Title
Environmental Enrichment as a Therapy for Autism: A Clinical Trial Replication and Extension

Journal
Behavioral Neuroscience, 129(4)

ISSN
0735-7044

Authors
Woo, Cynthia C
Donnelly, Joseph H
Steinberg-Epstein, Robin
et al.

Publication Date
2015-08-01

DOI
10.1037/bne0000068

Peer reviewed

Behavioral Neuroscience
2015, Vol. 129, No. 4, 412–422

0735-7044/15/$12.00 http://dx.doi.org/10.1037/bne0000068

Environmental Enrichment as a Therapy for Autism: A Clinical Trial Replication and Extension

Cynthia C. Woo, Joseph H. Donnelly, Robin Steinberg-Epstein, and Michael Leon
University of California, Irvine

Based on work done in animal models showing that autism-like symptoms are ameliorated following exposure to an enriched sensorimotor environment, we attempted to develop a comparable therapy for children with autism. In an initial randomized controlled trial, children with autism who received sensorimotor enrichment at home for 6 months had significant improvements in both their cognitive ability and the severity of their autism symptoms (Woo & Leon, 2013). We now report the outcomes of a similar randomized controlled trial in which children with autism, 3 to 6 years old, were randomly assigned to groups that received either daily sensorimotor enrichment, administered by their parents, along with standard care, or they received standard care alone. After 6 months, enriched children showed statistically significant gains in their IQ scores, a decline in their atypical sensory responses, and an improvement in their receptive language performance, compared to controls. Furthermore, after 6 months of enrichment therapy, 21% of the children who initially had been given an autism classification, using the Autism Diagnostic Observation Schedule, improved to the point that, although they remained on the autism spectrum, they no longer met the criteria for classic autism. None of the standard care controls reached an equivalent level of improvement. Finally, the outcome measures for children who received only a subset of sensory stimuli were similar to those receiving the full complement of enrichment exercises. Sensorimotor enrichment therapy therefore appears to be a cost-effective means of treating a range of symptoms for children with autism.

Keywords: autism, environmental enrichment, sensory enrichment therapy, sensorimotor enrichment, at-home treatment

Autism spectrum disorder (ASD) is characterized by deficits in verbal and nonverbal social communication, along with deficits in social interactions. Individuals with ASD also have repetitive and/or restricted patterns of behavior that include motor stereotypies, repetitive use of language, inflexible routines, and fixated interests. In addition, more than 90% of children with autism have sensory processing abnormalities that include sensory seeking behavior, avoidance of sensory stimuli, diminished responses to sensory stimulation, or enhanced perceptual abilities (Ben-Sasson et al., 2009; Happé & Frith, 2006; Hilton et al., 2010; Kern et al., 2007; Leekam, Nieto, Libby, Wing, & Gould, 2007; Mottron, Dawson, Soulières, Hubert, & Burack, 2006; Rogers & Ozonoff, 2005; Tomchek & Dunn, 2007; Watling, Deitz, & White, 2001). Indeed, abnormal sensory reactivity is included in the current *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM–5*; American Psychiatric Association, 2013) diagnostic criteria for ASD.

Individuals with ASD also appear to have problems integrating multisensory information into a single percept (Brandwein et al., 2013, 2015; Foss-Feig et al., 2010; Kwakye, Foss-Feig, Cascio, Stone, & Wallace, 2011). For example, the ability to combine information from concurrent auditory and visual senses is compromised in individuals with ASD (Marco, Hinkley, Hill, & Nagarajan, 2011; Stevenson et al., 2014). Using diffusion tensor imaging fiber tractography, Chang et al. (2014) evaluated individuals with ASD for the structural connectivity of their parieto-occipital tracts, which are involved in both sensory perception and multisensory integration, and found that they had decreased connectivity relative to controls.

Some of the sensory abnormalities that have been described in ASD also occur early in neural sensory processing pathways and therefore raise the possibility that the core features of ASD may be responses to abnormal sensory input (Behrmann et al., 2006; Caron, Mottron, Berthiaume, & Dawson, 2006; Gabriels et al., 2008; Kujala, Lepistö, & Näätänen, 2013). Alternatively, engaging

This article was published Online First June 8, 2015.

Cynthia C. Woo, Department of Neurobiology and Behavior, University of California, Irvine; Joseph H. Donnelly and Robin Steinberg-Epstein, Department of Pediatrics and Center for Autism and Neurodevelopmental Disorders, University of California, Irvine; Michael Leon, Department of Neurobiology and Behavior and Center for Autism Research and Translation, University of California, Irvine.

The study was conducted at the Institute for Clinical and Translational Sciences at University of California, Irvine (Grant UL1 TR000153). This article was supported by Eyal and Yael Aronoff, the Samueli Foundation, and the William and Nancy Thompson Family Foundation. The Aronoffs have subsequently invested in Mendability, a company that offers this treatment online, from which the authors receive no financial compensation. We thank Claudie Gordon-Pomares for her insights into child development; Brett A. Johnson, Robert Newcomb, and Michael Phelan for their help with data analysis; and all the families who participated in this study.

Correspondence concerning this article should be addressed to Michael Leon, University of California, Irvine, Department of Neurobiology and Behavior, 2205 McGaugh Hall, Irvine, CA 92697-4550. E-mail: mleon@uci.edu

in repetitive behaviors and/or insisting on sameness in the environment may ameliorate the anxiety evoked by abnormal sensory responses (Wigham, Rodgers, South, McConachie, & Freeston, 2015). Consistent with these notions is the finding that the severity of ASD symptoms involving temperament, personality, language, and social development are positively associated with the severity of their sensory problems (Brock et al., 2012; Watson et al., 2011).

Increasing sensory stimulation via environmental enrichment for a wide range of animal models of human neurological conditions has been shown to reduce the expression of their symptoms (Nithianantharajah & Hannan, 2006). When mouse models of syndromic forms of autism, such as Rett syndrome, fragile X syndrome, and Potocki–Lupski syndrome, were maintained in an enriched environment, many of their autism-like symptoms were ameliorated, including improved motor coordination, improved learning and memory, decreased repetitive behavior, increased social behavior, and increased exploratory behavior. In addition, environmental enrichment normalized both synaptic densities and long-term potentiation, and increased both BDNF and NGF levels in these mice (Kerr, Silva, Walz, & Young, 2010; Kondo et al., 2008; Lacaria, Spencer, Gu, Paylor, & Lupski, 2012; Lonetti et al., 2010; Nag et al., 2009; Restivo et al., 2005; Turner & Lewis, 2003).

BTBR T+tf/J (BTBR) mice have been bred to express behaviors that resemble the core symptoms of autism. They have impaired social interactions, deficits in communication (as judged by low levels of sniffing other mice), poor social transmission of food preferences, and increased repetitive behaviors (McFarlane et al., 2008; Moy et al., 2007, 2008; Pearson et al., 2011). Environmental enrichment normalizes both the repetitive grooming behaviors and repetitive object exploration in these mice (Reynolds, Urruela, & Devine, 2013).

In rats, environmental enrichment reversed many autism-like symptoms produced by prenatal valproic acid exposure (Schneider & Przewlocki, 2005; Schneider, Turczak, & Przewlocki, 2006). Enrichment normalized the responses to sensory stimuli, induced stronger acoustic prepulse inhibition, decreased locomotor activity, reduced repetitive behavior, increased exploratory behavior, decreased anxiety, and increased social interactions. The authors went on to suggest the use of environmental enrichment to treat autism symptoms in children. Likewise, after reviewing the literature describing the benefits of environmental enrichment for animal models of autism, Reynolds, Lane, and Richards (2010) suggested that environmental enrichment could benefit children with autism, noting that the key aspects of environmental enrichment appear to include novel and diverse sensory experiences. They further proposed that Ayres sensory integration therapy might be a useful means of exposing children with autism to an enriched environment.

