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The Modality Shift Experiment in Adults and Children with High Functioning Autism

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Abstract

This study used the modality shift experiment, a relatively simple reaction time measure to visual and auditory stimuli, to examine attentional shifting within and across modalities in 33 children and 42 adults with high-functioning autism as compared to matched numbers of age- and ability-matched typical controls. An exaggerated “modality shift effect” relative to the TD children occurred for the children with autism in conditions involving the reaction time when shifting from sound to light but not from light to sound. No exaggerated MSE was found for the adults with autism; rather, their responses were characterized by a generalized slowness relative to the adults with TD. These results suggest a lag in maturational development in autism in basic information processing mechanisms.

Keywords

autism; attentional shifting; speed of processing; perceptual development

Autism and autism spectrum disorders (ASD) have increasingly been characterized in terms of deficits in higher order abilities and enhanced or intact lower order abilities (Frith & Happé, 1994; Happé & Frith, 2006; Minshew & Goldstein, 1992; Minshew, Goldstein, & Siegel, 1997; Williams, Goldstein, & Minshew, 2006). This profile of deficits and enhanced abilities has led to two main theoretical models, both proposing that a disturbance in an underlying mechanism transcends cognitive domains and is responsible for both the deficits and the enhanced abilities in autism. This constellation was initially represented by the weak central coherence (WCC) theory, which proposed the existence of a unifying cognitive alteration, the lack of information integration, to explain the profile (Frith, 1989; Happé, 1999; Frith & Hill, 2003). It was represented later by the theory of disordered complex information processing (Minshew & Goldstein, 1992; Minshew et al., 1997; Williams et al., 2006), which emphasized a unifying alteration at the neurologic level, specifically the under-development of connections between cortical systems as the basis for the profile (Minshew & Goldstein, 1992). The latter theory was subsequently supported by the results of functional magnetic resonance imaging (fMRI) and functional connectivity studies and

was extended into ‘connectivity theory’ by Just and colleagues (Just, Cherkassky, Keller, & Minshew, 2004), which emphasized under development of cortical connectivity between posterior and frontal systems in high-functioning individuals with autism.

Other findings and theories in autism have primarily focused on lower level perceptual processes, and, in some instances, have attributed deficits in higher order abilities to these lower level alterations. The perceptual processing arguments have included both a model of generalized enhanced perceptual functioning (Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert, & Burack, 2006) and a model of a generalized deficit in visuospatial processing that interferes with configural processing (Behrmann, Thomas, & Humphreys, 2006). However, these models have primarily focused on the processing of visual stimuli and are not easily applicable across the cognitive domains.

Additional approaches to studying autism have focused on differences in processing related to the deployment of domain-general cognitive resources such as memory (for review see Boucher & Bowler, 2009) and attention (for review see Travers, Klinger, & Klinger, 2011). Whereas all aspects of attention, including selective attention, sustained attention, and visuospatial attention, have been studied in autism, shifting attention has been suggested as a particularly sensitive measure of the general impairment in the deployment of neural resources in autism (Allen & Courchesne, 2001).

The central role for shifting attention in autism was proposed by Courchesne and colleagues based on their research on cerebellar function and the study of a relatively small sample of adolescents with autism (8 patients, mean age = 13.9 years) (Courchesne et al., 1994). A substantive body of research continues to be grounded in the proposal that individuals with autism “... have a basic difficulty in automatically orienting to changing sensory stimuli” (Gomot et al., 2006, p. 475). In addition, recent reports and clinical observations have emphasized a related deficit in the disengagement of attention as a potentially important early clinical marker of autism (Bryson et al., 2007; Ibanez et al., 2008; Zwaigenbaum et al., 2005). For example, in one study, the failure of a 12-month-old child to shift attention from an object to the eyes of the examiner was the most significant predictor of whether an infant sibling of a child with autism would also fail to respond to his/her name, an early indicator of autism (Nadig et al., 2007); however, the social aspects of this behavior were considered potentially more salient than the attention shifting per se, highlighting the importance of further understanding the nature of attention shifting in autism to determine to what extent this skill is affected and whether it could be a contributory factor in this early behavioral marker for autism. Therefore, the shifting of attention continues to have clinical and research relevance in autism.

The nature and basis of the behavioral observations of difficulty in shifting attention in autism have never been completely resolved--either in terms of empiric support or the functional implications. For example, the results of a study completed with children with autism ages 6 to 12 years (Pascaulvaca et al., 1998) suggested that they could shift their attention continuously but had difficulty with disengaging attention, leading the authors to conclude that the deficit in attention was at the level of executive control originating from frontal lobe dysfunction rather than low level attentional shifting. Similarly, a study of visual attention in 3 to 7 year old children with autism proposed that the problem was primarily one of disengaging attention with subtle difficulty in executing rapid shifts of attention (Landry & Bryson, 2004). One study of adolescents and young adults with autism reported deficits on frontally-mediated volitional saccade tasks but not on reflexive saccade tasks of basic attention shifting mechanisms primarily dependent on subcortical mechanisms, again suggesting problems with higher level control processes (Minshew, Luna, & Sweeney, 1999). However, another study of high-functioning adolescents and adults with autism, ages

13 to 27 years, reported evidence of difficulty disengaging and shifting attention within a single modality using a visual orienting task, a task that did not require executive control (Wainwright-Sharp & Bryson, 1993). Even researchers who have provided evidence of a deficit in shifting attention in autism suggest that this difficulty is not evident if the participants are given adequate time in which to respond (Allen & Courchesne, 2001), potentially suggesting that the problem is related to speed of processing rather than attention per se.

