4
Music therapy-based approaches	4	1	0	5
Massage-based approaches	5	0	2	7
Additional approaches	2	0	0	2
Treatment duration (wk)				
<1–4	5	1	0	6
5–8	2	0	0	2
9–12	4	0	0	4
13–20	6	0	2	8
≥21	3	0	1	4
Region of study conduct				
Asia	3	1	2	6
Australia	1	0	0	1
Europe	2	0	0	2
North America	13	0	1	14
South America	1	0	0	1
Risk of bias				
Low	3	0	0	3
Moderate	10	0	0	10
High	7	1	3	11
Total participants, N	790	27	193	1010

- music therapy-based (interventions incorporating playing or singing music, or movement to music, to improve challenging behaviors and sensory difficulties);
- massage-based (interventions incorporating touch-based approaches by a therapist or caregiver); and
- other/additional (included interventions [tactile-based tasks, weighted blankets] not cleanly fitting into one of the broader categories).

Studies of Sensory Integration-based Approaches

In 3 out of 4 small, short-term studies (1 low,[21] 1 moderate,[20] and 2 high[13,34] risk of bias), sensory-related measures and motor skills measures improved for children receiving a sensory integration-based intervention compared with another intervention, but effects on other outcomes were typically not statistically significantly different between groups (Table 3). Several outcomes were also parent-reported, and parents were often aware of intervention status.

In 1 RCT, children with ASD and a diagnosed sensory processing disorder received treatment focused on sensory integration or treatment focused on building fine motor skills.[21] Both groups improved significantly on blinded parent and teacher ratings of goal attainment related to sensory processing, motor skills, and social functioning, with children receiving sensory integration improving significantly more than those receiving motor skills intervention ($P \leq .05$). Children in the sensory integration group had significantly fewer parent-rated autistic mannerisms posttreatment than the fine motor group ($P \leq .05$), but other measures of sensory processing, ASD symptoms, or neurologic functioning did not differ between groups. Another RCT compared manualized occupational therapy with sensory integration to care as usual.[20] After treatment, children receiving sensory integration-based treatment showed significantly more goals attained and significantly greater improvements in social skills and self-care measures compared with children receiving usual care ($P = .003$). Measures of adaptive behavior or other measures related to functional skills (eg, self-care and mobility) did not differ between groups.

In a retrospective study comparing sensory integration-based therapy in children with high functioning ASD (IQs >70), both groups received active treatment that included either sensory integration-based therapy or eclectic group therapy.[34] Participants in the sensory integration group improved significantly more than those in the control group in measures of motor abilities, memory and visualization, and combined sensory motor and cognitive skills assessed by an unblinded investigator (P values < .05). They did not show relative improvements in measures of spatial positioning, sense of touch, or verbal ability.

TABLE 3 Key Findings in Studies of Interventions Targeting Sensory Challenges

Source, Study Design, Groups, *N* Enrollment/*N* Final, Mean Age, Months ± SD, Treatment Duration/Follow-up Time Point Posttreatment, ROB	Outcome Measure/Baseline Scores, Mean ± SD	Outcome Measure/Posttreatment Scores, Mean ± SD
Iwanaga et al[34]	Japanese Miller assessment for preschoolers	Mean change score from baseline
Retrospective cohort	Total score	Total score
G1: sensory integration therapy, 8/8	G1: ND	G1: 34.38 ± 21.98
G2: group therapy, 12/12	G2: ND	G2: 8.25 ± 11.69
Age (mo)	Index score	G1 vs G2: $P = .005$
G1: 56.8 ± 9.0	G1: ND	Foundation index score
G2: 56.3 ± 6.8	G2: ND	G1: 34.13 ± 34.21
8–10 mo/EOT	Coordination index score	G2: 11.33 ± 25.54
High ROB	G1: ND	G1 vs G2: $P =$ ns
	G2: ND	Coordination index score
	Nonverbal index score	G1: 46.75 ± 36.26
	G1: ND	G2: 8.92 ± 17.87
	G2: ND	G1 vs G2: $P = .008$
	Complex index score	Nonverbal index score
	G1: ND	G1: 45 ± 24.26
	G2: ND	G2: 8.25 ± 36.6
	Verbal index score	G1 vs G2: $P = .016$
	G1: ND	Complex index score
	G2: ND	G1: 30.75 ± 20.73
		G2: 3.83 ± 31.2
		G1 vs G2: $P = .034$
		Verbal index score
		G1: 13 ± 44.26
		G2: 14.67 ± 31.2
		G1 vs G2: $P =$ ns
Schaaf et al[20]		Mean change score from baseline
RCT	GAS	GAS
G1: sensory integration, 17/17	G1: ND	G1: 56.53 ± 12.38
G2: usual care, 15/14	G2: ND	G2: 42.71 ± 11.21
Age (mo)		G1 vs G2: $P = .003$
G1: 71.35 ± 14.90	PEDI	PEDI
G2: 72.33 ± 10.81	Functional skills – self-care	Functional skills – self-care
10 wk/EOT	G1: ND	G1: 10.2 ± 22.6
Moderate ROB	G2: ND	G2: 1.12 ± 5.6
		G1 vs G2: $P =$ ns
	Functional skills – mobility	Functional skills – mobility
	G1: ND	G1: 6.57 ± 23.8
	G2: ND	G2: 6.38 ± 15.1
		G1 vs G2: $P =$ ns
	Functional skills – social	Functional skills – social
	G1: ND	G1: 9.3 ± 17.4
	G2: ND	G2: 4.4 ± 13.8
		G1 vs G2: $P =$ ns
	Caregiver assistance – self-care	Caregiver assistance – self-care
	G1: ND	G1: 16.6 ± 23
	G2: ND	G2: –0.43 ± 8.6
		G1 vs G2: $P = .008$
	Caregiver assistance – mobility	Caregiver assistance – mobility
	G1: ND	G1: 4.8 ± 24.1
	G2: ND	G2: 0.22 ± 11.8
		G1 vs G2: $P =$ ns
	Caregiver assistance – social	Caregiver assistance – social
	G1: ND	G1: 14.4 ± 23.4
	G2: ND	G2: –1.8 ± 19
		G1 vs G2: $P = .039$
	PDDBI	PDDBI
	G1: ND	Sensory/Perceptual approach
	G2: ND	G1: –5.9 ± 10.8
		G2: –0.67 ± 5.9
		G1 vs G2: $P =$ ns

