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Motor demands impact speed of information processing in Autism Spectrum Disorders

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Abstract

Objective—The apparent contradiction between preserved or even enhanced perceptual processing speed on inspection time tasks in autism spectrum disorders (ASD) and impaired performance on complex processing speed tasks that require motor output (e.g. Wechsler Processing Speed Index) has not yet been systematically investigated. This study investigates whether adding motor output demands to an inspection time task impairs ASD performance compared to **that of** typically developing control (TDC) children.

Method—The performance of children with ASD (n=28; mean FSIQ=115) and TDC (n=25; mean FSIQ=122) children was compared on processing speed tasks with increasing motor demand. Correlations were run between ASD task performance and Autism Diagnostic Observation Schedule (ADOS) Communication scores.

Results—Performance by the ASD and TDC groups on a simple perceptual processing speed task with minimal motor demand was equivalent, though it diverged (ASD worse than TDC) on two tasks with the same stimuli, but increased motor output demands. ASD performance on the moderate but not the high speeded motor output demand task was negatively correlated with ADOS communication symptoms.

Conclusions—These data address the apparent contradiction between preserved inspection time in the context of slowed “processing speed” in ASD. They show that processing speed is preserved when motor demands are minimized, but that increased motor output demands interfere with the ability to act on perceptual processing of simple stimuli. Reducing motor demands (e.g. through the use of computers) may increase the capacity of people with ASD to demonstrate good perceptual processing in a variety of educational, vocational and social settings.

Keywords

autism spectrum disorder; processing speed; motor abilities; communication

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Introduction

Individuals with autism spectrum disorders (ASD) often demonstrate dramatic peaks and valleys of ability and disability (Wallace, Happé, & Giedd, 2009), and, associated with that, unusually variable subdomain profiles on intelligence tests (e.g. Dawson, Soulieres, Gernsbacher, & Mottron, 2007). For example, studies of ASD performance on Wechsler intelligence tests identify weaknesses on the Processing Speed Index (PSI) when compared with verbal and perceptual abilities (e.g. Mayes & Calhoun 2007, 2008; Nyden, Billstedt, Hjelmquist, & Gillberg, 2001; Wechsler, 2003). The PSI is made up of two subtests. Both subtests provide two minutes to interpret small abstract visual designs and require a pencil-and-paper response. The Symbol Search subtest requires the determination of whether a specific design is repeated in a row of designs and the checking of a “yes” or “no” box after each row. The more motorically demanding Coding subtest requires the replication of nine designs that correspond to digits 1–9, based on a key that is provided at the top of the page. Below the key there are a series of boxes that contain the numbers but are missing the designs, into which the correct design must be drawn. Coding also makes more demands on working memory, because more items can be completed in the time limit if the key linking the nine numbers to unique designs is held in mind during the task.

In our recent investigation of ASD profiles on the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV), the Processing Speed Index (PSI) was the greatest area of relative and normative weakness. More than half (54%) of our sample of high functioning children with ASD scored at least a full standard deviation below the PSI normative mean score (Oliveras-Rentas, Kenworthy, Roberson, Martin, & Wallace, 2012). Furthermore, we found that PSI scores correlated positively with adaptive communication abilities and negatively with communication symptoms in our ASD sample, indicating that it is related to core autism deficits.

In contrast, recent studies using the inspection time (IT) task suggest intact or better processing speed among individuals with ASD. IT is a perceptual processing speed measure that minimizes motor demands and measures the minimum stimulus exposure duration needed to make a simple visual discrimination. Scheuffgen, Happé, Anderson, and Frith (2000) found that children with ASD and low average IQ (mean=82) demonstrated surprisingly fast IT, when asked to complete a perceptual discrimination in which the stimuli appeared on the computer screen for a variable amount of time, compared to children with intellectual disabilities. The task presents two “antennae” on a “spaceship” briefly on a computer screen. After the image is covered up (“masked”), children indicate whether the antennae are the same or different lengths with a key press. The ASD group’s processing speed was comparable to that of a group of typically developing control (TDC) children with IQ scores 25 points higher, on average. The two most recent studies using the IT task extend these results finding comparable processing speed between: 1) a group of relatively high-functioning children with ASD and age and IQ matched TDC children (Wallace, Anderson, & Happé, 2009) and 2) an adult savant with ASD and a control group of neurotypical adults matched on age and verbal ability (Wallace, Happé, & Giedd, 2009).