The results of all of these studies leave undetermined whether the deficit exhibited by individuals with autism is in the ability to shift attention or in a more general slowness of processing or an executive dysfunction. Task conditions and demands have differed significantly across studies with frequent confounds introduced such as the requirement of the application of a rule or other decision-making process, making it difficult to tease apart what is an impairment in a basic cognitive process such as attention, what is the result of slowness in processing or motor response, and what is the effect of an executive dysfunction. For example, in the Courchesne et al. (1994) study, the attention shifting task required the participants to correctly detect a rare target stimulus in one target modality while simultaneously inhibiting attention to the targets in the nontarget modality. Once the rare target was detected, the participants had to implement a rule that they were now to attend to the opposite modality and attempt to detect the rare target in the new target modality while ignoring the stimuli from the nontarget modality. Although the results were interpreted as difficulty with basic attention processes, these contingencies added substantially to the cognitive load and the executive processes required to perform the task.

Some illumination of these issues was provided by Stoet and Lopez (2011) who demonstrated the effect of cognitive demand on attention shifting within a single modality by using visual switching tasks with and without the requirement to memorize arbitrary rules. They demonstrated that children with ASD (ages 9 to 16 years; IQ range 55-139) performed as accurately and quickly as the age- and IQ-matched participants without ASD on task switching when no rule-memorization was required; however, the children with ASD exhibited a decrement in performance with the increase in cognitive demand required when a rule had to be applied (Stoet & Lopez, 2011). In another study, older children and adolescents with ASD (ages 12 to 18 years; Full Scale IQ range 75-129) were able to shift between two tasks, matching color or shape to a reference object without difficulty when the tasks were unambiguous (Poljac et al., 2010).

Switching between auditory and visual modalities may be particularly challenging for individuals with ASD. In a recent study, older children with ASD that had significant learning challenges (Leiter IQ range 34-87) performed poorer than typically-developing children (matched for mental-age) and children with learning difficulties (matched for mental and chronological age) when alternating between two visual tasks (Reed & McCarthy, 2012). Moreover, the children with ASD had significantly more difficulty than the two comparison groups when alternating between a visual task and an auditory task.

The purpose of the present study was to directly investigate shifting attention in autism using a modality shift experiment that imposes little demand for decision making and that allows for the assessment of the effect of speed of response and speed of processing on performance. Both children and adults with autism were included to ascertain differences related to developmental stage; all subjects had IQ scores within the normal or above normal range to ensure sufficient cooperation for the procedure, matching between groups, and avoidance of the confounding influence of general intellectual disability.

Method

Participants

Participants were 33 children and 42 older adolescents and adults with high functioning autism (HFA) and two comparison groups of typically developing individuals (TD) of the same sample sizes matched on chronological age, gender, and IQ. The children ranged in age from 8 to 15 years and the older adolescents and adults ranged in age from 16 to 55 years old. These age divisions were used to be consistent with the age-related versions of the IQ tests. The diagnosis of autism was established through administration of two widely used research instruments, the Autism Diagnostic Interview (ADI or ADI-R) (Le Couteur et al., 1989; Lord et al., 1994) and the Autism Diagnostic Observation Schedule--Generic (ADOS; Lord et al., 1989; Lord et al., 2000) and were verified by expert clinical opinion. The ADI and ADOS for each subject were administered by independent research technicians trained to research reliability on these instruments and demonstrating ongoing reliability. Conventional cut offs for autism were used for total scores, domain scores, and age of onset. All participants met diagnostic criteria for autism and not for autism spectrum disorder. Particular care was taken to exclude subjects with Asperger Disorder by requiring ADI and clinical interview documentation of a history of delayed and disordered language development typical of autism.

Potential subjects for the autism group were excluded if found to have an associated neurological, genetic, infectious, or metabolic disorder such as tuberous sclerosis, fragile-X syndrome, or fetal cytomegalovirus infection. Exclusion criteria for TD control subjects included: a current or past history of neurological or psychiatric disorder, a developmental cognitive disorder, learning disability, poor school attendance, or family history of developmental cognitive disorders, autism, or neuropsychiatric disorder. Participants or their guardians provided written consent and or assent for this study, which was approved by the Institutional Review Board at the University of Pittsburgh.

All participants received either the Wechsler Intelligence Scale for Children (WISC-III; Wechsler, 1991) or the Wechsler Adult Intelligence Scale (WAIS-III) (Wechsler, 1997). All participants had Full Scale IQ scores of 80 or above. The children with autism and the TD children did not differ significantly in chronological age or on IQ measures. The adults with autism and adult TD participants had no significant differences in chronological age, VIQ, and FSIQ but had a 9 point difference in mean PIQ scores that was significant at the .003 level without correction for multiple comparisons. This difference between means is within the confidence range of these instruments. Demographic and intelligence test data are presented for the children in Table 1 and for the adults in Table 2.

