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The structure of intelligence in children and adults with high functioning autism

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Abstract

Confirmatory factor analyses of the traditional 11 subtests of the Wechsler child and adult intelligence scales were accomplished for 137 children and 118 adults with high functioning autism (HFA) and for comparable age groups from the standardization samples contained in the Wechsler manuals. The objective was determining whether HFA groups produced similar best fitting models to those found in the normative samples or formed a separate “social intelligence” factor. Four-factor models incorporating a “social intelligence” factor provided the best fit in both the autism and normative, but the subtest intercorrelations were generally lower in the autism samples. Findings were interpreted in terms of underconnectivity or reduced communication among brain regions in autism.

The Wechsler intelligence scales (Wechsler, 1974; 1981; 1991) have had widespread application in the assessment of children and adults with autism. Aside from the traditional role of these procedures in educational, vocational, and clinical diagnostic applications, they have been used in autism research to separate high functioning from low functioning autism, for differential diagnostic purposes within the autism spectrum and, perhaps most significantly, for delineating the pattern of cognitive function in autism. The Wechsler contains 11 or more subtests depending upon the version used, making it possible to obtain a cognitive profile of diverse abilities in addition to the Verbal, Performance, and Full Scale IQ scores. A profile apparently unique to high functioning autism has been identified in numerous studies, characterized by relatively high scores on the Block Design subtest and relatively low scores on Comprehension (Rumsey, 1992; Siegel, Minshew & Goldstein, 1996; Yirmiya & Sigman, 1991). In fact, in a review of 14 studies reporting Wechsler IQ

subtest scores in autism conducted since 1965, Siegel et al. (1996) observed that all fourteen reported the Block Design subtest to be the highest Performance subtest, while Comprehension was the lowest Verbal subtest in thirteen of the studies. The consistency of these findings across studies is quite remarkable, given the differences in data analytic and research design methodologies across studies and sites, as well as the various versions of the Wechsler scales used. The Block Design subtest was of particular interest because, often enough, it was not only normal but in the superior range, suggesting the presence of an exceptional spatial constructional ability in some individuals with high functioning autism.

In addition to the subtest profile and IQ scores, the Wechsler scales have been repeatedly factor analyzed in both normal and clinical populations. Exploratory factor analysis has generally demonstrated that when the 11 subtest versions of these scales are studied, a three-factor solution is consistently found. The factors are called Verbal Comprehension (VC), Perceptual Organization (PO) and Attention/Concentration or Freedom from Distractibility (FFD). The VC factor receives high loadings from Information, Comprehension, Similarities, and Vocabulary subtests. The PO factor receives high loadings from Picture Completion, Picture Arrangement, Block Design, and Object Assembly subtests. The Digit Span, Arithmetic and, at times, Digit Symbol or Coding subtests, constitute the FFD factor.

More recent applications of factor analysis have employed confirmatory approaches, made possible by advances in structural equation modeling (Jorskog, 1979). Confirmatory factor analysis (CFA) is designed to evaluate specific hypotheses about the number of factors that make up a particular test battery and the pattern of factor loadings. Thompson, in his text on these two methods (2004), indicates that most investigators now find CFA more useful than exploratory approaches, particularly if they have specific expectations about the factor structure of the test. CFA studies of both the WISC-R and WAIS-R in normal and clinical samples have typically confirmed the three-factor model described here. More recently, the addition of several subtests to the WAIS-III and WISC-III allowed for testing of four- and five-factor models. The addition of these subtests made a four-factor solution more optimal than the previously reported three-factor model. In this four-factor solution, the VC, PO and FFD factors are retained. However, an additional subtest, Letter-Number Sequencing, is added to the FFD factor, which is renamed Working Memory (WM). Also, the Digit Symbol subtest is paired with the Symbol Search subtest to form a Processing Speed factor (PS). Thus, even for these newer versions of the Wechsler scales, the three-factor model identified in their predecessors continues to provide a meaningful organization of the major subtests of the Wechsler scales.