Ayres sensory integration therapy engages children with autism through the use of a variety of physical, sensory, and cognitive exercises, focusing on vestibular, tactile, and proprioceptive stimulation (Baranek, 2002). Indeed, two randomized clinical trials showed positive outcomes in response to that therapy (Pfeiffer, Koenig, Kinnealey, Sheppard, & Henderson, 2011; Shaaf et al., 2014), but the conclusions relied on parental reports of improvement, rather than on objective, blinded assessments (Ashburner, Rodger, Ziviani, & Hinder, 2014). On the other hand, many reports have shown a clear lack of effect of such therapy on autism symptoms (American Academy of Pediatrics, 2012; Baranek, 2002; Dawson & Watling, 2000; Goldstein, 2000; National Autism Center, 2009; Parham et al., 2007; Sniezyk & Zane, 2015). Ayres sensory integration therapy therefore may not deliver optimal stimulation for this purpose, either because the exercises do not adequately enrich the sensory world of children with autism, or because it is typically offered in a clinic, only 1 to 3 times a week. At the same time, it seemed possible that a more varied and more frequent sensory enrichment paradigm could be more effective in treating children with autism.

We therefore had parents engage in a wide range of sensorimotor experiences with their child several times each day for 6 months and found that the severity of autism symptoms and cognitive performance improved significantly in the enriched children compared to controls (Woo & Leon, 2013). In addition, parents of children in the enriched group were more than twice as likely as parents of controls to report an improvement in their child's symptoms at the termination of the study.

In the present study, we sought to replicate the objectively assessed improvement in cognitive abilities that had previously been found following sensorimotor enrichment, using the Leiter International Performance Scale–Revised (Leiter-R). We also sought to extend the conclusions reached in the initial study regarding improvement of autism symptoms in enriched children, using an objective assessment of those symptoms. To that end, we administered the Autism Diagnostic Observation Schedule (ADOS) at both the start of the study and after 6 months of treatment to determine whether sensorimotor enrichment could improve the diagnostic classification of children with autism. In addition, we did an objective assessment of the communication abilities of these children, using the Reynell Developmental Language Scales for both receptive and expressive language. We then used the Short Sensory Profile to determine whether the sensory reactivity of the children improved with enrichment therapy, as assessed by their parents. Finally, we determined whether the complete set of sensorimotor enrichment exercises was needed to obtain beneficial effects for the children.

Method

Recruitment for the study was done at the Center for Autism and Neurodevelopmental Disorders in Orange, California. The director sent recruitment letters to all of the parents of current patients who had been given a medical diagnosis of autism (*DSM–IV–TR*; American Psychiatric Association, 2000), and were between 3 and 6 years old. We also posted a recruitment flyer in the clinic waiting room. We then screened the children to confirm the diagnosis of autism using the ADOS. For inclusion in the study, their combined communication and social interactions scores had to fall within the autism classification, rather than the autism spectrum classification. Children were excluded from the study if they had syndromic forms of autism or childhood disintegrative disorder. No psychotropic medications were administered throughout the study and anticonvulsant medication was only administered if the child had been on a stable dose longer than 3 months. Children could not have initiated a new in-school behavioral therapy within 1 month before the start of the study or 2 months for a private program. Neither Ayres sensory integration therapy, nor therapies that involved physical restraint were permitted during the trial.

To block-assign individuals according to autism severity, we calculated calibrated severity scores (CSS) based on their ADOS scores to allow a comparison across the different ADOS modules (Gotham, Pickles, & Lord, 2009). Individuals with CSS values of 6 to 8 (lower severity) were blocked together, as were individuals with CSS values of 9 to 10 (higher severity). We then used a randomization schedule for these blocks to balance assignments across our experimental and control groups.

All children continued their standard care treatments. The combinations of various behavioral therapies that were utilized by the children are referred to as "standard care" and no statistically significant differences in the frequency of use of the therapies were observed between the groups (see Table 1). We randomly assigned children who met our inclusion criteria to one of three groups. The first group was composed of standard care controls who received only their ongoing treatments. The full treatment group continued to receive their standard treatments, but in addition, they received the complete set of sensorimotor exercises as reported previously (Woo & Leon, 2013), which activated different combinations of senses, including olfactory, tactile, thermal, auditory, visual, and motor systems (see Table 2). We also wanted to determine whether a smaller set of exercises that entailed less novelty and somewhat less time for the parents to complete would be as effective as the entire set of exercises. Therefore, we included a partial treatment group, which received a subset of the exercises that excluded the olfactory, olfactory/tactile exercises, and music (see Table 2).

The parents of the children in both of the treatment groups were given a kit with the items needed for the sensorimotor exercises, along with written instructions for their use. After a brief training session, both groups engaged their child in the morning and in the evening with four to seven exercises at home. Each session took a total duration of approximately 15 to 30 min., with some exercises requiring additional set-up time. Every 2 weeks, the parents were contacted via e-mail and were assigned a different set of exercises for their child; the exercises became increasingly challenging over the course of 6 months.

Of the 97 children that we recruited, six were excluded because they did not meet our inclusion criterion. Out of the 91 remaining participants, 55.9% dropped out of the full treatment group, 56.7% dropped out of the partial treatment group, and 18.5% dropped out of the control group, often due to time constraints by the parents, personal issues, or the initiation of new therapies. There were 50 children who completed the 6-month program (43 boys and 7 girls) and we analyzed their data (see Figure 1).

All testing was conducted at the initiation of the study and after 6 months (see Table 3). The ADOS is an objective test that is regarded as the standard for autism classification (Falkmer, Anderson, Falkmer, & Horlin, 2013; Lord, Rutter, DiLavore, & Risi, 1999). The Leiter–R is an objective nonverbal test of cognitive abilities that has been used for testing children with autism (Grondhuis & Mulick, 2013; Shah & Holmes, 1985; Tsatsanis et al., 2003). The Reynell Developmental Language Scales is another objective test designed to evaluate both expressive and receptive language in young children, including those with autism (Kaale, Fagerland, Martinsen, & Smith, 2014; Kjellmer et al., 2012; Reynell & Gruber, 1990). This test has revealed language comprehension delays, along with a high level of variability in the development of language comprehension in children with autism (Kjellmer et al., 2012; Reynell & Gruber, 1990). The Reynell test sessions were video recorded and we subsequently scored the performance of the children using both the testing session and the digitized files. We used raw Reynell scores for statistical analyses. One experienced, licensed PhD psychologist conducted all of the ADOS assessments and another experienced, licensed PhD psychologist administered all of the Leiter and Reynell tests. Both individuals were blind to group assignment of the children.

The Short Sensory Profile assesses the atypical sensory behaviors commonly observed in children with autism, including tactile sensitivity, taste/smell sensitivity, movement sensitivity, visual/auditory sensitivity, underresponsive to sensation, sensation seeking, auditory filtering, and low energy/weakness (Ben-Sasson et al., 2007, 2009; Dunn, 1999; Hilton et al., 2010; Kern et al., 2007; Leekam et al., 2007; Mayes & Calhoun, 1999; Tomchek & Dunn, 2007; Watling et al., 2001). Parents completed the Short Sensory Profile at entry to the study and after 6 months.

The parents of children in the treatment groups also were asked to complete a daily log of their treatment activities. Finally, the

Table 1
Participant Characteristics and Standard Treatments Received by Children in the Sensorimotor Enrichment Group and the Standard Care Group

Characteristics and concurrent interventions	Standard care[a]	Sensorimotor enrichment[b]	*p* value
Female	2/22	5/28	
Male	20/22	23/28	
Average age (years) ± *SD*	4.54 ± 1.10	4.76 ± 1.14	
Speech therapy	19/22	23/28	.75
Occupational therapy	18/22	9/28	.30
Applied behavioral analysis (1:1) therapy	11/22	14/28	1.00
Applied behavioral analysis (classroom) therapy	8/22	9/28	.75
Social skills therapy	6/22	7/28	.84
Adapted PE, adapted karate, physical therapy	8/22	12/28	.66
Other	7/22	11/28	.61

Note. The *p* values were based on a two sample test for proportions. PE = physical education; Other = physical exercise, swimming, gymnastics, soccer team, youth choir, parent education, feeding therapy, prekindergarten group, music therapy, neurofeedback, American sign language, reflex integration, or behavior class.
[a] $n = 22$. [b] $n = 28$.