Procedures

Modality Shift Procedure. The modality shift reaction time experiment is a task that requires only low-level attention processing and a minimal motoric response that also has a long history in schizophrenia research (Rist & Cohen, 1991). In addition, it can be administered to both children and adults because it uses a simple modification of the standard reaction time experiment in which the subject is asked to respond as quickly as possible to the presentation of a sound or light by pressing a button with the index finger. Therefore, no decision making or mapping of the stimulus to a particular button is required. In the modality shift modification, sound and light stimuli are presented in a series in which sounds or lights are presented consecutively (ipsi-modal) or a sound is followed by a light or a light is followed by a sound (cross-modal), allowing measurement of reaction time to the auditory and visual stimuli as well as reaction times when the modality changes.

The paradigm for the current study was developed using Coglab experimental control software developed at the Center for Cognitive Brain Imaging at Carnegie Mellon University [http://www.ccbi.cmu.edu/facilities_coglabsoftware.html]. The stimuli were created to closely resemble the ones used by Sutton and colleagues (1961) and were a red light, a green light, a 1200 Hz (high) tone and a 400 Hz (low) tone. In order to evaluate the effect of change in stimulus characteristics within ipsi-modal trial pairs, the initial tone or light was the same in the second stimulus as in the first, whereas in other trials they were different. Thus a high tone could be followed by another high tone or by a low tone, or the reverse. A red light could be followed by another red light or by a green light, or the reverse. The interstimulus interval was randomized between 3000-5000 milliseconds to reduce anticipation effects. There were 80 trials with 20 trials per stimulus. The visual stimuli were presented on a computer screen and the auditory stimuli were presented through the speakers of the computer. This method of presentation for the auditory stimuli was chosen because some of the participants with autism would not tolerate wearing headphones for extended periods of time. The auditory stimuli were presented at a moderate volume so that they would not be aversive by being excessively loud, high pitched or rasping. Both tones were in the frequency range of human speech and were not in a range that would typically elicit a startle response. None of the participants had observable startle responses nor did they voice any complaints about the tones. The tones had the same characteristics as those used in the Sutton et al. (1961) and numerous subsequent studies (Cohen & Rist, 1992), none of which reported that the auditory stimuli had aversive or startle eliciting properties. The task was described to the participants as a measure of reaction time and they were instructed to respond to every sound and every light by pressing a single button on a button box. The task lasted approximately 6 minutes. Reaction times (RTs) were recorded by computer and measured in milliseconds as the interval between the onset of a stimulus and the participant's response. This measurement method is consistent with what was used in the numerous MSE studies described by Cohen and Rist (1992).

Finger Tapping Test. As a measure of manual motor speed, the Finger Tapping Test (Reitan & Wolfson, 1993) was completed with each participant using the standard procedures and equipment. The measure used for each participant was the mean number of taps in 5 consecutive 10-sec trials for the dominant or preferred hand.

WISC-III/WAIS-III Coding/ Digit Symbol. Scaled scores from these subtests of the Wechsler scales were used to evaluate speed of information processing.

Data Analysis

The RT scores from the Modality Shift procedure for each of the participants were classified in relationship to the immediately preceding stimulus. Trials were cross-modal, ipsi-modal non-identical, and ipsi-modal identical. Each of these three conditions was subdivided into two conditions for a total of 6 conditions. The cross-modal conditions were either sounds that followed lights (L-S) or lights that followed sounds (S-L). In the ipsi-modal nonidentical condition for lights, a red light followed a green light or vice versa (G-R/R-G). For the ipsi-modal nonidentical sound condition, a low tone followed a high tone or vice versa (Hi-Lo/Lo-Hi). For each condition, the RT measure used in the data analysis was for the following stimulus in reference to the preceding stimulus. For example, in the L-S condition, the RT measured was for the sound when the previous stimulus was a light. In this case the dependent measure was RT to the sound.

The data was analyzed separately for each age group using the SPSS General Linear Model program repeated measures option. This procedure is a two way analysis of variance (ANOVA) with repeated measures on one factor, in this case, presentation, using a two-factor model of group (autism vs. TD) and presentation (cross-modal vs. ipsi-modal

identical OR cross-modal vs. ipsi-modal nonidentical). A separate analysis was performed comparing each cross-modal (second response to sound OR second response to light) to the ipsi-modal identical OR ipsi-modal non-identical presentation for that same modality. A significant main effect for presentation would mean that there was a difference in RT between pairs of cross-modal and ipsi-modal presentations. The modality shift effect (MSE) (Cohen & Rist, 1992; Mannuzza et al., 1984) occurs when the cross-modal RT is significantly longer than the RT for the ipsi-modal presentations. The RT dependent measure is calculated by subtracting the RT to the first stimulus from the RT to the second stimulus. The RT to the second stimulus is generally longer even in normal individuals to that of the first stimulus in cross-modal presentations. The results obtained from patients with schizophrenia with respect to the MSE were that the difference is *prolonged* relative to normal controls. Thus, a significant main effect for group would mean that the autism and TD groups had different reaction times regardless of whether the presentation was cross-modal or ipsi-modal. If the autism group had a wider discrepancy between cross-modal and ipsi-modal presentations than the TD group, they would be considered to have a greater or more exaggerated MSE. This result would be represented by a significant presentation by group interaction.