For autism, the factor structure of the Wechsler scales is of clinical interest because it has been shown that using the same tests, the factor structure, or loading pattern, may differ in different clinical groups so that there may be a group that does not show the pattern of VC, PO, and FFD factors found on the Wechsler scales produced by normally developing individuals. The implication of different loading patterns is that the organization of cognitive abilities may differ among these groups. Such an occurrence would bespeak a different organization of cognitive processing or intelligence from what is found in normal individuals. And in fact, in a study done some time ago with a small sample ($n = 33$), it was found that individuals with autism had a different factor structure on the Wechsler scales from normal controls suggesting the possibility of a "social intelligence" factor (Lincoln, Courchesne, Kilman, Elmasian, & Allen, 1988). Using principal components the investigators identified three factors in their autism sample. The first was the traditional verbal factor, but the second factor only received high loadings from Block Design, Object Assembly and Digit Symbol/Coding. The third factor only received high loadings from Picture Arrangement and Picture Completion. Thus, while the small sample size precluded any definitive conclusions, the findings were suggestive of a dissociation between

performance tests that the authors described as nonverbal, social, and context-relevant and performance tests that do not involve these abilities but assess visual analysis and integration. Lincoln et al. did not specifically characterize this third factor as a “social intelligence” factor, but rather described the pattern found in high functioning autism as a mismatch between verbal reasoning and context recognition with more well developed perceptual-motor organization abilities. They also suggested that factors may be representative of various aspects of brain function. We would suggest that the identification of such a dissociation may underlie a deficit in social intelligence in autism, but since the Wechsler scales assess cognitive processes and not social functioning the identification of a “social intelligence” factor using CFA is primarily of interest because of the insights it may provide relating to social cognition. Relevant aspects of such cognition would be appreciation of context and inference making.

The unusual subtest profile of those with high functioning autism is also suggestive of a factor structure that would substantially vary from that identified in normal populations. In autism, on the Verbal Comprehension Tests the Comprehension subtest is typically substantially lower than Information, Vocabulary and Similarities. On the Perceptual Organization subtests, Block Design is substantially higher than Picture Completion and Picture Arrangement. Digit Symbol may also be depressed. These profile differences would suggest that when a factor analysis is performed, while three or four factors may be extracted they will have different loading patterns from the national normative samples, and goodness-of-fit may not be as adequate as is found in the standardization samples.

In the current study we investigate these possibilities using CFA to evaluate a number of *a priori* models in children and adults with high functioning autism, and in the national samples. Using the traditional 11 subtest version of the Wechsler scales we tested the traditional one, two and three factor models, as well as two different four factor models based on profiles commonly associated with autism as reviewed in Siegel, Minshew and Goldstein (1996). The general hypothesis was that the autism groups would demonstrate a different factor structure than was found for the Wechsler scale national standardization samples.

Method

Participants

The sample consisted of 137 children and 118 adults with autism, all of whom were participants in Collaborative Programs of Excellence in Autism research at the University of Pittsburgh or Yale Child Study Center. Demographic and psychometric data are presented in Table 1. We restricted the sample to individuals with high-functioning autism (Full Scale and Verbal IQ scores of 70 or above) to assure that the participants could cooperate for psychological testing and were unlikely to have the numerous additional disorders commonly associated with low functioning autism. All participants met the cutoffs for autism according to the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, Goode, Heemsbergen, Jordan, Mawhood, & Schopler, 1989) for the Communication, Reciprocal Social Interaction, and total algorithm scores. In addition, all participants met cutoffs for autism on the Autism Diagnostic Interview-Revised (ADI-R; Le Couteur, Rutter, Lord, Rios, Robertson, Holdgrafer, & McLennan, 1989; Lord, Rutter, & Le Couteur, 1994) for Reciprocal Social Interaction, Communication, and Restricted, Repetitive, and Stereotyped Behaviors and had abnormal development before 3 years of age. The ADI-R assesses developmental history and reported current functioning based on caregiver report. The diagnosis of autism was verified by expert opinion. All participants with autism communicated in complete spoken sentences and had sufficient attention and cooperation to complete testing. The participants did not have any associated or causative known genetic,

metabolic, or infectious conditions, were in good medical health and had no history of seizures, birth injury, or head trauma.

Data were collected over several years spanning the period during which new editions of both the WAIS and the WISC appeared. Thus, the adults received either the WAIS-R ($n=77$) or the WAIS-III ($n=41$), and the children received either the WISC-R ($n=44$) or the WISC-III ($n=93$).