Table 2
Exercises for the Sensorimotor Treatment Groups

Exercises for the full and partial treatment groups	Additional exercises for the full treatment group
The child places his/her hands or feet in water of different temperatures.	The child is given a scented bath and a massage with scented oil.
The child squeezes objects of different shapes and textures.	The parent touches areas on the child's arms and legs with a cooled or warmed spoon while the parent speaks or sings.
The parent draws lines on the child's hand with objects of different texture while the child watches.	The child walks either on a sheet of foam or on large pillows, eventually blindfolded.
The blindfolded child walks on a pathway of different textures.	The child's finger is placed on a cool object and then a warm object.
The parent draws lines on the child's face, arms, and legs with objects having different textures while music plays.	The child pokes a hole in Play-Doh and then places grains of rice in it.
The child selects the twin of objects in a pillowcase after seeing it on the table.	The child selects a texture square that matches the texture of an object in a photo.
Lines are drawn on the child's arms and legs with a cooled or warmed spoon, or a neutral object.	Different objects are used to draw circles on the child's face.
The child is shown a picture of an object and picks out the real object on a table among other objects.	The child places cold straws filled with ice in Play-Doh using each hand.
The child is asked to walk on a 2″ × 8″ × 5′ board, then he/she is asked to do that task blindfolded.	The child walks on a 2″ × 8″ × 5′ board while holding a cooled tray.
The child picks out a colored bead among a plate full of ice cubes.	The parent rubs each of the child's fingers and toes in turn, while the child watches.
The child is shown a photo and his/her attention is drawn away from the photo using an auditory cue.	The child places coins in a piggy bank using only his/her reflection in a mirror.
The child lifts an object out of a cool bowl of water and then a warm bowl of water.	The child uses a magnet on the end of a small fishing line to pick up paper clips.
The child pulls a button from between the parent's fingers.	The child tracks a red object that is moved around a photo of a painting.
The child points to objects in a book and says the name of the object.	The child walks up and down stairs while holding a big ball or pillow.
The child matches the color of objects in a photo with colored beads.	The child draws shapes using pen and paper while the parent draws shapes on the child's back with a toy.
	The child draws lines using both hands simultaneously.
	The child blows a small piece of aluminum foil on the floor as far as possible.
	The child views a picture moving first behind and then in front of another picture.
	The child views a photo with music associated with that scene.
	Daily classical music for 10 min.
	Daily multiple pairings of fragrances (lemon, lavender, vanilla, anise, orange, apple, and hyacinth)[a] with gentle massage on the child's back 4 times/day for 1 min.
	Nightly scented pillow.

[a] Essential Oils, Portland, Oregon.

parents of the children in the control group were offered the complete therapy after the end of the trial.

Results

Baseline values for age, ADOS calibrated severity scores, Leiter–R scores, or Reynell scores were not statistically significantly different for the children who received sensorimotor enrichment and those who were in the standard care group (t tests, $p > .05$). In addition, there were no statistically significant differences in the outcomes between the two sensorimotor treatment groups (full treatment and partial treatment; t test, $p > .05$); we therefore combined the data from the two treatment groups to compare with the standard care controls. Differences between baseline and final test scores then were compared between the combined enriched groups and the standard care group using t tests adjusting for unequal variance (Satterthwaite; JMP software) or an analysis of covariance (ANCOVA) to control for baseline values. Statistical significance between enrichment and standard care groups was defined as a one-tailed p value $\leq .05$. All assessment scores are reported as mean ± standard error of the mean.

After 6 months, the children who received sensorimotor enrichment had a greater improvement in their average Leiter–R raw scores than did the children in the standard care group. The enriched children gained an average of 13.34 ± 2.14 points and the standard care children gained an average of 7.43 ± 1.94 points, $t(43) = 2.05$, $p = .024$; mean Leiter–R test score, sensorimotor enrichment: 35.85 ± 4.76 (baseline) and 49.19 ± 5.48 (6 months); standard care: 32.63 ± 6.07 (baseline) and 40.05 ± 6.25 (6 months).

In turn, we observed a greater increase for the enrichment group compared to the standard care group in average IQ score, which was generated from the Leiter raw score. The enrichment group gained an average of 8.42 ± 2.65 IQ points and the standard care group gained an average of 1.53 ± 2.66 IQ points (Figure 2), $t(43) = 1.84$, $p = .037$; mean IQ score, sensorimotor enrichment: 82.96 ± 5.17 (baseline) and 91.38 ± 5.58 (6 months); standard care: 76.63 ± 4.96 (baseline) and 78.16 ± 4.49 (6 months).

Sensory reactivity, as measured by the Short Sensory Profile, improved more in the enrichment group compared with the standard care group. The enriched children improved by an average of 11.36 ± 3.55 points, whereas the standard care children improved by an average of 2.85 ± 3.01 points (Figure 3), $t(46) = 1.83$, $p = .037$; mean Short Sensory Profile score, sensorimotor enrichment: 113.75 ± 4.76 (baseline), and 125.11 ± 5.42 (6 months); standard care: 129.3 ± 4.29 (baseline) and 132.15 ± 4.09 (6 months).

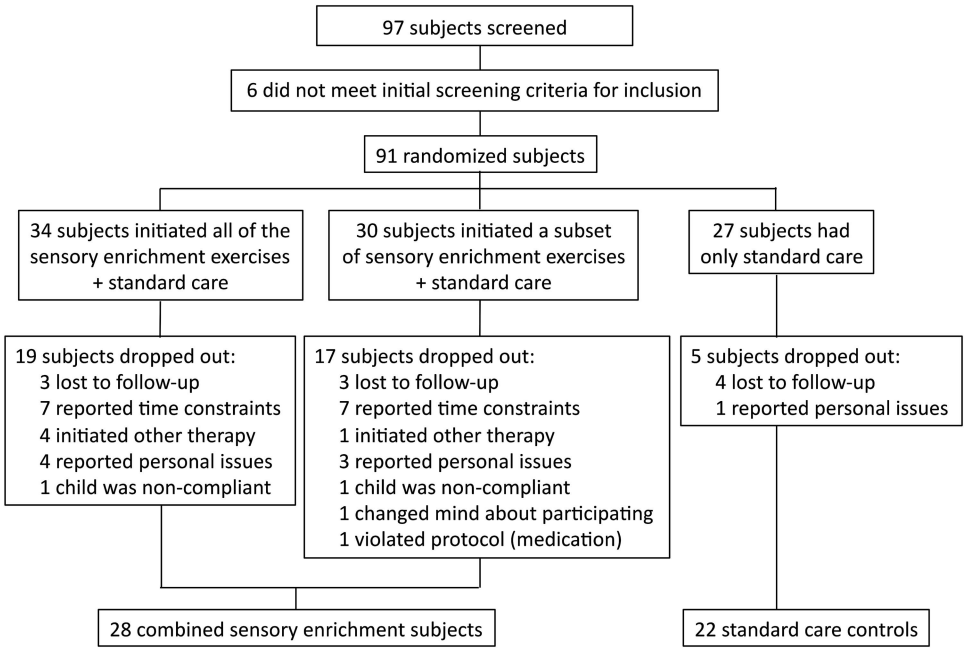

Figure 1. Flowchart for subject participation.

The scores for the receptive language subsection of the Reynell Developmental Language Scales showed that the enrichment group had an average increase of 7.42 ± 1.86 points, whereas the standard care group had an average increase of 3.63 ± 1.51 points (see Figure 4). An ANCOVA revealed a statistically significant increase in the mean score for the children in the enrichment group relative to the standard care group, $t(42) = -1.70$, $p = .048$; mean Reynell receptive language score, sensorimotor enrichment: 36.19 ± 4.64 (baseline) and 43.62 ± 4.14 (6 months); standard care: 33.37 ± 4.79 (baseline) and 37.0 ± 4.95 (6 months).

We found no difference between the enriched and standard care groups on the expressive language subsection of the Reynell Developmental Language Scales, with both groups showing improvement on this measure, sensorimotor enrichment: $t(25) = 5.16$, $p < .001$; standard care: $t(18) = 3.37$, $p < .002$. The enrichment group had an average increase of 7.19 ± 1.39 points and the standard care group had an average increase of 5.69 ± 1.69 points, $t(43) = 0.68$, $p = .248$; mean Reynell expressive language score, sensorimotor enrichment: 31.46 ± 4.14 (baseline) and 38.65 ± 4.16 (6 months); standard care: 31.47 ± 4.82 (baseline) and 37.16 ± 4.94 (6 months).