Given its importance to producing quick responses and, apparently, to communication skills, it is useful to understand how the PSI in ASD converges with, and diverges from, other processing speed measures, such as the IT task. An obvious point of divergence is motor demand. While the IT task requires a simple, untimed button press to measure speed of processing, divorcing the rapid processing of the visual image from the quality of the motor response, the PSI measures how quickly a child processes visual information and makes marks on a page. Unlike the IT task, both Wechsler subtests measure speed of processing in the context of significant visual-motor integration demands.

Both motor and sensorimotor integration abilities have been described as impaired in ASD (see Gowan & Hamilton, 2013 for review) and could be a source of difficulty on the PSI subtests. Since Kanner (1943) and Asperger (Frith, 1991/1944) noted motor clumsiness in their seminal case descriptions of autism and Asperger's syndrome respectively, motor problems have been associated with ASD, although not a part of the formal diagnosis. Manjiviona and Prior (1995) identified motor problems in half of the children with Asperger Syndrome and two-thirds of those with high functioning autism in their sample. Mostofsky and colleagues have confirmed basic motor control problems, as well as dyspraxia, in ASD (Mostofsky et al., 2006; MacNeil & Mostofsky, 2012). Perhaps most relevant to the motor demands of the PSI subtests, handwriting is impaired and it is related to fine motor skill deficits in ASD (Fuentes, Mostofsky, & Bastian 2009; Mayes & Calhoun, 2007).

It is not the case, however, that ASD processing speed deficits are only reported on tasks that make visual-motor integration and output demands. Yoran-Hegesh et al. (2009) report that an ASD group was slower than TDC adolescents on an IT task, a simple reaction time task, and a finger-tapping test. Interpretation of these results is clouded by the fact that the ASD and control groups were not matched on IQ, and different types of stimuli were used across the tasks, some of which were more complex than others. Indeed, the authors report that the complexity of information affected processing speed in their ASD sample, which raises a second point of divergence between Wechsler PSI subtests and the IT task. Both of the PSI subtests impose more complex perceptual processing demands than the IT task, as they require comparison of, and selection among, complex geometric shapes, in contrast to IT, which requires only comparison of the length of two lines.

In this study, we seek to investigate the role motor demands play in "processing speed" in ASD by increasing motor demands in a controlled fashion, while holding the complexity of stimuli constant. We asked children with and without ASD to respond to the IT stimuli (a figure of two antennae of varying lengths on a "spaceship") in three different conditions: the Low Motor Demand (LM) task which minimizes the motor response by requiring a button press after the image has left the screen, the Moderate Motor Demand (MM) task which increases motor demand by requiring the participant to respond quickly while the image remains on the screen, and the High Motor Demand (HM) task, in which responses are indicated by drawing lines on the stimuli. The HM task introduces grapho-motor output as a component of the response, but involves simpler stimuli than those in the Symbol Search subtest of the Wechsler PSI. Symbol Search was also administered as a comparison measure. We predicted that the groups would not differ in the LM task, but would in the MM and HM tasks, and that performance on the HM task would be related to performance

on the Symbol Search subtest because they both require grapho-motor output. Based on our earlier finding of WISC-IV Processing Speed/ADOS Communication score correlations, we also expected a significant negative correlation between Communication symptoms on the ADOS and both the MM and HM tasks.

Methods

Participants

Thirty-eight children with a diagnosis on the autism spectrum and 28 TDC children were recruited for this study. Thirteen children (10 ASD, 3 TDC) were enrolled but excluded due to performance of less than chance on the inspection time task ($n=10$) or performance over 2.5 standard deviations from the mean on the Moderate Motor Demand task (MM) task or the High Motor Demand task (HM) ($n=3$). Children were recruited through the local community via advertisements and a hospital's outpatient clinic specializing in ASD and neuropsychological assessment. All children were 7–14 years old, and were required to have a Full Scale IQ ≥ 85 , as measured by a Wechsler Intelligence scale (Wechsler Intelligence Scale for Children–4th Edition [WISC-IV], or Wechsler Abbreviated Scale of Intelligence [WASI]; (Wechsler, 1999, 2003)).