Data Analyses

For purposes of maximizing sample size, data from the two forms were combined in each age group. This step was taken after a determination that the intercorrelations among the subtests across the two forms were very close to each other, with differences that would not be sufficient to alter factor structures. Thus, data were obtained for 118 adults who had received a version of the WAIS and 137 children who had received a version of the WISC. Also, data analyses were performed only for the 11 traditional subtests of the WAIS-R and WISC-R, not including additional tests added to the WAIS-III and WISC-III. Thus the subtests entered into the analyses included Information, Comprehension, Similarities, Arithmetic, Vocabulary, Digit Span, Picture Completion, Picture Arrangement, Block Design, Object Assembly, and Digit Symbol/Coding. A consideration in using only these subtests was that they are the ones that have been used in most autism research. From a more practical standpoint, because data collection began before the WAIS-III and WISC-III were published, complete data were only available on the 11 subtests of the earlier “R” versions. Theoretically, the consistency in factor structure across the various versions of the Wechsler scales in normal populations indicates that the associations among the subtests remain stable despite revisions of the instruments. Similarly, the remarkable stability of Wechsler profiles for autism samples over the various versions of the tests provides additional assurance that despite revisions, the associations among the subtests have remained largely the same. Therefore models were tested that only included the 11 traditional subtests without inclusion of the additional subtests added to the “III” versions of the child and adult tests.

One, two, and three-factor models were examined in developing models for the current study, as most previous studies using CFA to examine the factor structure of the Wechsler Scales have evaluated these models (Burton, Ryan, Paolo, & Mittenberg, 1994; Burton, Sepehri, Hecht, VandenBroek, Ryan, & Drabman, 2001; Brown, Hwang, Baron, & Yakimowski, 1991; Dickinson, Iannone, & Gold, 2002; O’Grady, 1983; Plake, Gutkin, Wise, & Kroeten, 1987; Waller & Waldman, 1990). For the one-factor model, all of the subtests are specified to load on a single factor. The one-factor model evaluates the hypothesis that intelligence involves a single latent trait, consistent with views concerning the existence of a “g” (general) factor as the basis for intellectual function. The two-factor model is largely based on Wechsler’s original concept of intelligence divided along Verbal and Performance constructs, or possibly based on crystallized and fluid conceptualizations. In these models, subtests contributing to the Verbal IQ are specified to load on the Verbal construct, while those contributing to the Performance IQ load on the Performance construct. Three-factor models specified Verbal Comprehension (VC), Perceptual Organization (PO), and Freedom from Distractibility (FFD) factors. The FFD factor is primarily composed of the Arithmetic and Digit Span subtests, and is thought to reflect attention/concentration abilities. Slight variations of this three-factor model account for the tendency of Digit Symbol to load on both the PO and FFD factors in some populations, and on the FFD factor in others (Allen, Seaton, Huegel, Goldstein, Gurklis, & van Kammen, 1998; Burton, Ryan, Paolo, & Mittenberg, 1994; Burton, Sepehri., VandenBroek, Ryan, & Drabman, 2001; Waller & Waldman, 1990).

Three different three-factor models were evaluated in the current study. Two of them specified VC, PO and FFD factors, and differed only with regard to the loading of Digit Symbol/Coding, because previous investigations have been inconclusive regarding the loading of Digit Symbol/Coding. In the first three-factor model (M_3), the VC factor was composed of the Information, Vocabulary, Comprehension, and Similarities subtests, the PO factor was composed of the Picture Completion, Block Design, Picture Arrangement, and Object Assembly subtests, and the FFD factor was composed of the Digit Span, Arithmetic, and Digit Symbol/Coding subtests. The second three-factor model (M_{3D}) is the same as M_3 with the exception that Digit Symbol/Coding was specified as a doublet, loading on both the PO and FFD factors. The final three-factor model was based on the finding reported by Lincoln et al. (1988), of a VC, PO and a third factor which was composed of the Picture Arrangement and Picture Completion subtests and could be characterized as a “social intelligence” factor.