TABLE 3 Continued

Source, Study Design, Groups, *N* Enrollment/*N* Final, Mean Age, Months ± SD, Treatment Duration/Follow-up Time Point Posttreatment, ROB	Outcome Measure/Baseline Scores, Mean ± SD	Outcome Measure/Posttreatment Scores, Mean ± SD
		Ritualisms/Resistance to change G1: –6.5 ± 13.7 G2: –1.77 ± 6.3 G1 vs G2: *P* = ns Arouse G1: −7.1 ± 11.6 G2: −3.3 ± 6.0 G1 vs G2: *P* = ns
	VABS G1: ND G2: ND	VABS-II Communication G1: 5.06 ± 10.9 G2: −3.38 ± 18.6 G1 vs G2: *P* = ns Daily living skills G1: 4.2 ± 11.6 G2: −3.0 ± 18.5 G1 vs G2: *P* = ns Socialization G1: 3.8 ± 11.8 G2: −6.7 ± 21.8 G1 vs G2: *P* = ns Composite G1: 15.1 ± 44.7 G2: 0.0 ± 8.1 G1 vs G2: *P* = ns
Pfeiffer et al[21] RCT G1: sensory integration treatment, 20/20 G2: fine motor, 17/17 Age (mo) G1: 100.00 ± 24.78 G2: 110.47 ± 24.78 6 wk/EOT Low ROB	VABS Communication G1: 62.90 ± 13.39 G2: 64.24 ± 9.62 Socialization G1: 63.90 ± 17.71 G2: 64.24 ± 9.33 Motor G1: 60.70 ± 13.20 G2: 61.00 ± 11.24 Composite G1: 66.80 ± 16.66 G2: 70.18 ± 14.07 Sensory processing measure – total G1: 68.50 ± 5.62 G2: 67.88 ± 7.28 Social responsiveness scale – total G1: 82.95 ± 6.37 G2: 82.71 ± 9.10	VABS NR Sensory processing measure – total G1 vs G2: *P* = ns Social responsiveness scale – total G1 vs G2: *P* = ns GAS-parent rated G1 > G2 G1 vs G2: *P* < .05; ES = 0.125 GAS-teacher rated G1 > G2 G1 vs G2: *P* < .01; ES = 0.360
Fazlioğlu et al[13] RCT G1: sensory integration, 15/15 G2: control (special education), 15/15 Age (y) G1 + G2: 7–11 12 wk/EOT High ROB	Sensory evaluation form for children with autism G1: 98.2 ± 19.3 G2: 95.8 ± 17	Sensory evaluation form for children with autism G1: 66.5 ± 11.4 G2: 97.3 ± 17.8 G1 vs G2: *P* < .05
Woo and Leon[22] RCT G1: sensorimotor enrichment group + standard care, 13/13 G2: standard care, 15/15	CARS – autism severity, mean ± SE G1: 34.38 ± 0.72 G2: 38.07 ± 1.71	CARS – autism severity G1: 31.12 ± 1.46 G2: 37.61 ± 1.67

TABLE 3 Continued

Source, Study Design, Groups, *N* Enrollment/*N* Final, Mean Age, Months ± SD, Treatment Duration/Follow-up Time Point Posttreatment, ROB	Outcome Measure/Baseline Scores, Mean ± SD	Outcome Measure/Posttreatment Scores, Mean ± SD
Age (y)		G1 vs G2: *P* = .03
G1 + G2: 6.6 ± 2.5	Leiter-R – nonverbal test scale	Leiter-R – nonverbal test scale
6 mo/EOT	G1: 48.46 ± 5.52	G1: 57.23 ± 5.5
Moderate ROB	G2: 46.2 ± 6.36	G2: 43.7 ± 6.89
		G1 vs G2: *P* = .008
		Mean change from baseline,
	EOWPV – expressive language scale	EOWPV – expressive language scale
	G1: ND	G1: +4.7
	G2: ND	G2: +4.67
		G1 vs G2: *P* = ns
Woo et al[23]		
RCT	ADOS – severity	Number changing diagnostic classification on ADOS
G1: standard care + sensorimotor enrichment, 64/28	G1: ND	G1: 6 (21)
G2: standard care, 27/22	G2: ND	G2: 0 (0)
Age (y)		G1 vs G2: *P* = .01
G1: 4.76 ± 1.14	RDLS	RDLS
G2: 4.54 ± 1.10	Receptive language	Receptive language
6 mo/EOT	G1: 36.19 ± 4.64	G1: 43.62 ± 4.14
Low ROB	G2: 33.37 ± 4.79	G2: 37 ± 4.95
		G1 vs G2: *P* = .048
	Expressive language	Expressive language
	G1: 31.46 ± 4.14	G1: 38.65 ± 4.16
	G2: 31.47 ± 4.82	G2: 37.16 ± 4.94
		G1 vs G2: *P* = ns
	Leiter-R	Leiter-R
	Nonverbal test score	Nonverbal test score
	G1: 35.85 ± 4.76	G1: 49.19 ± 5.48
	G2: 32.63 ± 6.07	G2: 40.05 ± 6.25
		G1 vs G2: *P* = .024
	IQ score	IQ score
	G1: 82.96 ± 5.17	G1: 91.38 ± 5.58
	G2: 76.63 ± 4.96	G2: 78.16 ± 4.49
	SSP – atypical sensory responses	G1 vs G2: *P* = .037
	G1: 113.75 ± 4.76	SSP – atypical sensory responses
	G2: 129.3 ± 4.29	G1: 125.11 ± 5.42
		G2: 132.15 ± 4.09
		G1 vs G2: *P* = .037
Mudford et al[15]		Mean change from baseline
RCT	ABC – hyperactivity	ABC – hyperactivity
G1: auditory integration, 21/21	23.7 ± 9.4	G1: 0.3 ± 3.6
G2: control treatment, 21/21		G2: −4.1 ± 3.9
Age	NCBRF – hyperactivity	NCBRF – hyperactivity
G1 + G2: 9.42 y ± 29 mo	13.9 ± 5.5	G1: −0.3 ± 2
10 d (2 sessions/d)/EOT		G2: −2 ± 2.2
Moderate ROB		
Corbett et al[14]		
RCT	PPVT	PPVT
G1: Tomatis sound therapy/placebo, 11/11	G1: 20.83 ± 28.52	G1: 22.83 ± 29.36
G2: Placebo/Tomatis sound therapy, 11/11	G2: 32.20 ± 25.21	G2: 47.20 ± 24.45
Age (y)	EOWVT	EOWVT
G1 + G2: 3–7	G1: 16.50 ± 21.11	G1: 21.50 ± 23.30
25 d (2 blocks)/EOT	G2: 25.20 ± 19.82	G2: 34.40 ± 25
Moderate ROB		
Porges et al[26]		
RCT	Parent questionnaire	Parent questionnaire
G1: filtered music, 28/28	Hearing sensitivity	Hearing sensitivity

TABLE 3 Continued

Source, Study Design, Groups, *N* Enrollment/*N* Final, Mean Age, Months ± SD, Treatment Duration/Follow-up Time Point Posttreatment, ROB	Outcome Measure/Baseline Scores, Mean ± SD	Outcome Measure/Posttreatment Scores, Mean ± SD
G2: headphones only, 36/36	G1: 18 (50)	G1: 9 (50)
Age	G2: 12 (43)	G2: 1 (8)
NR		G1 vs G2: $P = .017$
1 wk/EOT	Affect	Affect
High ROB	G1: 16 (44)	G1: 3 (19)
	G2: 17 (61)	G2: 1 (18)
	Eye contact	Eye contact
	G1: 27 (75)	G1: 11 (41)
	G2: 17 (61)	G2: 4 (24)
	Behavioral organization	Behavioral organization
	G1: 19 (53)	G1: 5 (26)
	G2: 16 (57)	G2: 0 (0)
		G1 vs G2: $P = .027$
	Emotional control	Emotional control
	G1: 18 (50)	G1: 3 (17)
	G2: 12 (43)	G2: 0 (0)
	Spontaneous speech	Spontaneous speech
	G1: 27 (75)	G1: 13 (48)
	G2: 23 (82)	G2: 4 (17)
		G1 vs G2: $P = .022$
	Receptive speech	Receptive speech
	G1: 26 (72)	G1: 8 (31)
	G2: 23 (82)	G2: 2 (9)
	Listening	Listening
	G1: 29 (81)	G1: 12 (41)
	G2: 24 (86)	G2: 2 (8)
		G1 vs G2: $P = .006$
	Spontaneity	Spontaneity
	G1: 25 (69)	G1: 12 (48)
	G2: 20 (71)	G2: 4 (20)
	Relatedness	Relatedness
	G1: 30 (83)	G1: 9 (30)
	G2: 23 (82)	G2: 3 (13)
Porges et al[26]		
RCT	Parent questionnaire	Parent questionnaire
G1: filtered music, 50/50	Hearing sensitivity	Hearing sensitivity
G2: unfiltered music, 32/32	G1: 23 (46)	G1: 10 (43)
Age (mo)	G2: 16 (50)	G2: 2 (13)
G1: 53.33 ± 15.95		G1 vs G2: $P = .040$
G2: 56.74 ± 9.25	Affect	Affect
1 wk/EOT	G1: 32 (64)	G1: 8 (25)
High ROB	G2: 19 (59)	G2: 4 (21)
	Eye contact	Eye contact
	G1: 30 (60)	G1: 10 (33)
	G2: 20 (63)	G2: 8 (40)
	Behavioral organization	Behavioral organization
	G1: 28 (56)	G1: 8 (29)
	G2: 17 (53)	G2: 3 (18)
	Emotional control	Emotional control
	G1: 33 (66)	G1: 8 (24)
	G2: 19 (59)	G2: 0 (0)
		G1 vs G2: $P = .019$
	Spontaneous speech	Spontaneous speech
	G1: 41 (82)	G1: 21 (51)
	G2: 25 (78)	G2: 11 (44)
	Receptive speech	Receptive speech
	G1: 45 (90)	G1: 4 (9)
	G2: 26 (81)	G2: 4 (15)
	Listening	Listening