On the ADOS assessment, 21% of the children in the enriched environment group were no longer in the autism diagnostic classification after 6 months of therapy, although they all remained on the autism spectrum. No child in the standard care group changed their diagnostic classification on this assessment (Figure 5, two-sample test for proportions, $p = .01$). Within the sensorimotor enrichment group, there was no significant difference in age among those who changed classification compared to those who did not change their ADOS classification (mean ± *SD*; changed diagnosis: 5.29 ± 1.07 years; no change to diagnosis: 4.61 ± 1.09 years), $t(24) = 1.36$, $p = .209$. Correlations between any of the outcome measures that were used and the age at the initiation of treatment were not statistically significant (see Figure 6).

Standardized treatment effects based on Cohen's *d* for the standardized mean difference for the within-subject change on the Leiter, Short Sensory Profile, and Reynell Receptive Language assessments were .54, .51 and .45, respectively; therefore these

Table 3
Assessments

Assessment	Outcome measures	Assessors
Autism Diagnostic Observation Schedule (ADOS)	An objective diagnostic test for autism spectrum disorder	Licensed PhD psychologist "A" completed all ADOS assessments.
Reynell Developmental Language Scales	An objective test of receptive and expressive language	Licensed PhD psychologist "B" completed all Reynell assessments.
Leiter International Performance Scale–Revised	An objective nonverbal test of cognitive abilities	Licensed PhD psychologist "B" completed all Leiter assessments.
Short Sensory Profile	A parental assessment of atypical sensory responses	Parents completed all Short Sensory Profiles.

Note. All ADOS, Reynell, and Leiter assessments were conducted by individuals who were unaware of group assignments.

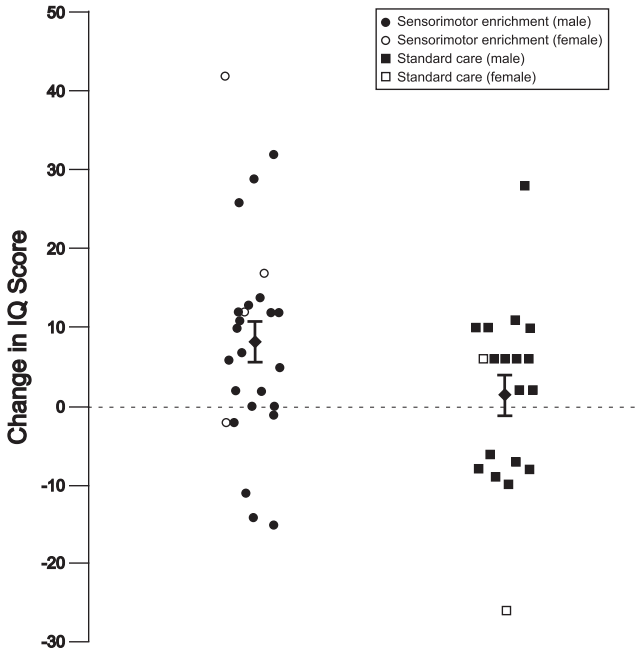

Figure 2. Scatterplots of the change in IQ score. Sensorimotor enrichment results in improvements in cognitive function in children with autism as measured using the Leiter International Performance Scale–Revised. The mean change in IQ score for each group is designated with a solid diamond, and error bars denote standard error of the mean.

outcomes should be regarded as showing a medium-size effect (Cohen, 1988). Because falling below the autism cutoff on the ADOS is a dichotomous variable, we calculated that five participants need to be treated for 6 months for one to fall below the autism cutoff. The therapy therefore should be characterized as effective (McQuay & Moore, 1997).

The average percentage compliance for the environmental enrichment group was 77% (range: 36–100%), according to the information contained in the daily diaries. The entries in the daily treatment diary did not reveal a significant correlation between the number of at-home therapy treatments and any of the outcomes for the study.

In an effort to predict who might benefit from therapy, the probability of falling below the ADOS autism score in the treatment group was modeled using principle components analysis with the baseline Leiter, Short Sensory Profile, and Reynell receptive language assessments. Correlations with scores on principle components 1 (PC1) and principle components 2 (PC2) for treatment and controls were quite weak. However, because the Short Sensory Profile scores appeared to contribute more noise than signal to the analysis, we performed principal components analysis for just the baseline Leiter and Reynell receptive language scores. The results of a reduced model based on the first principal component of baseline Leiter and Reynell receptive language scores showed that PC1 accounted for about 87% of the total variation among participants and it was an equally weighted average of Leiter and Reynell scores, indicating that PC1 was directly related to baseline scores on these assessments. Indeed, each one-unit difference in the PC1 score (effectively, the average baseline Leiter and Reynell receptive language scores) was associated with an approximate 11% increase in the odds of falling below the ADOS autism cutoff score after 6 months (estimated odds = 1.11, 95% CI [0.99, 1.25], $p = .07$).

Discussion

This randomized controlled trial replicated the findings that sensorimotor enrichment can improve outcomes in children with autism. We again found that the gains in cognitive performance of enriched children with autism significantly exceeded that of controls (Woo & Leon, 2013). Standardized treatment effects analysis using Cohen's *d* revealed that these improvements were medium-size effects. These gains could be due to improved cognitive functioning, improved attention, improved social skills, or a combination of such gains. It also is possible that the improvement in their reactions to sensory stimuli and/or improvements in language skills allowed children in the enriched group to be more attentive and interactive during the testing situation, thereby allowing their true cognitive abilities to be revealed. Indeed, sensory reactivity was shown to improve following sensorimotor enrichment, as revealed by the Short Sensory Profile. It should be noted that Pfeiffer et al. (2011) observed no significant improvement in sensory responses following Ayres sensory integration therapy for children with ASD, although Schaaf et al. (2014) did.

Both the Woo and Leon (2013) study on sensorimotor enrichment and the present study used the Leiter test to reveal a greater improvement in cognitive scores in the enriched group. The increase in raw Leiter scores in the Woo and Leon (2013) study was 8.77 points and the increase in the present study was 13.34 points, whereas controls fell by 2.50 points in the Woo and Leon (2013) study and rose by 7.42 points in this study. Although the change in Leiter scores was significantly larger in the enriched group than the control group in both studies, the higher scores in both groups in the present study may be due to the younger age of participants

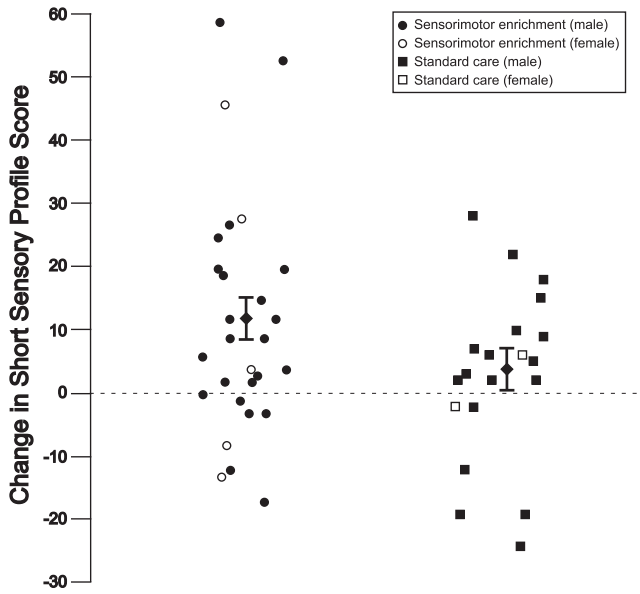

Figure 3. Scatterplots of the change in Short Sensory Profile score. Sensorimotor enrichment results in improvements in sensory responsiveness in children with autism. The mean change in Short Sensory Profile score for each group is designated with a solid diamond, and error bars denote standard error of the mean.