Children with ASD received a clinical diagnosis from experienced clinicians (Autism $n=13$, Asperger's Syndrome $n=10$, Pervasive Developmental Disorder-Not Otherwise Specified $n=5$) based on *Diagnostic and Statistical Manual of Mental Disorders–Fourth Edition–Text Revised* criteria (American Psychiatric Association, 2000). They also met the criteria for an ASD based on the Communication+Social score from Module 3 of the Autism Diagnostic Observation Schedule (Lord et al., 1999). In addition they met criteria, or were within one point of meeting criteria, for autism on the Reciprocal Social and Restricted Repetitive Behavior domains of the Autism Diagnostic Interview-Revised (Lord, Rutter, & Le Couteur, 1994). Children with ASD were screened and excluded for any history of known genetic, psychiatric, or neurological disorders (e.g., Fragile X syndrome or Tourette's syndrome). Stimulant medications were withheld at least 24 hours prior to testing. In addition, three of the ASD children were each prescribed two psychotropic medicines, including buspirone ($n=1$), selective serotonin reuptake inhibitors (SSRI; $n=2$), non-stimulant ADHD medication (guanfacine or atomoxetine; $n=3$). A fourth and fifth child received mono-therapy with an SSRI and atomoxetine respectively. TDC children were screened and excluded if they or a first-degree relative had developmental, language, learning, neurological, or psychiatric disorders, psychiatric medication usage, or if the child met the clinical criteria for a childhood disorder on the Child Symptom Inventory–Fourth Edition or Child and Adolescent Symptom Inventory–4R (Gadow & Sprafkin, 2002, 2005). Participant demographics are shown in Table 1; groups were matched on age, sex ratio, SES, and full scale IQ. Consistent with previous literature (e.g. Oliveras-Rentas et al., 2012), the TDC group performed better on the Symbol Search task than the ASD group.

Measures

Socioeconomic status (SES)—SES was determined based on the education level of the participant's mother. Mother's education level was coded categorically, with categories

ranging from 1–5 and lower numbers corresponding to a greater number of years of education.

Autism diagnosis—Children were diagnosed with the Autism Diagnostic Interview-Revised (ADI-R; Lord et al., 1994), which is a detailed parent or caregiver interview regarding developmental history and autism symptoms. Scores are aggregated into symptom clusters that correspond to DSM-IV criteria for a diagnosis of autism. Scores on the ADI Reciprocal Social Interaction, Communication and Restricted Repetitive Behaviors domains indicate the number and severity of autism symptoms observed, with higher scores indicating greater symptoms. Scores of 10 or greater on the Reciprocal Social Interaction domain, eight or greater on the Communication domain (for verbal people) and three or greater on the Restricted Repetitive Behaviors domain are required to make a diagnosis of autism. The Autism Diagnostic Observation Schedule, Module 3 (ADOS; Lord et al., 1999) is a structured play and conversational interview that includes a series of social presses and other opportunities to elicit symptoms of an ASD. Scores on the ADOS Communication-Social Interaction domain range from 0 to 21. Higher scores indicate a greater number of, or more abnormal, symptoms. Diagnosis of an ASD requires a score of at least seven. Scores for the ADI-R and ADOS are presented as raw scores.

Cognitive abilities—The WASI has four subtests and the WISC-IV has 10 core and five supplemental subtests (represented as scaled scores: mean=10; standard deviation=3). One of the 10 core WISC-IV subtests is Symbol Search, which is one of two subtests making up the Processing Speed Index of the WISC-IV. It was administered to all participants as a comparison measure for the experimental IT measures discussed below.