TABLE 3 Continued

Source, Study Design, Groups, *N* Enrollment/*N* Final, Mean Age, Months ± SD, Treatment Duration/Follow-up Time Point Posttreatment, ROB	Outcome Measure/Baseline Scores, Mean ± SD	Outcome Measure/Posttreatment Scores, Mean ± SD
	G1: 37 (74)	G1: 11 (30)
	G2: 21 (66)	G2: 6 (29)
	Spontaneity	Spontaneity
	G1: 22 (44)	G1: 8 (36)
	G2: 14 (44)	G2: 5 (36)
	Relatedness	Relatedness
	G1: 32 (64)	G1: 11 (34)
	G2: 21 (66)	G2: 6 (29)
Srinivasan et al[31,32]		Joint attention test – total score
RCT		G1 vs G2 vs G3, *P* = NS; SMD = 0.55; 95% CI, (SMD) = −0.13 to 1.24
G1: rhythm group, 12/11		G1 vs G2 vs G3, *P* = NS; SMD = 0.25; 95% CI (SMD) = −0.38 to 0.89
G2: robot group, 12/11		G1 vs G2 vs G3, *P* = NS; SMD = 0.71; 95% CI (SMD) = −0.01 to 1.43
G3: standard care, 12/11	Training-specific measure – response to social bids (total word count) early training session (session 2 of 32)	Training-specific measure – response to social bids (total word count) early training session
Age (y)	NR	G1: 4.4 ± 4.19
G1 + G2: 5–12		G2: 5.92 ± 7.04
8 wk/EOT		G3: 4.5 ± 3.9
Moderate ROB	Training-specific measure – response to social bids (total word count) mid training session (session 7 of 32)	Training-specific measure – response to social bids (total word count) mid training session
	NR	G1: 3.8 ± 3.29
		G2: 7.25 ± 6.74
		G3: 7.33 ± 8.81
	Training-specific measure – response to social bids (total word count) late training session (session 15 of 32)	Training-specific measure – response to social bids (total word count) late training session
	NR	G1: 9.8 ± 8.53
		G2: 7.67 ± 7.6
		G3: 5.67 ± 4.16
	Training-specific measure – verbalization to social partners (percent duration) early – trainer	Training-specific measure – verbalization to social partners (percent duration) early – trainer
	NR	G1: 6.1 ± 5.7
		G2: 3.9 ± 4.2
		G3: 12.1 ± 8.6
	Training-specific measure – verbalization to social partners (percent duration) early – adult model	Training-specific measure – verbalization to social partners (percent duration) early – adult model
	NR	G1: 2.1 ± 2.3
		G2: 1.9 ± 1.1
		G3: 2 ± 1.6
	Training-specific measure – verbalization to social partners (percent duration) mid – trainer	Training-specific measure – verbalization to social partners (percent duration) mid – trainer
	NR	G1: 12.8 ± 14.5
		G2: 5.1 ± 5.3
		G3: 14.5 ± 11.3
	Training-specific measure – verbalization to social partners (percent duration) mid – adult model	Training-specific measure – verbalization to social partners (percent duration) mid – adult model
	NR	G1: 1.8 ± 1.9
		G2: 3.4 ± 1.7
		G3: 2.2 ± 1.9
	Training-specific measure – verbalization to social partners (percent duration) late – trainer	Training-specific measure – verbalization to social partners (percent duration) late – trainer
	NR	G1: 14.8 ± 15
		G2: 6.3 ± 6.1
		G3: 14.4 ± 8.6
	Training-specific measure — verbalization to social partners (percent duration) late – adult model	Training-specific measure – verbalization to social partners (percent duration) late – adult model
	NR	G1: 2.2 ± 2.3
		G2: 5.4 ± 4.2

TABLE 3 Continued

Source, Study Design, Groups, *N* Enrollment/*N* Final, Mean Age, Months ± SD, Treatment Duration/Follow-up Time Point Posttreatment, ROB	Outcome Measure/Baseline Scores, Mean ± SD	Outcome Measure/Posttreatment Scores, Mean ± SD
		G3: 2.6 ± 2.4
	Training specific measure – vocalization patterns NR Training specific measure – verbalization patterns NR	Training-specific measure – vocalization patterns G2 vs G1, G3, *P* < .002; SMD = 0.75–0.76 Training-specific measure – verbalization patterns G1 vs G3, *P* = NS G3 vs G1, G2, *P* = .001; SMD = 0.78
Ghasemtabar et al[33] Non-RCT G1: music therapy, 13/13 G2: control, 14/14 Age (y) G1: 8.96 ± 1.36 G2: 9.23 ± 1.54 45 d/2 months High ROB	Social skills rating system G1: 27.69 ± 4.76 G2: 26.92 ± 4.49	Social skills rating system 2-mo follow-up G1: 30.61 ± 4.25 G2: 26.85 ± 3.82
Thompson et al[25] RCT G1: family-centered music therapy (FCMT), 12/11 G2: early intervention program, 11/10 Age (mo) G1: 43.92 ± 6.46 G2: 47.00 ± 7.18 16 wk/EOT Moderate ROB	VSEEC – social interaction G1: 49.1 ± 12.4 G2: 45.09 ± 8.13 SRS G1: 105.4 ± 27.1 G2: 106.2 ± 26.1 MBCDI Speech and language G1: 180 ± 108 G2: 170 ± 109 PCRI G1: 194.3 ± 23.1 G2: 191.6 ± 19.4	Change scores from baseline VSEEC – social interaction G1: 22.4 ± 10.1 G2: 0.9 ± 11.9 G1 vs G2: *P* < .001 SRS G1: −7.7 ± 17.3 G2: −1.4 ± 11.5 G1 vs G2: *P* = ns MBCDI Speech and language G1: 78.9 ± 73.4 G2: 58.7 ± 79.8 G1 vs G2: *P* = ns PCRI G1: 8.0 ± 9.19 G2: 0.2 ± 10.3 G1 vs G2: *P* = ns
Gattino et al[30] RCT G1: relational music therapy + clinical routine activities, 12/12 G2: clinical routine activities, 12/12 Age (y) G1 + G2: 9.75 ± 1.39 7 mo/EOT Low ROB	CARS – verbal communication G1: 2.67 ± 0.49 G2: 2.54 ± 0.33 CARS – nonverbal communication G1: 2.42 ± 0.42 G2: 2.08 ± 0.47 CARS – social communications G1: 12.29 ± 1.78 G2: 11.38 ± 1.65	CARS – verbal communication G1: 2.54 ± 0.45 G2: 2.58 ± 0.44 G1 vs G2, *P* = .50; SMD = 0.39 (95% CI, 0.21–0.57) CARS – nonverbal communication G1: 2.5 ± 0.37 G2: 2.33 ± 0.54 G1 vs G2, *P* = .35; SMD = 0.39 (95% CI, 0.08–0.86) CARS – social communications G1: 12.25 ± 1.54 G2:11.92 ± 1.24 G1 vs G2, *P* = .34; SMD = 0.39 (95% CI, 70.08–0.86)
Kim et al[16] RCT G1: music therapy, 15/10 G2: toy play, 15/10 Age (mo) G1 + G2: 51.20 ± 12.08 12 weekly, 30 min sessions/EOT High ROB	PDDBI Level of agreement at pre-treatment: 0.19	PDDBI Level of agreement at post-treatment: 0.67 G1 vs G2: *P* = ns
Silva et al[29] RCT G1: qigong massage, 55/42 G2: control, 48/42	Aberrant behavior checklist G1: 82.4 ± 25.9 G2: 83.1 ± 25.9	Aberrant behavior checklist G1: 62.4 ± 26.6 G2: 75.7 ± 28.6 G1 vs G2: *P* = .006