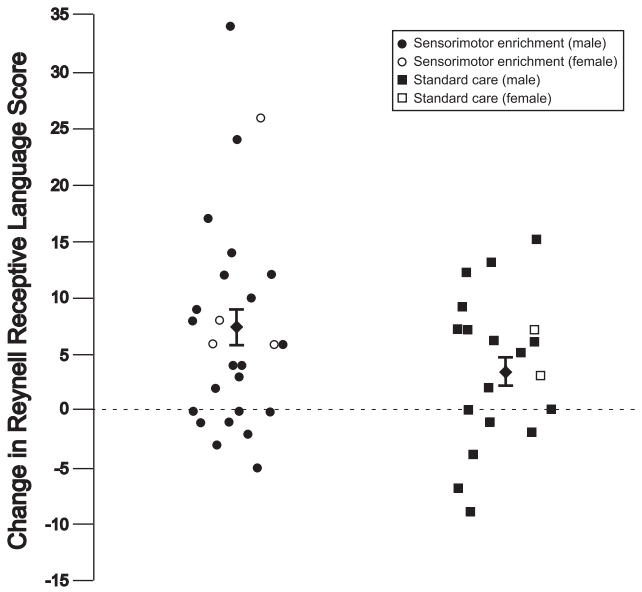

Figure 4. Scatterplots of the change in receptive language, assessed with the Reynell Developmental Language Scales. Sensorimotor enrichment results in improvements in receptive language skills in children with autism. The mean change in Reynell Receptive Language Scale score for each group is designated with a solid diamond, and error bars denote standard error of the mean.

($M \pm SD$; 4.66 ± 1.12, range 3–6 years), relative to the age of participants in the initial study ($M = 6.6 \pm 2.5$, range 3–12 years).

At the same time, a potential advantage of this therapy is that it does not require initiation at a very young age, which necessitates an early diagnosis of autism; it appears to be beneficial for both older children and younger children (Woo & Leon, 2013). Indeed, the present study showed no correlation between age and assessment outcomes.

Some of the children improved to the point that they no longer reached the autism cut-off on the ADOS, although they remained on the autism spectrum, whereas none of the children in the standard care group changed their diagnostic classification. High initial scores on the Leiter and Reynell assessments together predicted these beneficial outcomes for the children in the study.

Similar symptom improvements, as measured by the ADOS, were found for 24- to 48-month-old children who were given applied behavioral analysis with a socialization program over the course of 6 months (Muratori, Narzisi, & the IDIA Group, 2014). Although there was no control group in that study, Dawson et al. (2010) found comparable levels of improvement in children with autism, 24 to 30 months, after 2 years of intensive therapy in a randomized controlled trial. Given that the typical developmental trajectory of the symptoms for children with autism, as assessed by the ADOS, is stable over the course of 6 months (Szatmari et al., 2015), the finding of a change in diagnostic classification within that period should be considered to be clinically significant, and points to the potential of environmental enrichment therapy to induce clinically significant improvements in children with autism.

We did not find a difference in outcomes between enriched and control groups for expressive language abilities as measured using the Reynell Developmental Language Scales, with both groups showing statistically significant improvements on this measure. Likewise, Woo and Leon (2013) reported no outcome differences when comparing the enriched group to the controls on the Expressive One-Word Picture Vocabulary Test (Brownell, 2000), because both groups also showed comparable improvement on that test. At the same time, the present study showed a statistically significant difference in improvement in receptive language in the enriched group compared to the control group.

In Woo and Leon's (2013) study, they reported clinically significant improvements in the severity of autism symptoms, as measured with the Childhood Autism Rating Scale (Schopler, Reichler, DeVellis, & Daly, 1980), with 42% of the enriched children experiencing a clinically significant improvement of at least five points on that scale, compared to 7% in the standard care group. In the present study, the severity of autism symptoms also was reduced in a significant proportion of children in the enriched group as evaluated with the ADOS. In both studies, enriched children had a greater increase in their Leiter cognitive scores than did standard care children. Improved sensory responsiveness and enhanced receptive language skills in enriched children are novel findings in the present study. This treatment therefore can impact symptoms associated with autism in addition to the core symptoms of autism.

Although we consider it likely that it was the enriched sensory environment that promoted the improvements in their social, language, cognitive, and sensory status, it is also possible that the sensory exercises increased positive interactions between the child and their parents, and it was those interactions that mediated the improvements that we observed.

The outcome measures for children who received only a subset of sensory stimuli were similar to those receiving the full comple-

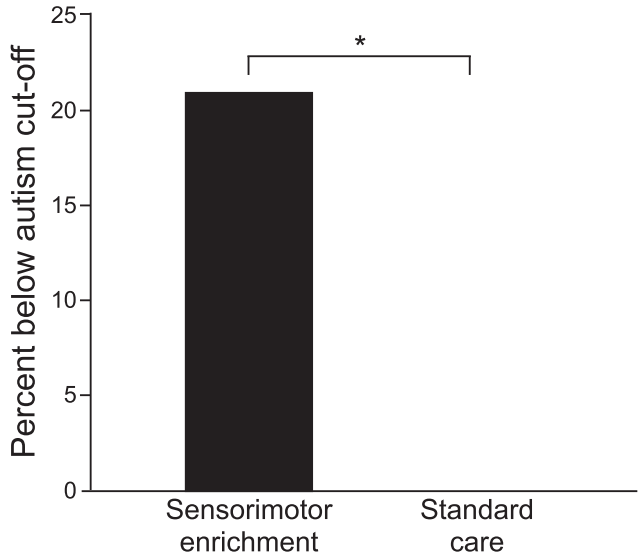

Figure 5. After six months, the percent of children who fell below the autism cut-off score using the Autism Diagnostic Observation Schedule (ADOS). We found that 21% of the children who received sensorimotor enrichment in addition to their standard care fell below that mark, while none of the children receiving standard care alone reached that level of improvement. * Two-sample test for proportions, $p = .01$.

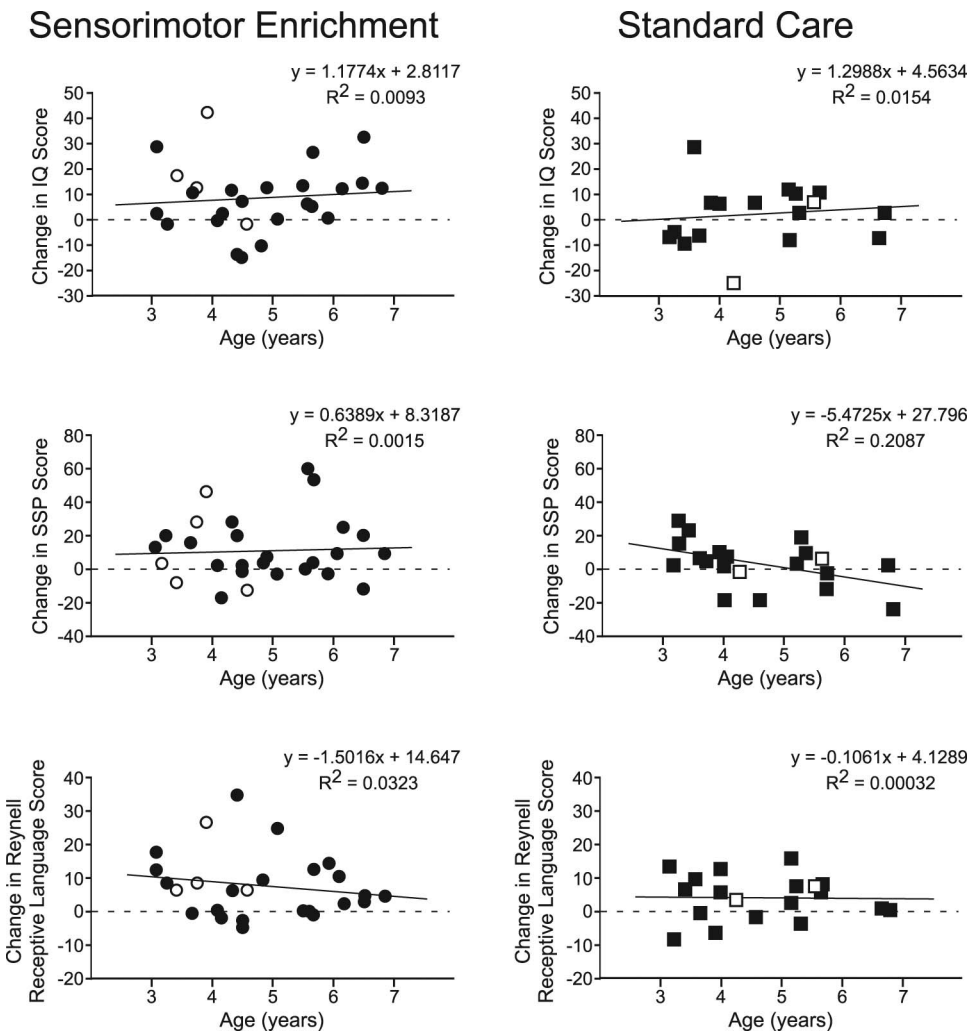

Figure 6. Correlation scatterplots of outcome measures as a function of age at initiation of the study. Leiter International Performance Scale–Revised (IQ), Short Sensory Profile, and Reynell Receptive Language scores for the children are shown relative to the children's age at the initiation of the study. Closed markers denote male participants and open markers denote female participants.

ment of stimuli, suggesting that the benefits of sensorimotor enrichment may not depend on the regular activation of all the senses. It may also be the case that olfactory, tactile, and music stimulation evoke transient comfort (Grandin, 1992) and may therefore have had less influence on the outcome measures reported in our study. It should be noted, however, that the parents in the full treatment group typically reported that the scents calmed their child during the day and allowed their child to sleep better at night. Indeed, many of the parents who were using the scents in their therapy said that it was the one exercise that they would continue to use after the termination of the trial.