Perceptual processing/motor output speed measures—These three experimental measures assess processing speed for tasks using the same stimuli but require differing levels of motor output demand (See Figure 1):

1. *Task 1: In the Low Motor Demand (LM) task*, participants were shown IT stimuli developed by Scheuffgen and colleagues, (2000), in which an “alien” spaceship appeared for varying, brief periods of time and they were asked whether the two “antennae” on it were the same length or different lengths. Four variations (both antennae short, both antennae long, left antenna longer, right antenna longer) were randomly presented. Stimulus duration was controlled by a mask. Participants were warned that the alien spaceship would appear for a very brief period before hiding behind a bush (the backward mask). After presentation of a stimulus the participant had unlimited time to select and press one of two computer keys to indicate same or different length antennae. The presentation of stimuli was adapted from Edmonds et al.’s (2008) IT task: 11 different exposure times were presented, with eight trials per exposure time, for 88 total trials. Each test trial began with a cue followed by the alien spaceship figure; the 11 exposure time durations for the alien spaceship figure were: 24, 30, 36, 42, 48, 54, 60, 70, 80, 90, and 100 milliseconds. Immediately after the stimulus offset, the mask was presented. The variable of interest was total accuracy, as measured by the percentage of correct trials.

2. *Task 2: The Moderate Motor Demand task (MM)* modifies the LM task by requiring a speeded motor response while viewing the stimulus. The same alien spaceship stimuli were presented over the same number of trials as in the LM task (88), but they remained on the screen until the participant pressed a key to indicate whether their antennae were the same length or different lengths. The participant was told to respond as quickly as possible. The variable of interest was total accuracy, as measured by the percentage of correct trials.
3. *Task 3: In the High Motor Demand task (HM)*, participants had to physically draw the antennae, on as many spaceships as possible during a two-minute period. The relationship of the antennae lengths was indicated by text on the page (“same” or “different”), and participants had to trace dots outlining where the antennae should be drawn to show the correct length relationship between the two antennae. The same number of dots is presented on each of the spaceships in this task. The size and image of the space ships presented on this task were consistent with that presented in the LM and MM tasks. The variable of interest was the total number correct minus the number of errors.

Procedure

This study was approved by the Children’s National Medical Center Institutional Review Board (IRB). Written informed consent from parents of participants, and assent from participants were obtained according to IRB guidelines. All participants completed diagnostic, intelligence and processing speed tasks on the same day as part of a larger study examining cognitive control in ASD.

Results

A 2 (group: ASD, TDC) x 3 (task: LM, MM, HM) mixed-model ANOVA revealed a significant main effect of group: $ASD < TDC$, $F(1,51)=7.52$, $p<0.01$, $\eta^2_p=0.13$, and the predicted group by task interaction: $F(1,51)=7.08$, $p<0.01$ (Greenhouse-Geisser corrected), $\eta^2_p=0.12$. Post-hoc t tests revealed significant group differences such that ASD individuals were less accurate than TDCs on the MM and HM tasks ($ps < 0.05$), but not the LM task. See Table 2 and Figure 1. Results remained unchanged after co-varying Full Scale IQ scores. As stated above, outlier data ((i.e., >2.5 SD) was observed and removed for three participants prior to analyzing the data. The resulting data was significantly skewed (-1.80) and kurtotic (3.25) for the MM task, but not the LM or HM tasks. This was consistent between the TDC, the ASD, and the combined TDC+ASD groups, and represented the fact that most participants achieved 90% or better accuracy rates. To address the skewed distribution in the MM data, the differences between the groups on the MM task were also assessed using a nonparametric statistical analysis (Mann-Whitney U Test). The Mann-Whitney U test is both more robust and less powerful and confirmed the same pattern of results, although the difference between the groups only trended toward significance ($p=0.06$).

Secondary analyses were conducted to insure impaired performance in the ASD groups on the MM and HM tasks did not reflect a speed accuracy trade off in which the ASD group was performing more quickly and, for that reason, making more errors. Correlations

between performance accuracy and reaction time for the MM task were not significant in the ASD or the combined ASD + TD group (p 's>0.5). There was a trend toward a positive correlation (accurate responses were faster) between speed and accuracy in the TD group ($r=0.35$, $p=0.09$). Furthermore, mean reaction times on the MM task were significantly *slower* ($t=-2.00$; $p=0.05$) for the ASD group (mean=818.6 milliseconds, $SD=249.1$) than the TDC group (mean=709.5 milliseconds, $SD=126.8$). Both of these analyses produced the opposite of what would be expected if a speed accuracy trade off were affecting the findings of reduced accuracy in the ASD group. A similar pattern was observed on the HM task. The ASD group was significantly slower than the TDC group, as indicated by the fact that each group had 60 seconds to respond to as many items as possible and the ASD group produced significantly ($t=2.37$, $p=.02$) fewer (mean=21.96, $SD=6.83$) responses than the TDC group (mean=26.12, $SD=5.96$).