TABLE 3 Continued

Source, Study Design, Groups, *N* Enrollment/*N* Final, Mean Age, Months ± SD, Treatment Duration/Follow-up Time Point Posttreatment, ROB	Outcome Measure/Baseline Scores, Mean ± SD	Outcome Measure/Posttreatment Scores, Mean ± SD
Age (y) G1 + G2: 2–5 5 mo/EOT Moderate ROB	VABS – daily living skills G1: 34.3 ± 17.7 G2: 37.5 ± 20	VABS – daily living skills G1: 42.7 ± 19.1 G2: 45.9 ± 22.7 G1 vs G2: *P* = NR
	VABS – socialization G1: 36 ± 14.4 G2: 40.7 ± 17.4	VABS – socialization G1: 45.7 ± 16.3 G2: 48.6 ± 21 G1 vs G2: *P* = NR
	Self-regulatory difficulties G1: 57.6 ± 11.2 G2: 57.4 ± 13.4	Self-regulatory difficulties G1: 45.1 ± 11.5 G2: 54 ± 14.5 G1 vs G2: *P* = .00006
	Abnormal sensory response G1: 39.7 ± 9.1 G2: 41.3 ± 10.3	Abnormal sensory response G1: 30.4 ± 9.8 G2: 38.6 ± 11.6 G1 vs G2: *P* = .00002
	CARS – total score G1: 39.7 ± 6.6 G2: 38 ± 7.8	CARS – total score G1: 38.2 ± 6.6 G2: 37.7 ± 7.8 G1 vs G2: *P* = ns
Silva et al[35] RCT G1: qigong massage + qigong sensory training, 97/97 G2: control, 32/32	Abnormal tactile response – total score G1: 20.91 ± 7.13 G2: 22.31 ± 8.52	Abnormal tactile response – total score G1: 15.57 ± 6.86 G2: 21.34 ± 8.41 G1 vs G2: *P* < .001
Age (y) G1: 3.87 ± 1.11 G2: 4.16 ± 0.95 5 mo/EOT High ROB	Self-regulatory difficulties G1: 45.43 ± 11.21 G2: 50.94 ± 15.69	Self-regulatory difficulties G1: 34.3 ± 10.88 G2: 49.03 ± 15.45 G1 vs G2: *P* < .001
Silva et al[24] RCT G1: qigong massage, 28/24 G2: wait-list control, 19/18 Age, mean mo G1 + G2: 58	Teacher ABC Autism severity score G1: 76.3 ± 19.6 G2: 76.7 ± 30.1	ABC Autism severity score G1: 56.1 ± 26.4 G2: 75.3 ± 38.9 G1 vs G2: *P* = ns
4 mo/EOT Moderate ROB	PDDBI Sensory G1: 56.4 ± 10.6 G2: 56.5 ± 11.5	PDDBI Sensory G1: 50.1 ± 11.8 G2: 55.6 ± 10.0 G1 vs G2: *P* = .032
	Maladaptive behavior G1: 60.9 ± 13.0 G2: 61.8 ± 15.8	Maladaptive behavior G1: 52.3 ± 14.9 G2: 61.3 ± 15.2 G1 vs G2: *P* = .003
	Social/language/communication abilities G1: 49.9 ± 11.4 G2: 51.6 ± 12.1	Social/language/communication abilities G1: 53.0 ± 10.7 G2: 53.1 ± 12.2 G1 vs G2: *P* = ns
	SSC Sense G1: 38.1 ± 12.1 G2: 40.6 ± 14.6	SSC Sense G1: 28.5 ± 12.2 G2: 39.4 ± 12.6 G1 vs G2: *P* = .001
	Self-regulation G1: 49.1 ± 11.7 G2: 48.9 ± 12.7	Self-regulation G1: 39.2 ± 14.7 G2: 49.2 ± 11.6 G1 vs G2: *P* = .00002
	Autism composite score	Autism composite score