Although parents typically did not indicate that they would continue with the music experiences, they did note that their child enjoyed the music exposure. Other researchers have shown some improvements with music therapy for children with autism (Boso, Emanuele, Minazzi, Abbamonte, & Politi, 2007; Edgerton, 1994; Kim, Wigram, & Gold, 2008). Music exposure, however, was not a crucial aspect for the outcomes that we measured in the present study.

A clear limitation of this study was the high proportion of families that did not complete the treatment, often due to the time difficulties involved with doing the exercises in the morning and evening. Although each set of exercises took 15 to 30 min, setting up the exercises often took additional time, and the impact on the ability of working parents to complete the exercises was significant. For the parents who finished the study, this issue could underlie the variability observed with the daily logs that were completed by the parents, with some parents at 100% compliance and with others at only 36% compliance. In addition, some of the children had recently been diagnosed at the start of the trial and parents continued to search for new therapies for their child after enrolling in our study. We were then forced to terminate their participation in the study. It may be that a higher level of communication (weekly phone calls rather than e-mail on alternate

weeks) would have fostered a higher rate of continuing participation.

It will be important to determine whether there is an effective level of sensorimotor enrichment that can have beneficial outcomes with significantly less effort expected from the parents. We also hope to determine whether having children treated by professionals in their special-needs classrooms will allow a greater proportion of children to benefit from this treatment by obviating the need for parental provision of the therapy. Another issue that should be addressed in future studies is whether sensorimotor enrichment can be effective as a monotherapy. If that is the case, then there would be significant financial savings in the treatment of autism. On the other hand, if this approach is effective only as a concurrent therapy, it could enhance current standard care outcomes. Additional research will be able to determine whether these effects are long lasting, and whether continued therapy can continue to improve outcomes for treated children. Other critical questions include whether it can be effective for older or younger children, whether it can be effective for medicated children, whether we can characterize the changes in the brain, and whether children across the autism spectrum can benefit from this treatment. It will be critical to conduct a large, multicenter randomized controlled trial to determine whether this approach can be clinically useful. With a sufficient number of participants, it may be possible to describe more differences among individuals that may reveal which children are likely to see improvement in their autism symptoms from this treatment. Finally, we would like to determine whether this approach to treatment can impact other developmental disorders, as would be predicted by the effects of environmental enrichment on animal models of human neurological disorders. At this time, these data support the conclusion that parents can initiate an autism therapy for their children at home at minimal cost, a therapy that has no known side effects, and that improves both the core and associated symptoms of autism.

References

American Academy of Pediatrics. (2012). Policy statement: Sensory integration therapies for children with developmental and behavioral disorders. *Pediatrics, 129,* 1186–1189. http://dx.doi.org/10.1542/peds.2012-0876

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th ed., text rev.). Washington, DC: Author.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC. Retrieved from http://dsm.psychiatryonline.org/doi/full/10.1176/appi.books.9780890425596.x00DiagnosticClassification

Ashburner, J. K., Rodger, S. A., Ziviani, J. M., & Hinder, E. A. (2014). Comment on: "An intervention for sensory difficulties in children with autism: A randomized trial" by Schaaf et al. (2013). *Journal of Autism and Developmental Disorders, 44,* 1486–1488. http://dx.doi.org/10.1007/s10803-014-2083-0

Baranek, G. T. (2002). Efficacy of sensory and motor interventions for children with autism. *Journal of Autism and Developmental Disorders, 32,* 397–422. http://dx.doi.org/10.1023/A:1020541906063

Behrmann, M., Avidan, G., Leonard, G. L., Kimchi, R., Luna, B., Humphreys, K., & Minshew, N. (2006). Configural processing in autism and its relationship to face processing. *Neuropsychologia, 44,* 110–129. http://dx.doi.org/10.1016/j.neuropsychologia.2005.04.002

Ben-Sasson, A., Cermak, S. A., Orsmond, G. I., Tager-Flusberg, H., Carter, A. S., Kadlec, M. B., & Dunn, W. (2007). Extreme sensory modulation behaviors in toddlers with autism spectrum disorders. *The American Journal of Occupational Therapy, 61,* 584–592. http://dx.doi.org/10.5014/ajot.61.5.584

Ben-Sasson, A., Hen, L., Fluss, R., Cermak, S. A., Engel-Yeger, B., & Gal, E. (2009). A meta-analysis of sensory modulation symptoms in individuals with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 39,* 1–11. http://dx.doi.org/10.1007/s10803-008-0593-3

Boso, M., Emanuele, E., Minazzi, V., Abbamonte, M., & Politi, P. (2007). Effect of long-term interactive music therapy on behavior profile and musical skills in young adults with severe autism. *Journal of Alternative and Complementary Medicine, 13,* 709–712. http://dx.doi.org/10.1089/acm.2006.6334

Brandwein, A. B., Foxe, J. J., Butler, J. S., Frey, H. P., Bates, J. C., Shulman, L. H., & Molholm, S. (2015). Neurophysiological indices of atypical auditory processing and multisensory integration are associated with symptom severity in autism. *Journal of Autism and Developmental Disorders, 45,* 230–244. http://dx.doi.org/10.1007/s10803-014-2212-9

Brandwein, A. B., Foxe, J. J., Butler, J. S., Russo, N. N., Altschuler, T. S., Gomes, H., & Molholm, S. (2013). The development of multisensory integration in high-functioning autism: High-density electrical mapping and psychophysical measures reveal impairments in the processing of audiovisual inputs. *Cerebral Cortex, 23,* 1329–1341. http://dx.doi.org/10.1093/cercor/bhs109

Brock, M. E., Freuler, A., Baranek, G. T., Watson, L. R., Poe, M. D., & Sabatino, A. (2012). Temperament and sensory features of children with autism. *Journal of Autism and Developmental Disorders, 42,* 2271–2284. http://dx.doi.org/10.1007/s10803-012-1472-5

Brownell, R. (2000). *Expressive One-Word Picture Vocabulary Test manual*. Novato, CA: Academic Therapy Publications.

Caron, M. J., Mottron, L., Berthiaume, C., & Dawson, M. (2006). Cognitive mechanisms, specificity and neural underpinnings of visuospatial peaks in autism. *Brain: A Journal of Neurology, 129,* 1789–1802. http://dx.doi.org/10.1093/brain/awl072

Chang, Y.-S., Owen, J. P., Desai, S. S., Hill, S. S., Arnett, A. B., Harris, J., . . . Mukherjee, P. (2014). Autism and sensory processing disorders: Shared white matter disruption in sensory pathways but divergent connectivity in social-emotional pathways. *PLoS ONE, 9,* e103038. http://dx.doi.org/10.1371/journal.pone.0103038

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed., pp. 284–285). Hillsdale, NJ: Erlbaum.

Dawson, G., Rogers, S., Munson, J., Smith, M., Winter, J., Greenson, J., . . . Varley, J. (2010). Randomized, controlled trial of an intervention for toddlers with autism: The early start Denver model. *Pediatrics, 125,* e17–e23. http://dx.doi.org/10.1542/peds.2009-0958

Dawson, G., & Watling, R. (2000). Interventions to facilitate auditory, visual, and motor integration in autism: A review of the evidence. *Journal of Autism and Developmental Disorders, 30,* 415–421. http://dx.doi.org/10.1023/A:1005547422749

Dunn, W. (1999). *The sensory profile: User's manual*. San Antonio, TX: Psychological Corporation.