An advantage of the MSE as a measure of attention shifting is that it is derived from the relationship between the reaction time for the cross-modal pairs and ipsi-modal pairs. It can be detected even if the comparison groups differ significantly on measures of basic reaction time. In numerous studies of schizophrenia reviewed by Cohen and Rist (1992), it was shown that whereas patients with schizophrenia had substantially longer basic reaction times than controls, the schizophrenia group nevertheless showed a substantially prolonged MSE relative to controls. Therefore basic reaction time differences did not appear to effect MSE results and it does not appear to be necessary to use ratio scores or related methods to correct for differences in basic reaction time. Furthermore, the use of actual scores in milliseconds allows for comparisons with previous research in which that score was always used.

To evaluate the influences of basic motor speed and speed of information processing on performance, these analyses were repeated using the tapping score with the dominant hand and Coding/Digit Symbol scaled scores as covariates in analyses of covariance. Three analyses were performed; one covarying tapping alone, one covarying Coding/Digit Symbol alone, and one for both procedures in the same ANCOVA. In both the ANOVAS and ANCOVAS effect sizes (η^2) were computed for significant interactions since the hypothesis concerned the interaction between cross-modal vs. ipsi-modal presentation and group status.

Results

Each of the age groups (children and adults) were initially considered separately. Then the performance of the adults and children was compared within each of the diagnostic groups. The results of the comparison for the child groups are presented first.

Results for the Child Groups

RT Measures—The RT measures and results of the repeated measures ANOVAs for the child groups are presented in Table 3. There was a significant main effect for presentation in all conditions with slower reaction times in the cross-modal than in the ipsi-modal conditions, demonstrating the presence of a MSE for both child groups. The group effect results indicate that the children with autism were significantly slower when responding to a light following a sound than the TD children. There were two significant presentation by group interactions for 1) the cross-modal (sound-light) versus ipsi-modal nonidentical (red light-green light); and 2) the cross-modal (sound-light) versus ipsi-modal identical (light-

light) comparisons, indicating a relatively exaggerated MSE in children with autism when switching from a sound to a light. Effect sizes (η^2) were in the moderate effect size range.

For the autism group, in the ipsi-modal trials, paired t-tests indicated that there was a non-significant difference in reaction time between the identical and non-identical presentation conditions for sound ($t(32)=-1.48$, $p=.149$ and light $t(32)=.92$, $p=.366$). In the case of the TD child group, there was a significant difference for sound ($t(33)=-.259$, $p=.014$) but not for light ($t(33)=.93$, $p=.36$). The TD child group had a significantly slower RT when the sound pairs were not identical.

Basic Motor Speed and Speed of Information Processing—The children with autism ($M = 41.55$; $SD = 10.20$) did not differ significantly from the TD children ($M = 43.24$; $SD = 7.38$) on the Finger Tapping Test, [$t(62) = -0.76$, $p = .45$]. For the Coding subtest from the WISC, a measure of speed of processing, the children with autism ($M = 7.63$; $SD = 2.92$) were significantly slower than the TD children ($M = 10.77$; $SD = 2.80$), [$t(51) = -3.99$, $p < .0001$].

The results for the ANCOVAs for the child data are presented in Table 4. Effect sizes (η^2) were computed for significant interactions. When the RT measures were covaried with motor speed, both groups were slower in response to a sound following a light than to two identical sounds. Previously obtained group differences in which the children with autism were slower than the TD children in responding to a light following a sound were no longer reliably different. The interaction, indicating an exaggerated MSE for the children with autism as compared to the TD children, remained significant for the cross-modal/ipsi-modal nonidentical condition in which a light followed a sound with a moderate range effect size.

When the speed of processing measure was covaried, the main effect of presentation remained significant for the cross-modal light-sound and ipsi-modal nonidentical sound comparison. However, the previously obtained significant autism versus TD group differences for the RT to light conditions was now non-significant. The interaction for one of the cross-modal and ipsi-modal comparisons (cross-modal light following sound versus ipsi-modal identical lights) remained significant with a moderate effect size indicating that the child autism group displayed a relatively *prolonged* MSE when a light followed a sound even when speed of processing was covaried.

Covarying motor speed and speed of processing measures simultaneously resulted in only one significant difference with respect to presentation—the comparison between RT to the cross-modal switch from sound to light and the RT to two different lights. There were no significant group effects or interactions; one of the previously significant group by presentation interactions, the RT for the cross modal switch from sound to light compared to the RT for the ipsi-modal two identical lights, was no longer significant.

These analyses for the child data indicate that tapping speed and speed of processing account for a great deal of the difference between ipsi-modal and cross-modal presentations but this is true for both groups. Children with autism still showed a prolonged MSE relative to the TD children when switching from a sound to a light, even after controlling separately for motor speed and speed of processing. However, this significant difference was attenuated when speed of processing and motor speed were simultaneously covaried.

Results for the Adult Groups

RT Measures—The RT measures and results of the repeated measures ANOVAs for the adult groups are presented in Table 5. There was a significant main effect for presentation in all conditions with slower reaction times in the cross-modal than in the ipsi-modal

conditions, demonstrating the presence of a MSE for both groups. Significant group differences were obtained for all of the sound and light conditions with the adult autism group being significantly slower to respond than the adult TD group. However, there was no significant presentation by group interactions that would indicate an exaggerated MSE for the adults with autism.