Additionally, given the consistent findings of an FFD factor in both clinical and nonclinical populations, along with the unique Wechsler subtest profile and factor structure in autism, two different four-factor models were also evaluated in order to evaluate the possibility of a factor unique to autism. In both of them, the VC, PO, and FFD factors were retained, but in the first model Picture Arrangement and Picture Completion were specified to load on a fourth factor, thereby evaluating the “social” factor identified by Lincoln et al. (1998) using principal components analysis. This model attempted to separate Performance subtests with social content and more neutral content. A variation of this idea was applied in the second model that specified Comprehension to load on the fourth factor with Picture Arrangement, producing a model with social content that assessed both Verbal and Performance abilities. In summary we employed a one-factor model (“g”), a two-factor model (Verbal and Performance abilities), a number of three-factor models (VC, PO, and FFD or “Social Intelligence”), and two four-factor models (VC, PO, FFD, and “Social Intelligence”). It was predicted that the model which would provide the best overall fit for the autism samples was the four-factor model specifying that Picture Arrangement and Picture Completion would form a “Social Intelligence” factor, while retaining the VC, PO, and FFD factors. All models were tested with confirmatory factor analysis (CFA) using LISREL 8 (Jöreskog & Sörbom, 1993). CFA differs from exploratory factor analysis (EFA) in that CFA requires *a priori* specifications indicating that certain observed variables, in this case the Wechsler subtests, are (a) related to specific unobserved variables called latent variables or factors, that they are thought to measure and (b) are not related to unobserved variables they are not thought to measure. These *a priori* specifications are based on theoretical or empirical evidence, and form the basis of hypothesized statistical models that can then be tested against an actual set of data. In order to determine if the hypothesized statistical model fits the actual data set, a number of goodness-of-fit statistics are used; the most common include the chi-square statistic, the goodness-of-fit index (GFI), and the adjusted goodness-of-fit index (AGFI). The chi-square statistic is used to evaluate the fit between the hypothesized statistical model and the actual data set. The GFI and AGFI provide estimates of the amount of variance and covariance that is explained by the model. Both the GFI and AGFI have ranges of 0.00 to 1.00, but the AGFI provides a correction for the complexity of the model, so that all else being equal, more parsimonious models attain higher AGFI's. For these indexes, an adequate fit is indicated by a GFI of .90 and above, and an AGFI of 0.80 or above (Cole, 1987; Ward, Ryan, & Axelrod, 2000).

The chi-square, GFI, and AGFI indexes are affected by sample size so that relatively high values can be attained even when models are specified poorly. To address this limitation, a number of other fit indexes were examined, including the Bentler and Bonnett Normed Fit Index (NFI), the Tucker-Lewis Index (T-LI), the Root Mean Square Error of Approximation (RMSEA), and the Comparative Fit Index (CFI). The NFI and T-LI indexes provide

estimations of improvement in model fit over a baseline model, typically the null model which specifies that there are no factors, i.e., there are no correlations among the variables in the model. The T-LI has been shown to be relatively unaffected by sample size (Bollen, 1990), and unlike the NFI also adjusts for the complexity of the model so that, all else being equal, a more complex model would attain a lower T-LI than a less complex one. NFI and T-LI at .90 and above indicate adequate fit, with values greater than .95 indicating good fit. The CFI and RMSEA provide additional estimates of fit based on the non-centrality parameter in which testing is done against an alternative rather than the null hypothesis. A good fit is indicated by a CFI of .95 or greater, and a RMSEA of less than .06. It should be noted that the cut-off values for all of these goodness of fit statistics are not universally agreed upon, and so decisions regarding the adequacy of a particular model are best based on considering all of the indexes together, rather than relying on only one or two. For the present study, comparisons with the Wechsler standardization samples were also important in selecting the optimal model, given the established factor structure for these scales in large, normal populations.

In judging improvement in model fit, comparisons were made to both the null model and the one-factor model, which was included as an informed baseline model. Comparisons were made to the null model to demonstrate that each of the hypothesized models provided a better fit than the null. Comparisons to the one-factor baseline model provided a more rigorous test of relative model fit, because it assumed that the Wechsler scale subtests are correlated with each other, an assumption that is consistent with numerous studies investigating them. Additionally, incremental improvement in model fit was evaluated by examining the difference in chi-square between competing models. Magnitude of the differences in chi squares between the models provides one indication of the relative improvement in model fit, with a larger difference indicating a greater improvement in fit.

For comparison purposes, the same models were also evaluated for the normative samples reported in the test manuals for the various Wechsler scales. The CFA analyses were repeated for the age appropriate matrices contained in the manuals for the WISC-R, the WISC-III, the WAIS-R and the WAIS-III. For the children, the WISC-R and WISC-III correlations matrices from the 11 year old age groups were used in the analyses. This age group was chosen as the comparison samples because they most closely approximated the age of our sample of children with autism (mean age = 11.01 SD = 2.94). For adults, the correlation matrices for the WAIS-R 25–34 year old age group and the WAIS-III 25–29 year old age group were selected for analysis, again because these age groups most closely approximated that of our adult autism sample (mean age = 27.53, SD=9.25). Using these values from the national standardization samples as baselines, we went on to test various models for children and adults with autism.