Edgerton, C. L. (1994). The effect of improvisational music therapy on the communicative behaviors of autistic children. *Journal of Music Therapy, 31,* 31–62. http://dx.doi.org/10.1093/jmt/31.1.31

Falkmer, T., Anderson, K., Falkmer, M., & Horlin, C. (2013). Diagnostic procedures in autism spectrum disorders: A systematic literature review. *European Child & Adolescent Psychiatry, 22,* 329–340. http://dx.doi.org/10.1007/s00787-013-0375-0

Foss-Feig, J. H., Kwakye, L. D., Cascio, C. J., Burnette, C. P., Kadivar, H., Stone, W. L., & Wallace, M. T. (2010). An extended multisensory temporal binding window in autism spectrum disorders. *Experimental Brain Research, 203,* 381–389. http://dx.doi.org/10.1007/s00221-010-2240-4

Gabriels, R. L., Agnew, J. A., Miller, L. J., Gralla, J., Pan, Z., Goldson, E., . . . Hooks, E. (2008). Is there a relationship between restricted, repetitive, stereotyped behaviors and interests and abnormal sensory response in children with autism spectrum disorders? *Research in Autism Spectrum Disorders, 2,* 660–670. http://dx.doi.org/10.1016/j.rasd.2008.02.002

Goldstein, H. (2000). Commentary: Interventions to facilitate auditory, visual, and motor integration: "show me the data." *Journal of Autism and Developmental Disorders, 30,* 423–425. http://dx.doi.org/10.1023/A:1005599406819

Gotham, K., Pickles, A., & Lord, C. (2009). Standardizing ADOS scores for a measure of severity in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 39,* 693–705. http://dx.doi.org/10.1007/s10803-008-0674-3

Grandin, T. (1992). Calming effects of deep touch pressure in patients with autistic disorder, college students, and animals. *Journal of Child & Adolescent Pharmacology, 2,* 63–72. http://dx.doi.org/10.1089/cap.1992.2.63

Grondhuis, S. N., & Mulick, J. A. (2013). Comparison of the Leiter International Performance Scale–Revised and the Stanford–Binet Intelligence Scales, 5th Edition, in children with autism spectrum disorders. *American Journal on Intellectual and Developmental Disabilities, 118,* 44–54. http://dx.doi.org/10.1352/1944-7558-118.1.44

Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 36,* 5–25. http://dx.doi.org/10.1007/s10803-005-0039-0

Hilton, C. L., Harper, J. D., Kueker, R. H., Lang, A. R., Abbacchi, A. M., Todorov, A., & LaVesser, P. D. (2010). Sensory responsiveness as a predictor of social severity in children with high functioning autism spectrum disorders. *Journal of Autism and Developmental Disorders, 40,* 937–945. http://dx.doi.org/10.1007/s10803-010-0944-8

Kaale, A., Fagerland, M. W., Martinsen, E. W., & Smith, L. (2014). Preschool-based social communication treatment for children with autism: 12-month follow-up of a randomized trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 53,* 188–198. http://dx.doi.org/10.1016/j.jaac.2013.09.019

Kern, J. K., Trivedi, M. H., Grannemann, B. D., Garver, C. R., Johnson, D. G., Andrews, A. A., . . . Schroeder, J. L. (2007). Sensory correlations in autism. *Autism, 11,* 123–134. http://dx.doi.org/10.1177/1362361307075702

Kerr, B., Silva, P. A., Walz, K., & Young, J. I. (2010). Unconventional transcriptional response to environmental enrichment in a mouse model of Rett syndrome. *PLoS ONE, 5,* e11534. http://dx.doi.org/10.1371/journal.pone.0011534

Kim, J., Wigram, T., & Gold, C. (2008). The effects of improvisational music therapy on joint attention behaviors in autistic children: A randomized controlled study. *Journal of Autism and Developmental Disorders, 38,* 1758–1766. http://dx.doi.org/10.1007/s10803-008-0566-6

Kjellmer, L., Hedvall, A., Holm, A., Fernell, E., Gillberg, C., & Norrelgen, F. (2012). Language comprehension in preschoolers with autism spectrum disorders without intellectual disability: Use of the Reynell Developmental Language Scales. *Research in Autism Spectrum Disorders, 6,* 1119–1125. http://dx.doi.org/10.1016/j.rasd.2012.03.003

Kondo, M., Gray, L. J., Pelka, G. J., Christodoulou, J., Tam, P. P., & Hannan, A. J. (2008). Environmental enrichment ameliorates a motor coordination deficit in a mouse model of Rett syndrome—Mecp2 gene dosage effects and BDNF expression. *The European Journal of Neuroscience, 27,* 3342–3350. http://dx.doi.org/10.1111/j.1460-9568.2008.06305.x

Kujala, T., Lepistö, T., & Näätänen, R. (2013). The neural basis of aberrant speech and audition in autism spectrum disorders. *Neuroscience and Biobehavioral Reviews, 37,* 697–704. http://dx.doi.org/10.1016/j.neubiorev.2013.01.006

Kwakye, L. D., Foss-Feig, J. H., Cascio, C. J., Stone, W. L., & Wallace, M. T. (2011). Altered auditory and multisensory temporal processing in autism spectrum disorders. *Frontiers in Integrative Neuroscience, 4,* 129. http://dx.doi.org/10.3389/fnint.2010.00129

Lacaria, M., Spencer, C., Gu, W., Paylor, R., & Lupski, J. R. (2012). Enriched rearing improves behavioral responses of an animal model for CNV-based autistic-like traits. *Human Molecular Genetics, 21,* 3083–3096. http://dx.doi.org/10.1093/hmg/dds124

Leekam, S. R., Nieto, C., Libby, S. J., Wing, L., & Gould, J. (2007). Describing the sensory abnormalities of children and adults with autism. *Journal of Autism and Developmental Disorders, 37,* 894–910. http://dx.doi.org/10.1007/s10803-006-0218-7

Lonetti, G., Angelucci, A., Morando, L., Boggio, E. M., Giustetto, M., & Pizzorusso, T. (2010). Early environmental enrichment moderates the behavioral and synaptic phenotype of MeCP2 null mice. *Biological Psychiatry, 67,* 657–665. http://dx.doi.org/10.1016/j.biopsych.2009.12.022

Lord, C., Rutter, M., DiLavore, P. C., & Risi, S. (1999). *Autism diagnostic observation schedule*. Los Angeles, CA: Western Psychological.

Marco, E. J., Hinkley, L. B., Hill, S. S., & Nagarajan, S. S. (2011). Sensory processing in autism: A review of neurophysiologic findings. *Pediatric Research, 69,* 48R–54R. http://dx.doi.org/10.1203/PDR.0b013e3182130c54

Mayes, S. D., & Calhoun, S. L. (1999). Symptoms of autism in young children and correspondence with the DSM. *Infants and Young Children, 12,* 90–97. http://dx.doi.org/10.1097/00001163-199910000-00011

McFarlane, H. G., Kusek, G. K., Yang, M., Phoenix, J. L., Bolivar, V. J., & Crawley, J. N. (2008). Autism-like behavioral phenotypes in BTBR T+tf/J mice. *Genes, Brain & Behavior, 7,* 152–163. http://dx.doi.org/10.1111/j.1601-183X.2007.00330.x

McQuay, H. J., & Moore, R. A. (1997). Using numerical results from systematic reviews in clinical practice. *Annals of Internal Medicine, 126,* 712–720. http://dx.doi.org/10.7326/0003-4819-126-9-199705010-00007

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders, 36,* 27–43. http://dx.doi.org/10.1007/s10803-005-0040-7

Moy, S. S., Nadler, J. J., Poe, M. D., Nonneman, R. J., Young, N. B., Koller, B. H., . . . Bodfish, J. W. (2008). Development of a mouse test for repetitive, restricted behaviors: Relevance to autism. *Behavioural Brain Research, 188,* 178–194. http://dx.doi.org/10.1016/j.bbr.2007.10.029

Moy, S. S., Nadler, J. J., Young, N. B., Perez, A., Holloway, L. P., Barbaro, R. P., . . . Crawley, J. N. (2007). Mouse behavioral tasks relevant to autism: Phenotypes of 10 inbred strains. *Behavioural Brain Research, 176,* 4–20. http://dx.doi.org/10.1016/j.bbr.2006.07.030

Muratori, F., & Narzisi, A., & the IDIA Group. (2014). Exploratory study describing 6 month outcomes for young children with autism who receive treatment as usual in Italy. *Neuropsychiatric Disease and Treatment, 10,* 577–586. http://dx.doi.org/10.2147/NDT.S58308

Nag, N., Moriuchi, J. M., Peitzman, C. G., Ward, B. C., Kolodny, N. H., & Berger-Sweeney, J. E. (2009). Environmental enrichment alters locomotor behaviour and ventricular volume in Mecp2 1lox mice. *Behavioural Brain Research, 196,* 44–48. http://dx.doi.org/10.1016/j.bbr.2008.07.008

National Autism Center. (2009). *National standards report: The national standards project addressing the need for evidence-based practice guidelines for autism spectrum disorders*. Randolph, MA: Author.