For the adult autism group in the ipsi-modal trials, there was a significant difference in reaction time between the identical and non-identical presentation conditions for sound ($t(41) = -3.23$, $p = .002$), but not for light ($t(41) = .87$, $p = .388$). In the case of the adult TD group there was also a significant difference for sound ($t(41) = -3.61$, $p = .001$) but not for light ($t(41) = .04$, $p = .97$). Both of the adult groups had a significantly slower RT when the sound pairs were not identical.

Basic Motor Speed and Speed of Information Processing—On the Finger Tapping Test, the mean number of taps with the dominant hand of the adults with autism ($M = 50.81$; $SD = 6.93$) was significantly slower than the mean number of taps of the TD adults ($M = 54.62$; $SD = 7.10$), [$t(81) = -2.47$, $p = .016$]. For the Digit Symbol subtest from the WAIS, a measure of speed of processing, the mean scores of the adults with autism ($M = 8.08$; $SD = 2.79$) was significantly lower than the mean score of the TD adults ($M = 10.14$; $SD = 2.50$), [$t(79) = -3.52$, $p < .001$].

The results for the ANCOVAs for the adult data are presented in Table 6. Covarying the measure of basic motor speed resulted in only one significant main effect group difference--the adults with autism were reliably slower than the TD adults when responding to a sound following a light than when responding to two identical sounds. When speed of processing was covaried, significant differences were found for Cross-Modal Light-Sound, Cross-Modal Sound-Light-Non-Identical, and Cross-Modal Sound-Light-Identical conditions. When the measures of basic motor speed and speed of processing were simultaneously covaried, the only significant difference was for presentation (cross-modal in which sound followed a light versus ipsi-modal of two identical sounds). Significant differences after covariance were generally associated with moderate effect sizes.

Comparing RTs in Children and Adults

In consideration of the developmental effects within the data, a comparison was made of the RT in the ipsi-modal identical and non-identical conditions for each of the modalities between the adult groups and their child counterparts. The adults and children with autism had similar RTs to identical sounds [$t(73) = .617$, $p = .539$], non-identical sounds [$t(73) = .189$, $p = .850$], identical lights [$t(73) = 1.87$, $p = .065$], and, non-identical lights [$t(73) = 1.69$, $p = .095$]. The TD children were reliably slower than the TD adults in RT to identical sounds [$t(73) = 2.05$, $p = .044$], but were not reliably different from the TD adults in response to non-identical sounds [$t(73) = 1.87$, $p = .066$]. The TD children were reliably slower than the TD adults in responding to both identical lights [$t(73) = 2.95$, $p = .004$] and non-identical lights [$t(73) = 2.46$, $p = .016$]. The TD children exhibited relative developmental differences in RT for both sound and light as compared to the TD adults that was not evident in the two age groups with autism.

Discussion

This study used the modality shift experiment, a relatively simple reaction time measure to visual and auditory stimuli, to examine attentional shifting in children and adults with autism as compared to chronological age- and ability-matched children and adults with typical development. This procedure allowed the investigation of attentional shifting in autism with minimal demand on decision-making processes using a relative comparison

between cross-modal and ipsi-modal pairs that is not affected by group differences on basic reaction time measures. The group sizes were also relatively large compared to previous studies of attentional shifting in autism, and the inclusion of both children and adult groups allowed for cross-sectional consideration of developmental effects. An exaggerated MSE relative to the TD children occurred for the children with autism in conditions involving the reaction time to a light following a sound but not for a sound following a light. No exaggerated MSE was found for the adults with autism; rather, their responses were characterized by a generalized slowness relative to the TD adults. Difficulty with shifting of attention between auditory and visual modalities in children with autism is consistent with previous research using different paradigms (Courchesne et al., 1994; Reed & McCarthy, 2012). Furthermore, unlike the paradigms used in previous research, the current paradigm required minimal use of executive processing (as no rule had to be remembered or implemented) or language, yet the difficulty with shifting between modalities was still evident. The children with autism also had no difficulty with shifting of attention within the visual modality consistent with previous research on visual task shifting with children at similar ages as those in the current study (Poljac et al., 2010; Stoet & Lopez, 2011).

The differential performance of child and adult participants with autism was not explained by differing modality-specific responses. The prolonged MSE found in the child autism group occurred with respect to responses to light. Different patterns of responses occurred for the children with autism relative to the TD child group and the two adult groups; however, this was with respect to response to sound. All three of the latter groups were statistically slower in responding to the second sound in a pair of non-identical sounds than to the second sound in a pair of identical sounds. None of the four groups had a relatively slower RT to a light followed by a non-identical light as compared to the RT to the second in a pair of identical lights.

The differential performance of the children with autism was also not explained by a difference in basic motor speed. That is, the children with autism did not differ from the TD children on the finger tapping measure, and the relatively exaggerated MSE when a light followed a sound was still present when motor speed was covaried. This finding of the lack of a difference in motor speed between the two groups of children was consistent with the results from previous research in modality shifting in children with autism (Courchesne et al., 1994). On the other hand, differences in speed of processing were evident between the two child groups and explained some, but not all, of the difference in the shifting between sound and light. A recent study examining the profile of children with ASD using the fourth edition of the Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2003), reported that processing speed was the most significant area of weakness for the children with ASD and was positively correlated with communication abilities (Oliveras-Rentas, Kenworthy, Roberson, Martin, & Wallace, 2011).