In order to assess the possible impact of psychotropic medicines on performance, the group x task ANOVA was rerun after excluding the children with ASD who were taking medication on the day of testing. The findings remained the same, with a significant effect for group ($F(1,46)=6.53$, $p<0.02$, $\eta^2_p=0.12$) and the predicted group by task interaction ($F(1,46)=6.15$, $p<0.02$, $\eta^2_p=0.12$).

There was a significant correlation between ADOS communication and MM scores in the ASD group ($\rho=-0.42$; $p<0.03$) but not between the ADOS communication and LM ($\rho=-0.29$; $p=0.13$) or HM scores ($\rho=-0.08$; $p=0.69$). A strong ($r=0.69$, $p<0.001$) correlation between Symbol Search raw scores and HM, but not MM ($r=-0.13$; $p=0.53$) or LM ($r=-0.22$; $p=0.30$), scores was observed in the ASD group. Symbol Search scores were not significantly related to any of the processing speed tasks in the TDC group (r s<.23; p s>0.29).

Discussion

This study compared speeded perceptual processing in children with ASD and typical development on three tasks that present the same stimuli and make low, moderate or high motor demands. While the two groups demonstrated equivalent performance on the task with low motor demand (LM), the ASD group was less accurate than the TDC group on the two tasks that made moderate or high motor demands (MM and HM). These data provide evidence that previously described "processing speed" deficits in ASD reflect impairments in the integration of visual processing and motor output, not perceptual processing speed alone. As such, they offer a possible resolution to apparently contradictory findings of intact or even superior perceptual processing speed on IT tasks and consistently impaired Processing Speed Index scores on Wechsler tests. To our knowledge, this is the first investigation to compare individuals with ASD and typical development on processing speed tasks that hold stimulus complexity constant while increasing motor demand and thus allow a true contrast of perceptual processing with increasingly demanding motor output expectations. ASD performance on the moderate motor output version of the task (MM) was correlated with ADOS communication scores, indicating a relationship between core ASD communication deficits and speeded motor output, although the predicted relationship was not observed between the high motor demand task (HM) and ADOS scores. Finally, the

Wechsler Symbol Search subtest was strongly correlated with HM scores in ASD, but not TDC, participants, a finding that indicates that motor ability may be a stronger determinant of Wechsler processing speed in ASD than in TDC children.

Citing the lack of the expected correlation between IQ and IT in ASD, Scheuffgen and colleagues (2000) argue that ASD defies a unitary model of IQ, and ask why, when children with ASD typically have the speeded perceptual processing abilities that are needed for successful learning, do they fail to learn the information and develop the abilities measured by Full Scale IQ scores. The authors note that others have argued that cognitive deficits, such as impaired attention may play a role. This investigation supports the complementary theory that difficulty with motor output contributes to this gap, and affects communication as well as the demonstration of cognitive knowledge and skills. The fact that performance on the HM task correlates so highly with a more complex processing/speed output task (Symbol Search) in ASD, but not TDC participants, is consistent with data presented elsewhere (Yoran & Hegesh, 2009; Stephens & Sreenivasan, 2002) indicating that motor output demands interfere on Wechsler type processing speed tasks for people with ASD but not those with typical development. This could reflect the fact that motor impairment in ASD creates a greater impact of motor demands on task success than occurs in typical populations where motor abilities are not generally a limiting factor on performance. This speculation is supported by the fact that there is a much smaller range of Symbol Search scores in the TDC than in the ASD group, where the additional variability increases power to detect a relationship between the Symbol Search and HM tasks.