TABLE 3 Continued

Source, Study Design, Groups, *N* Enrollment/*N* Final, Mean Age, Months ± SD, Treatment Duration/Follow-up Time Point Posttreatment, ROB	Outcome Measure/Baseline Scores, Mean ± SD	Outcome Measure/Posttreatment Scores, Mean ± SD
	G1: 59.8 ± 11.1 G2: 60.2 ± 15.9	G1: 50.9 ± 14.8 G2: 58.9 ± 12.3 G1 vs G2: *P* = NR
Piravej et al[18] RCT G1: traditional thai massage + sensory integration therapy, 30/30 G2: sensory integration therapy, 30/30 Age (y) G1: 4.84 ± 1.86 G2: 4.48 ± 1.8 8 wk/EOT High ROB	CPRS – conduct problem G1: 0.69 ± 0.31 G2: 0.59 ± 0.34	CPRS – conduct problem G1: 0.6 ± 0.26 G2: 0.63 ± 0.33 G1 vs G2, *P* = .03
	CPRS – learning problem G1: 1.86 ± 0.55 G2: 2.02 ± 0.56	CPRS – learning problem G1: 1.76 ± 0.48 G2: 1.87 ± 0.53 G1 vs G2, *P* = ns
	CPRS – psychosomatic G1: 0.41 ± 0.45 G2: 0.43 ± 0.34	CPRS – psychosomatic G1: 0.41 ± 0.32 G2: 0.39 ± 0.25 G1 vs G2, *P* = ns
	CPRS – impulsivity-hyperactivity G1: 1.62 ± 0.6 G2: 1.65 ± 0.65	CPRS – impulsivity-hyperactivity G1: 1.44 ± 0.4 G2: 1.69 ± 0.57 G1 vs G2, *P* = ns
	CPRS – anxiety G1: 0.76 ± 0.53 G2: 0.62 ± 0.49	CPRS – anxiety G1: 0.62 ± 0.56 G2: 0.73 ± 0.5 G1 vs G2, *P* = .01
	CPRS – hyperactivity G1: 1.45 ± 0.51 G2: 1.53 ± 0.48	CPRS – hyperactivity G1: 1.32 ± 0.41 G2: 1.42 ± 0.42 G1 vs G2, *P* = ns
	CTRS – conduct problem G1: 0.98 ± 0.38 G2: 1.11±0.27	CTRS – conduct problem G1: 0.64 ± 0.35 G2: 0.71 ± 0.26 G1 vs G2, *P* = ns
	CTRS – hyperactivity G1: 1.59 ± 0.49 G2: 1.8 ± 0.36	CTRS – hyperactivity G1: 1.24 ± 0.5 G2: 1.49 ± 0.37 G1 vs G2, *P* = ns
	CTRS – inattention-passivity G1: 1.56 ± 0.41 G2: 1.67 ± 0.27	CTRS – inattention-passivity G1: 1.18 ± 0.51 G2: 1.34 ± 0.36 G1 vs G2, *P* = ns
	CTRS – hyperactivity index G1: 11.5 ± 9.23 G2: 13.9 ± 7.67	CTRS – hyperactivity index G1: 1.1 ± 0.49 G2: 1.28 ± 0.4 G1 vs G2, *P* = ns
	Sleep behavior – sleep diary G1: 11.5 ± 9.23 G2: 13.9 ± 7.67	Sleep behavior – sleep diary G1: 5.33 ± 3.28 G2: 8.2 ± 6.83 G1 vs G2: *P* = ns
Silva et al[17] RCT G1: qigong sensory training, 25/25 G2: waitlist control, 21/21 Age (mo) G1: 65.2 ± 20.7 G2: 53.3 ± 18.7 5 mo/EOT High ROB	ABC – total score G1: 48.5 ± 20.8 G2: 64.3 ± 33.8	ABC – total score G1: 33.9 ± 18.6 G2: 59.4 ± 35.4 G1 vs G2: *P* = .003
	PDDBI – maladaptive behavior score (parent) G1: 56.8 ± 11.5 G2: 59.5 ± 10.7	PDDBI – maladaptive behavior score (parent) G1: 45.6 ± 10.8 G2: 57.5 ± 10.4 G1 vs G2: *P* = .0003
	PDDBI – maladaptive behavior score (teacher) G1: 50.9 ± 10.4	PDDBI – maladaptive behavior score (teacher) G1: 44 ± 7.6

TABLE 3 Continued

Source, Study Design, Groups, *N* Enrollment/*N* Final, Mean Age, Months ± SD, Treatment Duration/Follow-up Time Point Posttreatment, ROB	Outcome Measure/Baseline Scores, Mean ± SD	Outcome Measure/Posttreatment Scores, Mean ± SD
	G2: 56.5 ± 13.3	G2: 49.7 ± 12.2
		G1 vs G2: *P* = ns
	PDDBI – social/language/communication score (parent)	PDDBI – social/language/communication score (parent)
	G1: 57.5 ± 6.8	G1: 56.7 ± 9.7
	G2: 49 ± 13.1	G2: 49.2 ± 12.8
		G1 vs G2: *P* = .007
	PDDBI – social/language/communication score (teacher)	PDDBI – social/language/communication score (teacher)
	G1: 53.7 ± 9.7	G1: 56.7 ± 9.7
	G2: 47 ± 13	G2: 47.6 ± 12.1
		G1 vs G2: *P* = .010
	PDDBI – sensory score (parent)	PDDBI – sensory score (parent)
	G1: 54.2 ± 9.6	G1: 46.2 ± 9.1
	G2: 56 ± 9.6	G2: 55.3 ± 10
		G1 vs G2: *P* = .005
Lee[36]	Social maturity scale	Social maturity scale
Prospective cohort	G1: 63.13 ± 15.76	G1: 70.74 ± 16.39
G1: massage therapy + attachment promotion program, 23/23	G2: 51.24 ± 10.48	G2: 52.86 ± 10.18
G2: attachment promotion program, 21/21		G1 vs G2, *P* = .005
Age (mo)	CARS – total score	CARS – total score
G1: 19 ± 4	G1: 44.31 ± 0.57	G1: 37.74 ± 7.49
G2: 9 ± 12	G2: 41.76 ± 5.07	G2: 39.19 ± 5.43
4 mo/EOT		G1 vs G2, *P* = NS
High ROB		
Silva et al[19]		Mean change score from baseline
RCT	VABS – living skills	VABS – living skills
G1: qigong massage, 8/8	G1: 28.8	G1: 9.8
G2: no treatment, 7/7	G2: 24.1	G2: 0.9
Age (y)		G1 vs G2: *P* = .02
G1 + G2: 2–6	VABS – socialization	VABS – socialization
5 mo/EOT	G1: 29.8	G1: 10
Moderate ROB	G2: 24.7	G2: 4.7
		G1 vs G2: *P* = .04
	VABS – receptive language	VABS –receptive language
	G1: 33.8	G1: 8.3
	G2: 23.6	G2: 10.6
		G1 vs G2: *P* = ns
	VABS – expressive language	VABS – expressive language
	G1: 31.5	G1: 8.9
	G2: 24.4	G2: 6.7
		G1 vs G2: *P* = ns
	VABS – gross motor skills	VABS – gross motor skills
	G1: 37.5	G1: 6.5
	G2: 33.4	G2: 0.9
		G1 vs G2: *P* = ns
	VABS – fine motor skills	VABS – fine motor skills
	G1: 36	G1: 8.8
	G2: 29	G2: 7.6
		G1 vs G2: *P* = ns
	Short sensory profile – total score	Short sensory profile – total score
	G1: 16.2	G1: –5.4
	G2: 15.7	G2: 2.7
		G1 vs G2: *P* = .01
	ABC – total score	ABC – total score
	G1: 71.3	G1: –13.3
	G2: 87.7	G2: –24.3
		G1 vs G2: *P* = ns
Latham and Stockman[28]	Verbal scoring	Verbal scoring