The basis of the modality shift effect in children with autism is unknown as is the difference found between the children and adults with autism. This latter finding was unanticipated and might be associated with developmental or educational considerations that are beyond the scope of the current study to determine.

Exaggeration of the MSE has been found in patients with schizophrenia (Rist & Cohen, 1991). According to an explanatory theory for this phenomenon called *trace theory*, the MSE occurs because each stimulus leaves *traces* in activated neurons that either inhibit the processing of subsequent stimuli that are different or enhances the processing of subsequent stimuli that are the same, and these traces are thought to persist longer in individuals with schizophrenia (Zubin, 1975). Alternative explanations involving general response speed and biased expectations regarding the forthcoming stimulus have not been supported by the

experimental literature, but there is strong evidence that the response of individuals with schizophrenia is overly influenced by immediately preceding events.

When considering the influence of immediately preceding events on the MSE, the relative aversiveness of auditory and visual stimuli should be considered because auditory stimuli, particularly when they are loud or high-pitched may be more aversive than visual stimuli. However, the RTs of the children in this study to sound and light were highly similar suggesting that the modalities did not differ regarding aversiveness. In any event, as discussed earlier, the auditory stimuli were not in the aversive range. In addition, in the schizophrenia literature, it was shown that the intensity of stimuli did not appear to affect the discriminatory power of the MSE (Manuzza et al., 1984).

The over-influence of preceding stimuli in schizophrenia described above may be similar to the difficulty in disengagement of attention that has been described in individuals with autism (Courchesne, 1994). Therefore, the exaggerated MSE exhibited by the children with autism for the shift from sound to light may reflect difficulty with disengagement from the auditory stimulus to shift attention to the following visual stimulus. However, it is not clear why the problem with disengagement would occur when the children with autism were shifting from an auditory to a visual stimulus but not when shifting from a visual to an auditory stimulus. In addition, if the difficulty was with disengagement from the sound stimulus, then the children with autism would be predicted to also have overall reliably slower responses between the pairs of non-identical sound stimuli, but this did not occur. Alternatively, the slowness in shifting from a sound stimulus to a light stimulus in the children with autism could have been due to difficulty in engaging to the light stimulus rather than disengagement from the sound stimulus. Unfortunately, the current paradigm did not allow us to determine whether the underlying problem was one of disengagement or engagement for the children with autism when shifting from sound to light.

In the schizophrenia literature, Cohen and Rist (1992) report that a differential MSE relative to controls is found primarily for sounds; crossmodal retardation to light stimuli is less pronounced. The presence of the MSE for tones in individuals with schizophrenia is possibly an exaggeration of the relatively slower response to non-identical sounds that occurred for the TD children and adults and the adults with autism. The MSE in the children with autism appears to differ from that reported in the schizophrenia literature in that it occurred for lights and not sounds. Why should the children with autism have greater difficulty than TD individuals shifting from a sound to a light but not from a light to a sound? Whereas the effective difference is not particularly large, the crossmodal difference is consistent with prior research with TD children. There is evidence to suggest that auditory and visual abilities mature at different rates in typically developing children with the auditory system maturing faster than the visual system (Lewkowicz & Lickliter, 1994). Furthermore, recent work with 10 and 11-year-old TD children compared to TD adults suggests later maturation for detection of audiovisual temporal asynchrony when the auditory stimulus precedes the visual stimulus (sound to light) but performance comparable to adults when the visual stimulus precedes the auditory stimulus (light to sound) (Hillock, Powers, & Wallace, 2011). Based on these findings, it could be argued that the condition in which the auditory stimulus precedes the visual stimulus (sound to light) is potentially the one that is the most sensitive to a lag in maturational development relative to TD individuals with the exaggerated MSE for the children with autism occurring in the condition which was most likely to detect a maturational difference between the two groups. However, such a maturational difference is speculative at this point, requiring additional supportive evidence from future research.

Unlike the children with autism, the adults with autism did not have a relatively exaggerated MSE as compared to the TD adults even though group differences occurred in the speed of reaction to shifts from light to sound and shifts from sound to light. The adults with autism were also reliably slower than the TD adults on measures of basic motor speed and in speed of processing. Controlling for basic motor speed reduced the significant differences between the groups to only one—the cross-modal versus ipsi-modal comparison in which the reaction time to a sound following a light is compared to the reaction time to two identical sounds. No group differences remained when controlled for speed of processing. These results suggest that both basic motor speed and speed of processing affected the performance of the adults with autism. However, the adults with autism did not have relatively greater difficulty with shifting from one modality to the next than the TD adults, despite being significantly slower in both motor-based reaction time and speed of cognitive processing. That is, the response cost of a change in stimulus across modalities or a change in stimulus within a modality was no greater for the adults with autism than for the TD adults.

The primary characteristic of the response of the adults with autism was an overall slower response time to both the sounds and the lights as compared to the adult control group. It is well established that individuals with autism have psychomotor deficits in the form of slowness, awkwardness, or poor coordination (Bauman, 1992; Gillberg & Coleman, 1992; Hughes, 1996; Minshew et al., 1997; Smith & Bryson, 1994). A generally slow response time in adults with autism in comparison to age- and IQ-matched participants with typical development was also reported in a study that failed to find differences using the Sternberg (1969) set shifting task (Bogte, Flamma, van der Meere, & van Engeland, 2008).