The exact level of motor demand that impairs performance in ASD is not completely clear based on the data presented here. We found a significant difference in ASD performance compared to TDC performance when the response mode shifts from an untimed button press to a timed button press response. Relative problems with accuracy on the MM task in the ASD group are not accounted for by a speed accuracy trade off. Indeed, reaction time is slower in the ASD group on this task, and there is a medium effect size for the difference in accuracy between the ASD and TDC groups. However, the data from the MM task were not normally distributed in the ASD, TDC or combined ASD/TDC group due to highly accurate performance in both groups, and a nonparametric contrast of ASD and TDC MM performance only trended ($p=0.06$) toward significance. This diminished effect might be expected with a more robust, but less powerful statistical measure, but raises questions about whether the motor demand in a speeded button press is a clinically meaningful obstacle in ASD.

Furthermore, it is unclear whether this relationship between motor demand and processing speed is universal in autism. Close inspection of the data in this investigation as afforded by Figure 1 reveals greater variability in the ASD group, for which the range of scores is wider on all three of the tasks than it is for the TDC group. As pointed out by Hill and Bird (2006), variability of performance is often a hallmark of ASD. The final dataset did not contain outliers, and different participants were among the least accurate on the different tasks, implying that there is not a simple subset of ASD participants who struggled with the task demands. A future investigation with a larger sample size would be helpful however, as it would allow a more nuanced interrogation of the data to identify subsets of individuals with

specific patterns of performance on these tasks. Furthermore, this study is limited to unusually bright individuals, as the ASD mean IQ is in the high average range and thus skewed relative to the broader ASD population. Future investigations including participants with lower IQ scores are necessary to determine if the pattern observed here holds with less intellectually able individuals.

Future investigations would also be important to rule out alternative explanations for the findings presented here. Avoiding an unintended confound in the present data between motor integration and perceptual processing demand would be important in confirming these results. By comparing the LM task, which separates perceptual processing temporally from the motor response (which occurs after the image leaves the screen), to the MM task in which perception and motor output demands are made simultaneously, the current task inadvertently confounded reduced perception and increased motor integration demands, as participants universally took more time to respond in the MM task than they were allowed to view the stimuli in the LM task, and were as a result more accurate in the MM demand task. Furthermore, controlled investigation of how the complexity of the stimuli presented affect perceptual processing speed in ASD would address whether complexity, in addition to motor demand, can undermine the ability of individuals with ASD to demonstrate their fast perceptual processing capabilities.

Like Wallace, Anderson, and Happé (2009), we show intact performance on the IT task in children with ASD compared to TDC, but not an advantage in speeded perceptual processing in ASD as described by Scheuffgen et al. (2000). Unlike either of these previous investigations of IT in ASD, in which the IT variable of interest was an individually determined mean exposure duration at which the subject was 70% accurate, we measured mean accuracy across 11 different exposure times, an approach that has been used in a large study of IT in typical development (Edmonds et al., 2008). In addition, the mean IQ scores of the children with ASD in both the present study and that done by Wallace and colleagues (2009) are considerably higher than the low average IQ found in Schuffeugen et al.'s (2000) sample. A future study contrasting an adaptive IT measure, with and without motor demand, that adjusts to the speed at which the child can respond accurately for a majority of the time would allow inclusion of children with ASD and intellectual disability.

Nevertheless, this investigation highlights difficulties with the term processing speed as it is applied in ASD to perceptual speed tasks such as IT and much more complex tasks which place greater demands on cognitive control and motor output. Processing speed has been conceptualized as relying on a variety of abilities (Roberts & Stankov, 1999), including visualization speed, perceptual speed, decision time, and movement time (O'Connor & Burns, 2003). In the case of ASD at least, movement demands are a significant limiting factor, and should be considered separately. These data raise the possibility that motor output demands may play a role in the communication difficulties associated with ASD. This clearly requires further investigation, however, because the relationship was observed in one (MM) but not the other (HM) demanding motor task, and also because communication is a highly complex, multiply determined skill. The data also highlight the need for educational and vocational accommodations to minimize requirements for motor output. For example, the provision of computerized devices with voice activated software

can alleviate motor demands for written expression, and tracking and recording assignments, directions and tasks. These supports in turn increase the possibility for unlocking the potential to successfully problem solve that is implied by the strong Verbal and Performance IQ scores of many high functioning children with ASD.