TABLE 3 Continued

Source, Study Design, Groups, *N* Enrollment/*N* Final, Mean Age, Months ± SD, Treatment Duration/Follow-up Time Point Posttreatment, ROB	Outcome Measure/Baseline Scores, Mean ± SD	Outcome Measure/Posttreatment Scores, Mean ± SD
RCT	Day 1 – verbal 1	Day 2 – verbal 3
G1: participation (tactual-kinesthetic experience), 17/17	G1: 8.12 ± 5.52	G1: 8.35 ± 6.06
G2: observation, 17/17	G2: 6.00 ± 5.20	G2: 5.39 ± 4.76
Age (y)	G1 vs G2: *P* = .041	G1 vs G2: *P* = .031
G1: 8.36 ± 2.6	Day 1 – verbal 2	Day 2 – verbal 4
G2: 8.69 ± 3.0	G1: 7.76 ± 5.51	G1: 8.25 ± 5.62
24–48 h/EOT	G2: 5.74 ± 5.41	G2: 5.66 ± 5.02
High ROB	G1 vs G2: *P* = .065	G1 vs G2: *P* = .017
	Nonverbal scoring	Nonverbal scoring
	Day 1 – score 1	Day 2 – score 2
	G1: 8.10 ± 1.97	G1: 8.35 ± 1.66
	G2: 4.60 ± 3.42	G2: 6.13 ± 3.47
	G1 vs G2: *P* = .001	G1 vs G2: *P* = .010
	Day 1 – rating 1	Day 2 – rating 2
	G1: 2.95 ± 1.08	G1: 2.88 ± 0.96
	G2: 3.90 ± 1.16	G2: 3.57 ± 1.23
	G1 vs G2: *P* = .010	G1 vs G2: *P* = .020
Gringras et al[27]		
RCT	% of time blanket in place, *n* = 67	% of time blanket in place
G1: weighted blanket, 36/27	G1: 75.6 ± 25.4	G1 vs G2: *P* = ns
G2: control blanket, 37/27	G2: 73.7 ± 25.7	
Crossover trial 73/54	TST, *n* = 67	TST
Age (y)	G1: 528.9 ± 127.1	G1 vs G2: *P* = ns
G1: 8.7 ± 3.3	G2: 513.0 ± 154.1	
G2: 9.9 ± 2.8	SOL min, *n* = 67	SOL min
2 wk/EOT	G1: 55.6 ± 37.8	G1 vs G2: *P* = ns
Moderate ROB	G2: 57.2 ± 42.8	
	Proportion of nights with ≥1 wake, *n* = 67	Proportion of nights with ≥1 wake
	G1: 0.2 ± 0.3	G1 vs G2: *P* = ns
	G2: 0.2 ± 0.3	
	Average time awake, *n* = 67	Average time awake
	G1: 15.6 ± 13.4	G1 vs G2: *P* = ns
	G2: 14.6 ± 13.3	
	TST min, *n* = 65/66	TST min
	G1: 454.4 ± 62.4	G1: 452.8 ± 65.0
	G2: 457.7 ± 64.6	G2: 455.4 ± 65.8 *P* = ns
	SOL min, *n* = 59	SOL min
	G1: 74.3 ± 48.7	G1: 71.4 ± 48.2
	G2: 69.9 ± 43.8	G2: 70.6 ± 44.3 *P* = ns
	Sleep efficiency, %, *n* = 59	Sleep efficiency (%)
	G1: 73.4 ± 9.3	G1: 73.6 ± 9.3
	G2: 74.2 ± 7.8	G2: 74.2 ± 8.0 *P* = ns
	No. of night awakenings, *n* = 65/66	No. of night awakenings
	G1: 19.1 ± 6.7	G1: 19.5 ± 7.0
	G2: 19.5 ± 6.9	G2: 19.5 ± 6.8 *P* = ns
	Time awake after sleep onset, *n* = 65/66	Time awake after sleep onset
	G1: 84.1 ± 43.1	G1: 84.6 ± 42.6
	G2: 83.8 ± 41.4	G2: 84.5 ± 41.5 *P* = ns

ABC, Autism Behavior Checklist; ADOS, Autism Diagnostic Observation Schedule; CARS, Childhood Autism Rating Scale; CI, confidence interval; CPRS, Conners' Parent Rating Scale; CTRS, Conners' Teacher Rating Scale; EOT, end of treatment; EOWPV, Expressive One-Word Picture Vocabulary Test; EOWVT, Expressive One Word Vocabulary Test; ES, effect size; G1, group 1; G2, group 2; GAS, Goal Attainment Scaling; Leiter-R, Leiter International Performance Scale-Revised; MAP, Miller Assessment for Preschoolers; MBCDI, MacArthur-Bates Communicative Development Inventories; NCBRF, Nisonger Child Behavior Rating Form; ND, no data; NR, not reported; ns, not significant; PCRI, Parent–Child Relationship Inventory; PDDBI, Pervasive Developmental Disorders Behavior Inventory; PEDI, Pediatric Evaluation of Disability Inventory; PPVT, Peabody Picture Vocabulary Test; RDLS, Reynell Developmental Language Scales; ROB, risk of bias; SMD, standardized mean difference; SSC, Sense and Self-Regulation Checklist; SOL, sleep onset latency; SRS, Social Responsiveness Scale; SSP, Short Sensory Profile; TST, total sleep time; VABS, Vineland Adaptive Behavior Scale; VSEEC, Vineland Social-Emotional Early Childhood Scales.

Finally, in an RCT evaluating the effects of a sensory integration-based protocol on low-functioning children with ASD, children receiving sensory integration-based intervention had significantly fewer parent-rated sensory problems at follow-up than children in the usual-care control group.[13]

Studies of Environmental Enrichment-based Approaches

Two small RCTs (low[23] and moderate[22] risk of bias) of environmental enrichment examined the same protocol and reported improvements in ASD symptoms, receptive language, and nonverbal cognitive skills after 6 months of treatment (Table 3). Compared with usual care, children receiving environmental enrichment had a more significant decrease in clinician-rated ASD symptoms ($P = .03$) at the end of treatment in 1 RCT, with nearly 5 times as many participants in the treatment group showing clinically significant drops of ≥5 points (42% vs 7%, $P = .03$).[22] The treatment group also had a 9-point increase in nonverbal cognitive skills compared with a decrease of ~3 points in the usual care group ($P = .008$). Both groups improved on expressive language skills, with no significant differences.

A second RCT built on the preliminary work by examining use of the same sensorimotor enrichment regimen over 6 months.[23] The treatment groups, which experienced significant attrition, showed more improvement than did the control group in receptive language skills, but both groups improved comparably for expressive language. The treatment group had significantly more improvement on mean nonverbal IQ scores as well as parent-rated sensory reactivity. Although more children in the treatment group compared with the control group shifted their diagnostic classification on the Autism Diagnostic Observation Schedule-2 from "autism" to "autism spectrum," all children across both groups continued to meet the cut-offs for ASD, making it difficult to interpret the clinical significance of the findings.

Studies of Auditory Integration-based Approaches

Two small, short-term RCTs of auditory integration-based approaches (moderate risk of bias) reported no significant differences between groups in language outcomes assessed on parent, teacher, and clinician observation measures.[14,15] Two high risk of bias RCTs (reported in a single publication) reported significant parent-rated improvements in hearing sensitivity and behavior (Table 3).[26] One crossover RCT comparing music passed through an electronic ear for attenuation and modulation to commercially produced music reported no statistically significant treatment effects on language skills.[14] Another RCT of auditory integration therapy for children with significant language delays reported no significant benefits of auditory integration.[15] Two RCTs examined the use of filtered music and reported some parent-rated improvement in hearing sensitivity, spontaneous speech, listening, and behavioral organization after filtered music compared with children in the control condition ($P \leq .05$).[26] Across both trials, groups did not differ in the other behavioral domains rated.

Studies of Music Therapy-based Approaches

Five small studies (2 low,[30–32] 1 moderate,[25] and 2 high[16,33] risk of bias) addressing music therapy-based approaches reported some significant effects on measures of behavior (social engagement, behavioral organization), verbal and nonverbal communication, and joint attention (directing and sharing attention to objects or events) with music-based intervention compared with control interventions (Table 3). Studies used different protocols and addressed different outcomes, and thus, drawing conclusions across studies is challenging.

One RCT (reported in 2 publications) compared a trainer-led rhythm and movement-based approach, a robot group focused on imitation, and a control group engaging in tabletop activities.[31,32] Both rhythm and robot treatment groups demonstrated greater posttest attention to trainers than to objects than did the control group ($P < .001$), with greater attention in the rhythm group than the robot group ($P < .001$). The rhythm group also demonstrated the greatest duration of spontaneous social attention, followed by the robot group and the control group ($P < .001$). Children in the robot group had greater self-directed vocalization compared with the other groups ($P < .002$), whereas children in the rhythm and control groups had greater spontaneous social verbalization to trainers than did children in the robot group ($P < .03$). In another RCT, children who received family-centered music therapy plus early intensive intervention had more improvement than those receiving early intensive intervention alone in parent-rated social engagement ($P < .001$), but remained significantly impaired relative to typically developing peers.[25] Groups did not differ on parent-reported autism symptoms, speech and language, or quality of the parent-child relationship.