Nithianantharajah, J., & Hannan, A. J. (2006). Enriched environments, experience-dependent plasticity and disorders of the nervous system. *Nature Reviews Neuroscience, 7,* 697–709. http://dx.doi.org/10.1038/nrn1970

Parham, L. D., Cohn, E. S., Spitzer, S., Koomar, J. A., Miller, L. J., Burke, J. P., . . . Summers, C. A. (2007). Fidelity in sensory integration

intervention research. *The American Journal of Occupational Therapy, 61,* 216–227. http://dx.doi.org/10.5014/ajot.61.2.216

Pearson, B. L., Pobbe, R. L., Defensor, E. B., Oasay, L., Bolivar, V. J., Blanchard, D. C., & Blanchard, R. J. (2011). Motor and cognitive stereotypies in the BTBR T+tf/J mouse model of autism. *Genes, Brain & Behavior, 10,* 228–235. http://dx.doi.org/10.1111/j.1601-183X.2010.00659.x

Pfeiffer, B. A., Koenig, K., Kinnealey, M., Sheppard, M., & Henderson, L. (2011). Effectiveness of sensory integration interventions in children with autism spectrum disorders: A pilot study. *The American Journal of Occupational Therapy, 65,* 76–85. http://dx.doi.org/10.5014/ajot.2011.09205

Restivo, L., Ferrari, F., Passino, E., Sgobio, C., Bock, J., Oostra, B. A., . . . Ammassari-Teule, M. (2005). Enriched environment promotes behavioral and morphological recovery in a mouse model for the fragile X syndrome. *Proceedings of the National Academies of Science, USA, 102,* 11557–11562. http://dx.doi.org/10.1073/pnas.0504984102

Reynell, J., & Gruber, C. (1990). *Reynell Developmental Language Scales*. Los Angeles, CA: Western Psychological.

Reynolds, S., Lane, S. J., & Richards, L. (2010). Using animal models of enriched environments to inform research on sensory integration intervention for the rehabilitation of neurodevelopmental disorders. *Journal of Neurodevelopmental Disorders, 2,* 120–132. http://dx.doi.org/10.1007/s11689-010-9053-4

Reynolds, S., Urruela, M., & Devine, D. P. (2013). Effects of environmental enrichment on repetitive behaviors in the BTBR T+tf/J mouse model of autism. *Autism Research, 6,* 337–343. http://dx.doi.org/10.1002/aur.1298

Rogers, S. J., & Ozonoff, S. (2005). Annotation: What do we know about sensory dysfunction in autism? A critical review of the empirical evidence. *Journal of Child Psychology and Psychiatry, 46,* 1255–1268. http://dx.doi.org/10.1111/j.1469-7610.2005.01431.x

Satterthwaite, F. E. (1946). An approximate distribution of estimates of variance components. *Biometrics Bulletin, 2,* 110–114.

Schaaf, R. C., Benevides, T., Mailloux, Z., Faller, P., Hunt, J., van Hooydonk, E., . . . Kelly, D. (2014). An intervention for sensory difficulties in children with autism: A randomized trial. *Journal of Autism and Developmental Disorders, 44,* 1493–1506. http://dx.doi.org/10.1007/s10803-013-1983-8

Schneider, T., & Przewlocki, R. (2005). Behavioral alterations in rats prenatally exposed to valproic acid: Animal model of autism. *Neuropsychopharmacology, 30,* 80–89. http://dx.doi.org/10.1038/sj.npp.1300518

Schneider, T., Turczak, J., & Przewlocki, R. (2006). Environmental enrichment reverses behavioral alterations in rats prenatally exposed to valproic acid: Issues for a therapeutic approach in autism. *Neuropsychopharmacology, 31,* 36–46.

Schopler, E., Reichler, R. J., DeVellis, R. F., & Daly, K. (1980). Toward objective classification of childhood autism: Childhood Autism Rating Scale (CARS). *Journal of Autism and Developmental Disorders, 10,* 91–103. http://dx.doi.org/10.1007/BF02408436

Shah, A., & Holmes, N. (1985). The use of the Leiter International Performance Scale with autistic children. *Journal of Autism and Developmental Disorders, 15,* 195–203. http://dx.doi.org/10.1007/BF01531605

Sniezyk, C. J., & Zane, T. L. (2015). Investigating the effects of sensory integration therapy in decreasing stereotypy. *Focus on Autism and Other Developmental Disabilities, 30,* 13–22. http://dx.doi.org/10.1177/1088357614525663

Stevenson, R. A., Siemann, J. K., Schneider, B. C., Eberly, H. E., Woynaroski, T. G., Camarata, S. M., & Wallace, M. T. (2014). Multisensory temporal integration in autism spectrum disorders. *The Journal of Neuroscience, 34,* 691–697. http://dx.doi.org/10.1523/JNEUROSCI.3615-13.2014

Szatmari, P., Georgiades, S., Duku, E., Bennett, T. A., Bryson, S., Fombonne, E., . . . the Pathways in ASD Study Team. (2015). Developmental trajectories of symptom severity and adaptive functioning in an inception cohort of preschool children with autism spectrum disorder. *Journal of the American Medical Association Psychiatry, 72,* 276–283. http://dx.doi.org/10.1001/jamapsychiatry.2014.2463

Tomchek, S. D., & Dunn, W. (2007). Sensory processing in children with and without autism: A comparative study using the short sensory profile. *The American Journal of Occupational Therapy, 61,* 190–200. http://dx.doi.org/10.5014/ajot.61.2.190

Tsatsanis, K. D., Dartnall, N., Cicchetti, D., Sparrow, S. S., Klin, A., & Volkmar, F. R. (2003). Concurrent validity and classification accuracy of the Leiter and Leiter-R in low-functioning children with autism. *Journal of Autism and Developmental Disorders, 33,* 23–30. http://dx.doi.org/10.1023/A:1022274219808

Turner, C. A., & Lewis, M. H. (2003). Environmental enrichment: Effects on stereotyped behavior and neurotrophin levels. *Physiology & Behavior, 80,* 259–266. http://dx.doi.org/10.1016/j.physbeh.2003.07.008

Watling, R. L., Deitz, J., & White, O. (2001). Comparison of sensory profile scores of young children with and without autism spectrum disorders. *The American Journal of Occupational Therapy, 55,* 416–423. http://dx.doi.org/10.5014/ajot.55.4.416

Watson, L. R., Patten, E., Baranek, G. T., Poe, M., Boyd, B. A., Freuler, A., & Lorenzi, J. (2011). Differential associations between sensory response patterns and language, social, and communication measures in children with autism or other developmental disabilities. *Journal of Speech, Language, and Hearing Research, 54,* 1562–1576. http://dx.doi.org/10.1044/1092-4388(2011/10-0029)

Wigham, S., Rodgers, J., South, M., McConachie, H., & Freeston, M. (2015). The interplay between sensory processing abnormalities, intolerance of uncertainty, anxiety and restricted and repetitive behaviours in autism spectrum disorder. *Journal of Autism and Developmental Disorders, 45,* 943–952. http://dx.doi.org/10.1007/s10803-014-2248-x

Woo, C. C., & Leon, M. (2013). Environmental enrichment as an effective treatment for autism: A randomized controlled trial. *Behavioral Neuroscience, 127,* 487–497. http://dx.doi.org/10.1037/a0033010

Received January 5, 2015
Revision received March 27, 2015
Accepted April 16, 2015 ■