This is a cross-sectional study comparing two different age groups; thus limiting the extent of the comments that can be made about a developmental process. However, as in a number of other developmental areas, the individuals with autism in this study appear to be developing both more slowly and differently than the comparison TD individuals. Furthermore, whereas the adults with autism exhibit positive maturational differences in the ability to shift between modalities relative to children with autism, they were slower relative to the TD adults in both basic motor speed and speed of processing.

This study has the limitation of being restricted to high functioning children and adults with autism and different results may be obtained in lower functioning groups. Attentional functioning may be affected to a greater extent in individuals with autism who have more significant cognitive and linguistic challenges.

Clinical Implications

With respect to clinical implications, the analysis of covariance findings indicate that attention tasks that involve motor responses are not likely to accurately reflect attention in autism, particularly when used with older adolescents and adults with autism. Such tasks may instead reflect general psychomotor deficits and not an attention problem per se. In line with recent research on cross-modal attention-switching in lower functioning children with ASD (Reed & McCarthy, 2012), the results of the current study suggest that even more able children with autism may have difficulty switching between auditory and visual modalities with a resultant performance cost. In addition, younger children with autism, in particular, may take longer to shift from auditory to visual stimuli or vice versa. Therefore, children with autism may need explicit cues to shift focus. On the other hand, the additional processing time for shifting between auditory and visual stimuli could have positive effects during the presentation of intervention targets. Interestingly, a number of interventions that employ a paradigm in which an auditory cue is closely followed by a visual cue have been reported to be effective at scaffolding the attention of children with autism (Patten & Watson, 2011). For example, the use of a verbal “look” plus a pointing gesture to a target

object increased orienting to objects in children with autism (Leekham, Hunnisett, & Moore, 1998).

Conclusions

In conclusion, the presence of the exaggerated MSE in this group of children with autism is potentially related to an underlying neuropsychological factor that is also related to the difference in speed of processing and may be indicative of a lag in maturational development relative to the control children. By adulthood, this maturational difference is no longer evident in the group with autism but instead has merged into a generalized slowness in both processing and motor production relative to the control adults. Further investigation of differences in the maturation of attention in autism would require both the inclusion of children with autism at even younger ages than those in the current study and/or longitudinal studies of children as they develop.

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Table 1

Demographic Data for the Children with Autism and Matched TD Group

	Autism		TD		
	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>	<i>p</i>
Chronological Age	11.22	1.99	12.19	2.26	.067
Verbal IQ	104.06	14.32	107.85	8.72	.071
Performance IQ	102.55	12.09	107.61	9.22	.060
Full Scale IQ	103.61	12.40	108.45	8.70	.199
Male: Female	28.5		24:9		

Table 2

Demographic Data for the Adults with Autism and Matched TD Group

	Autism		TD		T	p
	M	SD	M	SD		
Chronological Age	28.43	11.05	28.76	10.77	-.140	.889
Verbal IQ	106.83	16.40	109.74	8.38	-1.02	.310
Performance IQ	102.05	13.94	109.67	8.40	-3.03	.003
Full Scale IQ	105.26	14.84	110.40	8.19	-1.96	.053
Male: Female	38: 4		36: 6			

Table 3

Child Data: Reaction Time Results Comparing the Autism and Control Groups

Conditions ¹	Autism (SD)	Modality Shift Effect (ms)	TD (SD)	Modality Shift Effect (ms)	Fp ²	Fg ³	Fpxg ⁴	η^2
Second Response to Sound								
Cross-modal Light-Sound	463.07 (132.22)		407.14 (125.20)					
Ipsi-modal Sounds Nonidentical Hi-Lo/Lo-Hi	425.69 (127.20)	37.38 (44.00)	395.47 (122.27)	11.67 (65.69)	12.70 ***	2.00	3.49	
Ipsi-modal Sounds Identical Hi-Hi/Lo-Lo	413.68 (113.21)	49.40 (53.12)	373.06 (114.65)	34.08 (48.54)	44.42 ***	2.72	1.50	
Second Response to Light								
Cross-modal Sound-Light	435.16 (97.76)		375.15 (90.87)					
Ipsi-modal Lights Nonidentical R-G/G-R	396.47 (106.16)	38.69 (49.03)	362.24 (89.71)	12.91 (46.46)	19.26 ***	4.20 *	4.81 *	.07
Ipsi-modal Lights Identical R-R/G-G	405.66 (97.32)	29.50 (49.55)	368.83 (82.04)	6.32 (40.49)	10.35 **	4.84 *	4.33 *	.063

¹ In all cases, the RT measure is for the second stimulus that follows the first stimulus.² p = presentation effects.³ g = group effects.⁴ pxg=interaction effects.* $p < .05$,** $p < .01$,*** $p < .001$.Effect sizes (η^2) are presented for significant interactions.

Note: Hi-Lo/Lo-Hi = high tone followed by low tone and vice versa; Hi-Hi/Lo-Lo = high tone followed by high tone and low tone followed by low tone; R-G/G-R = red light followed by green light and vice versa; R-R/G-G = red light followed by red light and green light followed by green light.