In a crossover RCT comparing music therapy and toy play, investigators observed more joy, emotional synchronicity, and initiation of engagement during music therapy than in play sessions. In addition, children had significantly more compliant behavior and significantly fewer episodes of lack of response in the music therapy condition.[16]

Finally, 2 studies evaluating different forms of music therapy compared with treatment as usual or no treatment reported no significant group differences in outcome measurements, including ASD symptom severity and social skills at follow-up.[30,33]

Studies of Massage

Studies compared either massage with no massage; massage plus sensory integration-based treatment versus sensory integration-based treatment alone; and massage plus attachment therapy versus attachment therapy alone (Table 3). Almost all studies were from 1 group of investigators, and the participant overlap is unclear. Studies comparing massage to no massage generally reported improvements related to sensory processing, autism symptoms, and parent stress in both treatment and control groups over the course of 5 months of either parent- or parent and therapist-delivered intervention, with treatment groups improving significantly more than controls. The difficulty differentiating populations in these studies limits the SOE for their findings, although results seem promising regarding a sensory-focused intervention that can be delivered within the home environment with minimal risk of harms.

Five studies[17,19,24,29,35] (3 moderate[19,24,29] and 2 high[17,35] risk of bias) with unclear participant overlap compared children who received massage to wait-listed controls or those who received usual care. Children receiving massage improved significantly on parent ratings of autism symptoms as well as parent ratings of sensory challenges and self-regulation skills compared with children not receiving massage ($P \leq .05$).[17,19,24] Gains were maintained for 19 treatment group participants whose parents were available to provide data 5 months posttreatment, but data were unavailable on other participants.[17] In a retrospective report, children receiving either parent-delivered or parent and therapist-delivered massage had greater improvements in tactile defensiveness, self-regulation skills, and parent stress than did children not receiving massage ($P < .001$).[35] In 1 report assessing parent and therapist-delivered massage, post-hoc analyses revealed specific treatment effects on parent-rated, but not clinician-rated, measures of autism symptoms, receptive (but not expressive) language, sensory processing, and parent stress improved more in the treatment group compared with the control group ($P < .01$). Group differences in social and daily living skills were not significant.[29]

One RCT (high risk of bias) comparing sensory integration-based therapy compared with sensory integration-based therapy plus traditional Thai massage, parent-rated measures of anxiety and conduct improved in the massage group versus the control group ($P \leq .03$).[18] Children in both conditions had improved sleep as well as teacher ratings of conduct, attention, and activity level (P = NS). One retrospective cohort study (high risk of bias) investigating massage therapy with and without attachment therapy reported significant improvements in social maturity in the massage group compared with attachment therapy alone ($P = .005$), but measures of symptom severity did not differ significantly between groups.[36]

Additional Studies

Other interventions with sensory-related components reported limited differences between treatment groups (Table 3). One RCT (high risk of bias) examining the impact of a hands-on, tactile-based activity on the ability to learn a novel task reported greater perceived ease of learning for children in the hands-on participation group compared with children in the control, observation-only condition immediately posttreatment (P values $\leq .05$).[28] In another RCT (moderate risk of bias), parents were more likely to rate their children as calmer and sleeping better when using a weighted blanket ($P \leq .04$), despite a lack of physiologic evidence to support this (no significant group differences in actigraphy measures).[27] Investigators reported that 1 child developed a rash that may have been due to the blanket (resolved in 2 days).

SOE

Table 4 outlines SOE ratings. Sensory-related and motor skill outcomes improved in children receiving a sensory integration-based intervention compared with those receiving usual care or other treatment (significant improvements in 3 of 4 studies addressing the outcome). We have low confidence in these conclusions given the small sample sizes and short study durations (low SOE). Similarly, we have low confidence in the conclusion that environmental enrichment approaches improved nonverbal cognitive skills (low SOE). These enrichment approaches did not affect expressive language. We have low confidence in this conclusion (low SOE). We have low confidence in the conclusion that auditory integration-based approaches do not improve language outcomes (low SOE).

Massage improved sensory challenges and ASD symptom severity compared with no massage. Our confidence in this conclusion is low (low SOE). Massage did not improve maladaptive behavior (low SOE). We could not make conclusions about other comparisons, including for music therapy or the effects of sensory or auditory integration-based approaches or massage on other outcomes, given the lack of data (insufficient SOE).

TABLE 4 SOE for Interventions Targeting Sensory Challenges

Intervention/Outcome, Study Design, Risk of Bias, and No. of Studies, (*N* Total)	Study Limitations	Consistency	Directness	Precision	Reporting Bias	Finding SOE Grade
Sensory Integration-based Approaches Versus Control Approaches						
Sensory challenges RCT: 1 low,[21] 1 moderate,[20] 1 high[13] ($N = 99$) Retrospective cohort: 1 high[34] ($N = 20$)	High	Inconsistent	Direct	Imprecise	Undetected	Low SOE for positive effects of sensory integration-based approaches on sensory challenges. Significant improvements in sensory-related behaviors in treatment groups compared with control in 2 RCTs and 1 cohort study. No group differences in third RCT on parent-reported measure of sensory behaviors, but significant improvement in treatment group in sensory-related goals; all studies were small and short-term.
Motor skills RCT: 1 low,[21] 1 moderate[20] ($N = 69$) Retrospective cohort: 1 high[34] ($N = 20$)	High	Consistent	Direct	Imprecise	Undetected	Low SOE for positive effects of sensory integration on motor skills. Significant improvements in treatment groups versus control in 3 small studies.
Environmental Enrichment Versus Usual Care						
Nonverbal cognitive skills RCT: 1 low,[23] 1 moderate[22] ($N = 78$)	High	Consistent	Direct	Imprecise	Undetected	Low SOE for positive effects of enrichment on IQ. Significant improvements in IQ (Leiter Scale) in children receiving enrichment compared with those receiving usual care in 2 small RCTs with short-term follow-up and high limitations given small sample size
Expressive language RCT: 1 low,[23] 1 moderate[22] ($N = 78$)	High	Consistent	Direct	Imprecise	Undetected	Low SOE for lack of effect of enrichment on expressive language. No group differences in expressive language in 2 small RCTs with short-term follow-up and high limitations given small sample size.
Auditory Integration-based Approaches Versus Control						
Language RCT: 2 moderate,[14,15] 1 high[26] ($N = 91$)	High	Inconsistent	Direct	Imprecise	Undetected	Low SOE for lack of effects of auditory integration approaches on language No group differences in outcomes in 2 small crossover RCTs with short-term follow-up; parent-rated improvements in spontaneous speech in treatment group versus control in a third RCT.
Massage Versus Waitlist Control						
ASD symptom severity RCT: 2 moderate,[24,29] 1 high[17] ($N = 191$)	High	Consistent	Direct	Imprecise	Undetected	Low SOE for improvements in ASD symptom severity with massage versus control in the short term (<6 mo) Significant group differences in all 3 studies; SOE is low given unclear overlap in participants and high study limitations.