Results

Goodness of Fit Indexes for Hypothesized Models

The correlation matrices used in the analyses for the child and adult autism samples are presented in Table 2. The goodness of fit indexes for the seven hypothesized models are presented in Table 3 (Child) and Table 4 (Adult). For the child samples, the results of the one-, two- and three-factor models are in the expected direction and are highly consistent across the WISC-R, WISC-III, and Autism groups. In all cases, the one- and two-factor models provided a relatively poor fit for all three groups. The three factor models provided relatively better fit, with little difference present between the model where Digit Symbol/Coding was specified to load on the FFD factor (M_3) and the model where it was specified as a doublet, loading on both the PO and FFD factors (M_{3D}). Because M_3 is the more parsimonious of the two models, it is considered the better of the two. An exception to this

was the three-factor model that was based on the work of Lincoln et al. (1988), and suggested a “social intelligence” factor composed of the Picture Arrangement and Picture Completion subtests (M_{3SI}). This model provided a relatively poor fit for the data, producing fit indexes that were comparable to the two-factor model, and much poorer than the other three-factor models. Results for the four-factor models were also consistent across groups, with the model specifying Picture Arrangement and Comprehension (M_{4C}) as the fourth factor providing a poorer fit of the data when compared to the model with Picture Arrangement and Picture Completion (M_{4PC}) loading on the fourth factor. For the WISC-R, WISC-III and Autism samples, this latter model demonstrated improved fit over the three factor models, whereas model M_{4C} did not exhibit a substantial improvement in fit over the three-factor models.

As can be seen from Table 4, comparable results were obtained for the adult samples. There was relatively little difference in fit between the three-factor models specifying VC, PO and FFD factors, which provided better fit for the WAIS-R, WAIS-III and Autism groups than did either the one-factor model, two-factor model, or alternative three-factor model (M_{3SI}). Again, given that model M_3 is more parsimonious than M_{3D} , model M_3 is considered the better model of the two. Of the four-factor models, the model with Picture Arrangement and Picture Completion loading on the fourth factor (M_{4PC}) was the superior model, and provided the best overall fit of the data when all seven models are considered. In the four factor models for both children and adults, Digit Symbol/Coding was retained on the FFD factor, given that M_3 was the best three-factor model. In summary, no substantial difference in the pattern of the goodness-of-fit statistics was found across the seven models between the autism and national standardization samples in both children and adults, although the indices were generally lower in the autism groups, particularly the children

Incremental Improvement in Model Fit

For the analyses examining incremental improvement in model fit, only certain models were selected for comparison purposes. The one-, two- and three-factor models were compared in order to establish that the increase in model complexity was associated with comparable increases in fit for the national and autism samples. Because of concerns regarding parsimony between the three-factor models, only the less complex of the two was included in these analyses (M_3). Correspondingly, while two different four-factor models were initially examined, only the model specifying Picture Arrangement and Picture Completion as loading on the fourth factor (M_{4C}) was included, as the other model (M_{4PC}) was no better than the three-factor models. Tables 5 and 6 present the χ^2 difference and NFIs for these models. These indexes provide estimates of incremental improvement in model fit. The significant χ^2 difference statistics indicate that for all groups, M_2 provided significantly better fit than M_1 , M_3 provided significantly better fit than M_2 , while M_{4PC} provided significantly better fit than M_3 . With regard to this latter result, although it was anticipated that M_{4PC} would provide statistically significant improvement in model fit over the other models in the autism groups, the finding for the Wechsler comparison samples was not anticipated.

Examination of Subtest Intercorrelations

Despite the similarities noted across the autism and control groups for both the goodness of fit and incremental fit indexes, some notable differences were also apparent. In almost all cases, the goodness of fit indexes (GFI, AGFI, NFI, T-LI, CFI) were lower for the autism samples. Comparing the correlation matrices for the autism samples to those of the standardization samples provides some insight into why this was the case. For example, with regard to the children, in the 11 year old group of the national sample for the WISC-R, the VC tests correlate with each other in the range of .40 to mid .60. The PO subtests correlate with each other in the mid .40 to mid .50 range. For the FFD factor, Digit Span and

Arithmetic have a .53 correlation but the correlations with Coding are low. No subtest correlates with Coding higher than the mid .20 range. In the case of the children with autism the VC tests correlate with each other in the .50 to .60 range, but the PO subtests show some differences. Intercorrelations among Picture Completion, Picture Arrangement, Block Design, and Object Assembly are lower, falling into the .20 to mid-.40 range. The most extreme case is the correlation between Block Design and Picture Completion. It is .54 in the national sample and .31 in the autism group.