Table 4

Child Data: Analysis of Covariance Results for Motor Speed and Speed of Processing

Tapping Covariate Results	F_p I	p	F_g 2	p	F_p x g 3	p	η²
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Nonidentical	1.94	.169	1.52	.222	3.40	.070	
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Identical	5.32 *	.024	2.21	.142	1.25	.267	
Cross-modal Sound-Light Compared to Ipsi-modal Lights Nonidentical	1.72	.195	2.94	.091	5.64 *	.021	.09
Cross-modal Sound-Light Compared to Ipsi-modal Lights Identical	.307	.582	3.79	.056	3.74	.058	
Coding Covariate Results							
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Nonidentical	4.17 *	.046	2.28	.137	1.26	.268	
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Identical	3.331	.074	2.66	.109	.54	.465	
Cross-modal Sound-Light Compared to Ipsi-modal Lights Nonidentical	3.69	.060	2.01	.163	2.12	.151	
Cross-modal Sound-Light Compared to Ipsi-modal Lights Identical	.004	.953	1.85	.180	4.14 *	.047	.08
Tapping + Coding Covariate Results							
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Nonidentical	3.14	.083	1.48	.230	.95	.335	
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Identical	2.92	.094	1.79	.187	.32	.572	
Cross-modal Sound-Light Compared to Ipsi-modal Lights Nonidentical	4.95 *	.031	1.19	.281	1.60	.213	
Cross-modal Sound-Light Compared to Ipsi-modal Lights Identical	.12	.730	1.05	.310	3.46	.069	

1 p = presentation effects.
 2 g = group effects.
 3 pxg=interaction effects.
 * $p < .05$

Table 5

Adult Data: Reaction Time Results Comparing the Autism and Control Groups

Conditions ¹	Autism (SD)	Modality Shift Effect (ms)	Controls (SD)	Modality Shift Effect (ms)	Fp ²	Fg ³	Fpxg ⁴
Second Response to Sound							
Cross-modal Light-Sound	446.76 (164.84)		375.07 (118.70)				
Ipsi-modal Sounds Nonidentical Hi-Lo/Lo-Hi	418.92 (171.40)	27.84 (47.38)	343.00 (119.71)	32.07 (37.82)	41.01 ***	5.50 *	.21
Ipsi-modal Sounds Identical Hi-Hi/Lo-Lo	393.35 (160.34)	53.41 (60.80)	320.21 (108.17)	54.86 (52.20)	76.68 ***	5.84 *	.01
Second Response to Light							
Cross-modal Sound-Light	386.25 (132.04)		334.59 (107.14)				
Ipsi-modal Lights Nonidentical R-G/G-R	352.81 (114.49)	33.44 (48.13)	308.38 (97.74)	26.22 (31.74)	44.97 ***	3.88 *	.66
Ipsi-modal Lights Identical R-R/G-G	359.48 (112.33)	26.77 (55.61)	308.53 (92.04)	26.06 (36.34)	26.57 ***	4.63 *	.01

¹ In all cases, the RT measure is for the second stimulus that follows the first stimulus.

² p = presentation effects.

³ g = group effects.

⁴ pxg=interaction effects.

* p<.05,

*** p<.001.

Effect sizes are not reported (η^2) because there are no significant interactions.

Note: Hi-Lo/Lo-Hi = high tone followed by low tone and vice versa; Hi-Hi/Lo-Lo = high tone followed by high tone and low tone followed by low tone; R-G/G-R = red light followed by green light and vice versa; R-R/G-G = red light followed by red light and green light followed by green light.

Table 6

Adult Data: Analysis of Covariance Results for Motor Speed and Speed of Processing

Tapping Covariate Results		F_{p1}	p	F_{g2}	p	F_{pxg3}	P
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Nonidentical		.61	.435	3.70	.058	.28	.596
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Identical		8.86**	.004	4.28 *	.042	.47	.497
Cross-modal Sound-Light Compared to Ipsi-modal Lights Nonidentical		3.02	.086	2.40	.125	.40	.529
Cross-modal Sound-Light Compared to Ipsi-modal Lights Identical		2.08	.153	2.95	.090	.006	.939
Coding Covariate Results							
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Nonidentical		3.65	.060	1.23	.271	.58	.451
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Identical		7.61**	.007	1.31	.256	.28	.600
Cross-modal Sound-Light Compared to Ipsi-modal Lights Nonidentical		9.13**	.003	.43	.513	.01	.907
Cross-modal Sound-Light Compared to Ipsi-modal Lights Identical		6.39 *	.014	.51	.477	.07	.788
Tapping + Coding Covariate Results							
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Nonidentical		.35	.555	1.16	.285	.58	.451
Cross-modal Light-Sound Compared to Ipsi-modal Sounds Identical		6.21 *	.015	1.35	.249	.62	.435
Cross-modal Sound-Light Compared to Ipsi-modal Lights Nonidentical		2.64	.108	.38	.537	.01	.929
Cross-modal Sound-Light Compared to Ipsi-modal Lights Identical		2.01	.160	.46	.500	.07	.795

- 1 p = presentation effects.
- 2 g = group effects.
- 3 pxg=interaction effects.
- * $p < .05$,
- *** $p < .001$.

Effect sizes are not reported (η^2) because there are no significant interactions.