TABLE 4 Continued

Intervention/Outcome, Study Design, Risk of Bias, and No. of Studies, (*N* Total)	Study Limitations	Consistency	Directness	Precision	Reporting Bias	Finding SOE Grade
Sensory challenges RCT: 2 moderate,[24,29] 1 high[17] (*N* = 191) Retrospective cohort: 1 high[35] (*N* = 129)	High	Consistent	Direct	Imprecise	Undetected	Low SOE for positive effects on sensory challenges with massage versus control in the short term (<6 mo). Significant group differences in all 4 studies; SOE is low given unclear overlap in participants and high study limitations.
Maladaptive behaviors RCT: 1 moderate,[24] 1 high[17] (*N* = 88)	High	Consistent	Direct	Imprecise	Undetected	Low SOE for no effect on maladaptive behaviors with massage versus control in the short term (<6 mo). No significant group differences in 2 studies; SOE is low given unclear overlap in participants and high study limitations

We could not make conclusions about effects of music therapy, a tactile-based task, and weighted blankets given the number of studies addressing each intervention or outcome (insufficient SOE). We also could not make conclusions about other outcomes reported in studies of sensory integration-based approaches, auditory integration-based approaches, environmental enrichment, or massage given differences in outcome reporting (insufficient SOE).

DISCUSSION

We identified limited evidence for positive effects of sensory integration-based, environmental enrichment, and massage modalities. The lack of consistency in implementation combined with generally small sample sizes (median sample size = 34 total) and limited follow-up make it difficult to draw strong conclusions regarding treatment efficacy. Populations across studies were heterogeneous in terms of sensory challenges, ASD severity, age, and intellectual and adaptive functioning. Interventions, even within our broader categories, used differing sensory-specific approaches in differing combinations of components, settings, and duration, complicating our ability to draw conclusions across the body of literature. Longer-term outcomes are limited as is our ability to determine the effects of interventions on the underlying sensory challenges themselves. Potential harms of interventions were addressed in only 1 study, and few studies assessed factors that may modify effectiveness or drive the effects of interventions. Studies often used multicomponent strategies, and teasing apart the effects of specific components is not currently possible. These limitations in the evidence underscore the need for caregivers and referring providers to assess the possible benefits of specific sensory-focused intervention modalities based on the individual needs of the child, broader family goals and capacities, and interventions of more established effectiveness. In this capacity, some practice groups have recommended clear communication regarding the limits of intervention.[37,38]

Despite these limitations, investigators have made significant improvements in incorporating commonly used measures of symptom severity, behavior, language, and sensory difficulties to facilitate comparisons across studies. Parent-reported outcomes are necessary in this population of children, many of whom may not be able to complete aspects of assessments; however, studies are increasingly incorporating standardized interactive or observational measurement strategies. Moreover, an increasing use of treatment fidelity measures and replicable intervention protocols establishes a promising baseline for future investigations. Investigators in the area are also well aware of the challenges of conducting research using a disparate and variously defined set of approaches in a highly heterogeneous population and have made strides in incorporating outcome measures that attempt to balance heterogeneity and comparative effectiveness and measures of intervention fidelity.[39]

Our findings generally align with recent previous reviews of sensory-focused interventions.[6,40–49] Previous reviews typically noted low to moderate support for sensory integration-based approaches and limited evidence for other approaches. Reviews differentiating sensory integration approaches and more general "sensory-based" approaches reported better evidence from those studies that evaluated specific, typically manualized, sensory integration modalities compared with sensory-based approaches.[3,47] One review of auditory integration approaches reported no evidence of effectiveness.[41] One review of music therapy reported promising findings related to improvements in social interaction and communication,[50] and 1 review addressing massage reported that limited evidence precluded conclusions.[40] Previous reviews also consistently noted considerable heterogeneity, limited study quality/high risk of bias, limited follow-up, and lack of treatment fidelity.

Limitations of the Review

We included studies published in English only and did not include gray literature. Based on a scan of non-English publications, we concluded that excluding non-English studies would not introduce significant bias into the review, and previous studies have noted limited bias from such exclusion.[51–53] We also included only comparative studies of interventions with a sensory-specific focus and that included at least 10 children with ASD, and this undoubtedly means that most single-subject design studies were not included in this review. Single-subject designs can be helpful in assessing response to treatment in short time frames and under tightly controlled circumstances, but they typically do not provide information on longer-term or functional outcomes.

As noted, other approaches to categorizing sensory-focused interventions could also be used, and widespread consensus on a categorization approach is lacking. This review was also focused specifically on children with ASD and only on interventions targeting sensory challenges. Sensory approaches may be used with individuals with other diagnoses, and findings may be generalizable to children with ASD. However, including studies of children with other conditions was beyond our scope, as was inclusion of any intervention approach (eg, primarily behavioral or educational) reporting a sensory-related outcome. Finally, we used a nonvalidated tool to assess risk of bias, although the tool evaluates similar constructs to those assessed by tools such as that used by the Cochrane Collaboration, with the addition of ASD-specific domains.

Areas for Future Research

Several adjustments to study design would strengthen our ability to draw conclusions from future work. Many sample sizes were small, limiting their power to detect effects. Duration of treatment and follow-up were generally short, and the extent to which the effects of therapies could be expected to continue after cessation of treatment is not clear. Although some approaches may not hypothesize such durability, such data are nevertheless necessary for guiding pragmatic implementation and setting realistic expectations of effects for clinicians and families. In addition, few studies adequately accounted for concomitant interventions that might confound observed effectiveness.

Compared with our previous review, more studies used a common set of outcome measures. The extent to which these measures assess changes in potential underlying sensory-related impairments remains unclear, and understanding whether intervention can alter underlying vulnerabilities rather than short-term behavioral responses is a critical need. Translational work to understand the relationship between sensory symptoms and their potential neurobiology would inform intervention design.

It will be important for future work to compare sensory-based interventions not only to treatment as usual, but also to other interventions that involve engaged and active time with an adult, as did some studies in the current review.[21,23,36] Additional research is needed that controls for environmental or social factors that could cloud our ability to draw conclusions regarding effects. It will be important to identify which children are likely to benefit from particular interventions. To date, studies have provided limited characterization of treatment responders as well as the extent or type of sensory challenges children experience at baseline. Interventions targeting sensory challenges by their nature often employ multiple components, but our understanding of which components may drive effectiveness is lacking. Component analyses in this field would be productive for refining intervention approaches and for assessing the generalizability of results.

CONCLUSIONS

In sum, some interventions targeting sensory challenges may yield modest improvements, primarily in sensory- and ASD symptom severity-related outcomes. However, the evidence base for any category of intervention is small, and the durability of the effects beyond the immediate intervention period is unclear. Sensory integration-based approaches improved outcomes related to sensory challenges and motor skills, and studies of massage reported improvements in sensory responses and ASD symptoms. Environmental enrichment was also associated with improvements in nonverbal cognitive skills in the short term. Auditory integration-based approaches did not improve language outcomes. Some positive effects were associated with other approaches studied (music therapy, weighted blankets), but findings in these small studies were not consistent. Data on longer-term results are lacking. Although some therapies may hold promise and warrant additional study, substantial needs exist for continuing improvements in methodologic rigor in the field.

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ABBREVIATIONS

ASD: autism spectrum disorder
DSM-5: *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition*
RCT: randomized controlled trial
SOE: strength of the evidence

helped to conceptualize and design the review, helped to acquire, analyze, and interpret data, and helped to draft the initial manuscript; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Interventions Targeting Sensory Challenges in Autism Spectrum Disorder: A Systematic Review

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