There were similar findings for the adults. In the national sample the intercorrelations among the VC tests were quite high, ranging from approximately .50 to .80. There is a more coherent FFD factor in the national sample adults than in children with mid .40 range correlations with Digit Symbol and a .60 correlation between Digit Span and Arithmetic. In the autism group, there is also a coherent FFD factor with correlations in the mid .40 range. The PO factor is characterized by mid .30 to mid .60 range correlations in the national sample. These correlations are always lower in the autism group ranging from .34 to .55.

In total, for the children, out of 55 intercorrelations, the correlation was lower in the autism than in the national sample in 44 cases. In the adults it was 47 cases. This raises the possibility that the lower goodness of fit and incremental fit indexes for the autism samples is related primarily to a reduced association among cognitive abilities in autism. While this comparison suggests that children and adults with autism do not have remarkably different factor structures, there may be a difference in the coherence of those structures.

Maximum Likelihood Factor Loadings

The tables of maximum likelihood factor loadings indicate little difference between the autism and national samples in the magnitudes of loadings both in the children and adults. Reduced loadings relative to the national sample associated with reduced tendencies toward simple structure did occur in the autism samples. It seems that the autism samples, like the national samples, have a four-factor structure but because of the psychometric characteristics of the Wechsler scale it only approached the level of simple structure, but did not fully achieve it. It is interesting to note that, as in the case of the Lincoln et al. (1988) study, Picture Completion and Picture Arrangement loaded on a separate factor from Block Design and Object Assembly in the autism sample but the same loading pattern was found in the WISC-III and WAIS-III standardization samples. Thus, at least within the context of a four factor solution, children and adults with autism do not appear to have a unique “social intelligence” factor.

Discussion

The results of the study indicate that in both children and adults with autism goodness-of-fit with the latent structure of the Wechsler scales is not as strong as it is when using subtest intercorrelations from age appropriate components of the national samples from which these tests were standardized. This finding is a general one involving all models tested. Even when an effort was made to evaluate a hypothetical “social intelligence” factor involving the Comprehension, Picture Completion, and Picture Arrangement subtests, less robust goodness-of-fit was obtained in the autism samples than in the national samples using four factor models based upon this structure. Despite the existence of a clearly prototypic subtest profile in individuals with autism, there is no indication of a particular model that has a comparable goodness-of-fit to those obtained by typically developing individuals

It is noted that in the case of the national samples the goodness-of-fit-indices for the various models range around .90 or above. Thompson (2004) indicates that an NFI of .95 or above means there is an excellent fit. In the case of the WAIS-R several of the models are at or

approach .95, but the autism group never exceeds .92. For the WISC-R several of the models approach .95 for the national sample, but the NFIs for the autism group never exceed .85. In the case of the WISC-III, which involves several additional subtests, the published AGFIs for four and five-factor models exceed .95. Thus, while CFA of the Wechsler scales do not always achieve a fully adequate fit even for three or four-factor models, it is adequate in some cases. The fit in autism, particularly children, was always found to be less than adequate. The absence of a less than ideal goodness-of-fit for the Wechsler scales has been noted previously (Burton et al., 1994; O'Grady, 1983; Waller & Waldman, 1990) and apparently reflects the fact that the Wechsler scales are not factorially pure instruments.

The most direct interpretation of these findings would appear to be that while the factorial structure of the Wechsler scales in autism is similar to structures found in the general population, cognitive abilities are less strongly associated among each other in autism than is the case for typically developing individuals. As seen in this study, even individuals with high functioning autism who may have average or above general intelligence demonstrate this phenomenon. Put another way, if one knew the score of an individual on a test of one particular ability, one would be less accurate in estimating the score of another ability for an individual with autism than for an individual without autism.