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References

- American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 4. Washington, DC: American Psychiatric Association; 2000. text revision
- Brock J, Xu JY, Brooks KR. Individual differences in visual search: relationship to autistic traits, discrimination thresholds, and speed of processing. *Perception*. 2011; 40:739–742. [PubMed: 21936301]
- Dawson M, Soulieres I, Gernsbacher MA, Mottron L. Research report: The level and nature of autistic intelligence. *Psychological Science*. 2007; 18:657–662. [PubMed: 17680932]
- Edmonds CJ, Issacs EB, Visscher PM, Rogers M, Lanigan J, Singhal A, Lucas A, Deary IJ. Inspection time and cognitive abilities in twins aged 7 to 17 years: Age-related changes, heritability and genetic covariance. *Intelligence*. 2008; 36:210–225.
- Frith, U. Asperger and his syndrome. In: Frith, U., translator and editor. *Autism and Asperger syndrome*. Cambridge, UK: Cambridge University Press; 1991. p. 37-92.(Original work published 1944)
- Fuentes CT, Mostofsky SH, Bastian AJ. Children with autism show specific handwriting impairments. *Neurology*. 2009; 73:1532–1537. [PubMed: 19901244]
- Gadow, KD.; Sprafkin, J. *Child Symptom Inventory-4 screening and norms manual*. Stony Brook, NY: Checkmate Plus; 2002.
- Gadow, KD.; Sprafkin, J. *Child and Adolescent Symptom Inventory-4R*. Stony Brook, NY: Checkmate Plus; 2005.
- Gowen E, Hamilton A. Motor abilities in autism: A review using a computational context. *Journal of Autism and Developmental Disorders*. 2013; 43:323–344. [PubMed: 22723127]
- Hill EL, Bird CA. Executive Processes in Asperger Syndrome: Patterns of performances in multiple case series. *Neuropsychologia*. 2006; 44:2822–2835. [PubMed: 16930637]
- Kanner L. Autistic disturbances of affective contact. *Nervous Child*. 1943; 2:217–250.
- Lord, C.; Rutter, M.; DiLavore, PC.; Risi, S. *Autism Diagnostic Observation Schedule–WPS (ADOS–WPS)*. Los Angeles, CA: Western Psychological Services; 1999.
- Lord C, Rutter M, LeCouteur A. Autism diagnostic interview – revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders*. 1994; 24:659–685. [PubMed: 7814313]
- Manjiviona J, Prior M. Comparison of Asperger syndrome and high-functioning autistic children on a test of motor impairment. *Journal of Autism and Developmental Disorders*. 1995; 25:23–39. [PubMed: 7608032]
- Mayes SD, Calhoun SL. Learning, attention, writing, and processing speed in typical children and children with ADHD, autism, anxiety, depression, and oppositional-defiant disorder. *Child Neuropsychology*. 2007; 13:469–493. [PubMed: 17852125]
- Mayes SD, Calhoun SL. WISC-IV and WIAT-II profiles in children with high-functioning autism. *Journal of Autism and Developmental Disorders*. 2008; 38:428–439. [PubMed: 17610151]