It is possible that the lower correlations in the autism group are not primarily because their intellectual function is not organized into four factors but because individual abilities associated with the various subtests are not as highly associated with each other as they are in the national normative samples. A possibility is that their intellectual function is characterized by a reduced relative to normal "g" factor or general intelligence and their intellectual function is more modular (Gardner, 1999). In its extreme this tendency may be the basis for the existence of "autism savants", individuals with an outstanding ability relative to other abilities.

There is a possibility that this organization has neurobiological significance. Some years ago John McFie said: "It is perhaps a matter of luck that many of the Wechsler subtests are neurologically relevant. They were evidently not designed with this purpose in mind; yet it follows that tests based on the major group factors of ability are likely to be sensitive to lesions in specific cerebral areas" (1975, p. 14). He then goes on to briefly review the already extensive literature concerning the Wechsler scales and brain lesion localization. However, the Wechsler profiles of children and adults with high-functioning autism do not resemble the profiles obtained by individuals studied in the Wechsler neuropsychological research. Clearly, they do not have the generalized substantial depression of intellectual function associated with dementia. They do not have the large discrepancies between Verbal and Performance IQ scores often found in individuals with lateralized brain lesions. Nor do they have the reduced scores on Block Design seen in patients with focal right parietal lobe lesions or the substantially impaired Picture Arrangement score found in some patients with temporal lobe lesions. In effect, the prototypic profile in high-functioning autism does not resemble what is often found in individuals with focal or generalized structural brain damage.

Recently, functional magnetic resonance imaging (fMRI) studies have extended the understanding of the altered pattern of information processing in autism. Across a range of social cognition (Kana, Keller, Williams, Minshew, & Just, 2005; Koshino, Carpenter, Minshew, Cherkassky, Keller, & Just, (2005), language (Just, Cherkassky, Keller, & Minshew, 2004; Kana, Keller, Cherkassky, Minshew, & Just, in press), and problem solving tasks (Just, Cherkassky, Keller, Kana, & Minshew, in press), reliably different reductions in the functional correlations (the degree of synchronization or correlation of the time series of the activation) occurred in the autism group. Thus, autism is thought to be characterized by a

pattern of functional underconnectivity and reduced synchrony among the cortical regions supporting these higher order abilities. We are suggesting that the reduced correlation among the tasks on the multiple subtests of the Wechsler scales reflects a similar underlying principle. For the autism group, the cognitive skills measured by the individual scales are less correlated than those in the normative samples mirroring the lack of coordination among cognitive processing centers for higher order cognitive tasks. Thus, for example, while Block Design and Vocabulary measure clearly different abilities, the correlation in the national children's sample is .38 explaining 14% of the variance, while it is .23 for the children with autism, explaining only 5% of the variance. With regard to the matter of the confirmatory factor analyses, it might be expected that more adequate goodness-of-fit will be achieved when there is more coherence among the individual variables contributing to factors. For example, a relatively pure PO factor would require high correlations among the Performance tests with the exception of Digit Symbol/Coding and a low correlation with Digit Symbol/Coding. In the case of the national sample, as an example, the correlation between Block Design and Picture Completion is .54 and the correlation between Picture Arrangement and Coding is .17. In the case of the children with autism, Block Design and Picture Completion correlate .31 while Picture Arrangement and Coding correlate .31. It is suggested that these small but consistent differences in the intercorrelation pattern are associated with the relatively reduced goodness-of-fit in the autism group. In general, the direction of the difference was toward lower correlations in the autism sample with some exceptions in which the autism sample correlation is higher than that of the national sample appear to occur in a manner that is not consistent with established factor structures such as in the example given above where there is a relatively high correlation between a PO (Picture Arrangement) and an FFD (Coding) subtest.

Generalizing from connectivity theory makes the implicit assumption that correlations exist among intelligence test subtests because of physical connections among the brain structures required for adequate test performance such as the system involved in language comprehension. However, Willerman and Bailey (1987) have indicated that, based on genetic research, correlations may exist because each test requires a common genetic matrix. Thus, correlations among subtests may not document connections between brain regions, but occur because the tasks considered involve what Willerman and Bailey describe as the same "qualities" of brain function. While connectivity theory still remains a possibility, it needs to be documented by direct evidence from functional MRI or related procedures demonstrating intact or impaired physical connections associated with intelligence test correlations.