- Mostofsky SH, Dubey P, Jerath VK, Jansiewicz EM, Goldberg MC, Denckla MB. Developmental dyspraxia is not limited to imitation in children with autism spectrum disorders. *Journal of the International Neuropsychological Society*. 2006; 12:314–326. [PubMed: 16903124]
- MacNeil LK, Mostofsky SH. Specificity of dyspraxia in children with autism. *Neuropsychology*. 2012; 26:165–171. [PubMed: 22288405]
- Nyden A, Billstedt E, Hjelmquist E, Gillberg C. Neurocognitive stability in Asperger syndrome, ADHD, and reading and writing disorder: A pilot study. *Developmental Medicine and Child Neurology*. 2001; 43:165–171. [PubMed: 11263686]
- O'Connor TA, Burns NR. Inspection time and general speed of processing. *Personality and Individual Differences*. 2003; 35:713–724.
- Oliveras-Rentas R, Kenworthy L, Roberson RB, Martin A, Wallace GL. WISC-IV profile in high-functioning autism spectrum disorders: Impaired processing speed is associated with increased autism communication symptoms and decreased adaptive communication abilities. *Journal of Autism and Developmental Disorders*. 2012; 42:655–64. [PubMed: 21638108]
- Roberts RD, Stankov L. Individual differences in speed of mental processing and human cognitive abilities: Toward a taxonomic model. *Learning and Individual Differences*. 1999; 11:1–120.
- Scheuffgen K, Happé F, Anderson M, Frith U. High “intelligence,” low “IQ”? Speed of processing and measured IQ in children with autism. *Development and Psychopathology*. 2000; 12:83–90. [PubMed: 10774597]
- Stephens R, Sreenivasan B. Analysis of substitution test performance using eye movement and video data. *Applied Neuropsychology*. 2002; 9:179–183. [PubMed: 12584083]
- Wallace GL, Anderson M, Happé F. Brief Report: Information processing speed is intact in autism but not correlated with measured intelligence. *Journal of Autism and Developmental Disorders*. 2009; 39:809–814. [PubMed: 19148736]
- Wallace GL, Happé F, Giedd JN. A case study of a multiply-talented savant with an autism spectrum disorder: Neuropsychological functioning and brain morphometry. *Philosophical Transactions of the Royal Society: Section B: Biological Sciences*. 2009; 364:1425–32.
- Wechsler, D. Wechsler Abbreviated Scale of Intelligence. San Antonio, TX: Psychological Corporation; 1999.
- Wechsler, D. Wechsler Intelligence Scale for Children. 4. San Antonio, TX: Psychological Corporation; 2003.
- Yoran-Hegesh R, Kertzman S, Vishne T, Weizman A, Kotler M. Neuropsychological mechanisms of Digit Symbol Substitution Test impairment in Asperger Disorder. *Psychiatry Research*. 2009; 166:35–45. [PubMed: 19215988]

Figure 1.

Accuracy on the low motor demand (LM), moderate motor demand (MM) and high motor demand (HM) tasks are reported for each individual in the ASD and TD groups. The solid black line indicates the mean score for each group. Representations of the stimuli presented for each task are presented in the far right pane. The stimuli for the LM and MM tasks are presented on a computer screen, while the stimuli for the HM task are presented on paper on which the participants draw their response. The stimuli are all presented as representing a space ship with antennae. For the LM and MM tasks, Figure 1 presents the sequence of three images that appears to the participants: a fixation point, the space ship and then a mask.

Table 1

Participant demographics

Total N	TDC <i>M (SD)</i> 25	ASD <i>M (SD)</i> 28	t-value/ Chi-Sq.	p-value
Chronological Age (Years)	10.64 (1.70)	10.88 (1.40)	-0.57	0.57
Full Scale IQ ^a	121.84 (12.47)	115.21 (14.64)	1.76	0.08
Symbol Search	11.79 (2.67)	9.25 (2.57)	3.49	0.001
Sex ratio (male:female)	17:8	20:8	0.07 ^c	0.79
SES				
Mother's education level	1.88 (1.09)	2.00 (1.06) ^b	2.06 ^c	0.72
ADI-R				
Social	--	19.07(5.46)	--	--
Communication	--	15.61 (4.28)	--	--
Repetitive Behaviors	--	5.29 (2.05)	--	--
ADOS				
Social+Communication	--	11.07 (2.87)	--	--

^a Wechsler Abbreviated Scale of Intelligence, or Wechsler Intelligence scale for Children-4th Edition

^b Mother's education level, ASD N=24

^c Pearson Chi-Square

Table 2

Group Differences in Accuracy of Response during Low, Moderate and High Motor Demand Tasks with Post-Hoc *t* and Cohens-*d* Values

Task	TDC <i>M</i> (<i>SD</i>) (n=25)	ASD <i>M</i> (<i>SD</i>) (n=28)	<i>t</i> -value	Cohens- <i>d</i>
Low Motor Demand	0.77 ^a (0.11)	0.72 (0.13)	1.76	0.48
Moderate Motor Demand	0.95 ^a (0.05)	0.91 (0.08)	2.10 *	0.58
High Motor Demand	25.84 ^b (6.27)	20.86 (7.13)	2.69 **	0.74

^a Low and Moderate Motor Demand means and standard deviations reflect the **proportion** of accurate responses

^b High Motor Demand means and standard deviations reflect the total number of correct minus incorrect responses

* p-value < 0.05

** p-value < 0.01