A limitation of this study was that sufficient cases were not available to do separate studies of the "R" and "III" versions of the Wechsler scales. The "R" versions have the advantage of a large factor analytic and neuropsychology literature, but the more recent "III" versions utilize more current standardization data and contain additional subtests. It is believed that addition of contributing variables tend to increase goodness-of-fit in CFAs. It is possible that a four-factor model utilizing the new subtests would lead to a different conclusion making it desirable to test both models with the appropriate tests. A four-factor model utilizing the traditional 11 subtests did provide improvement in goodness-of-fit over a three-factor model.

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Table 1

Demographics of Child and Adult Autism Samples

Child Sample (n = 137)	M	SD
Age	11.04	2.95
Years of Education	4.82	2.98
Verbal IQ	100.18	11.04
Performance IQ	96.39	14.79
Full Scale IQ	98.13	15.22
Adult Sample (n = 118)		
Age	27.53	9.25
Years of Education	12.80	2.46
Verbal IQ	102.07	19.08
Performance IQ	94.28	13.93
Full Scale IQ	98.52	16.61

Table 2

Pearson correlations between Wechsler Subtest Scores for the Adult and Child Samples with Autism

Subtests ^a	Group	I	V	C	S	D	A	BD	PC	PA	OA	C/D
I	Child	1.0										
	Adult	1.0										
V	Child	.65	1.0									
	Adult	.80	1.0									
C	Child	.42	.55	1.0								
	Adult	.71	.85	1.0								
S	Child	.55	.67	.48	1.0							
	Adult	.71	.75	.76	1.0							
D	Child	.31	.32	.25	.33	1.0						
	Adult	.47	.48	.45	.36	1.0						
A	Child	.58	.50	.38	.48	.44	1.0					
	Adult	.60	.55	.57	.49	.61	1.0					
BD	Child	.24	.23	.13	.18	.29	.55	1.0				
	Adult	.34	.43	.39	.40	.44	.45	1.0				
PC	Child	.45	.27	.23	.33	.24	.35	.31	1.0			
	Adult	.39	.44	.42	.43	.24	.29	.46	1.0			
PA	Child	.31	.34	.37	.27	.01	.24	.28	.21	1.0		
	Adult	.47	.39	.30	.43	.27	.26	.34	.42	1.0		
OA	Child	.21	.23	.32	.25	.13	.29	.46	.40	.40	1.0	
	Adult	.31	.38	.36	.40	.17	.12	.55	.37	.36	1.0	
C/D	Child	.32	.20	.24	.19	.28	.41	.18	.18	.31	.05	1.0
	Adult	.29	.32	.28	.30	.45	.45	.36	.16	.15	.18	1.0

^aI = Information, V = Vocabulary, C = Comprehension, S = Similarities, D = Digit Span, A = Arithmetic, BD = Block Design, PC = Picture Completion, PA = Picture Arrangement, OA = Object Assembly, C/D = Coding/Digit Symbol.

Table 3

Goodness of Fit Indexes for all Models in Child samples

Models ^a	Fit Indexes ^b								
	X ²	df	X ² /df	GFI	AGFI	NFI ^c	T-LI ^c	RMSEA	CFI
WISC-R									
1) M ₁	155.29	44	3.53	.87	.80	.85	.86	.120	.89
2) M ₂	100.17	43	2.33	.92	.87	.91	.93	.082	.94
3) M ₃	78.00	41	1.90	.94	.90	.93	.95	.065	.96
4) M _{3D}	77.99	40	1.95	.94	.89	.93	.95	.067	.96
5) M _{3SI}	93.97	41	2.29	.92	.87	.91	.93	.082	.95
6) M _{4PC}	69.86	38	1.84	.94	.90	.93	.95	.063	.97
7) M _{4C}	78.97	38	2.08	.94	.89	.93	.94	.070	.96
WISC-III									
1) M ₁	148.67	44	3.38	.87	.81	.84	.85	.110	.88
2) M ₂	90.75	43	2.11	.92	.88	.90	.93	.076	.94
3) M ₃	64.47	41	1.57	.95	.91	.93	.96	.052	.97
4) M _{3D}	60.82	40	1.52	.95	.91	.93	.97	.051	.98
5) M _{3SI}	88.02	41	2.15	.93	.88	.90	.93	.075	.95
6) M _{4PC}	49.04	38	1.29	.96	.93	.95	.98	.037	.99
7) M _{4C}	70.80	38	1.86	.94	.90	.92	.95	.061	.96
Autism									
1) M ₁	165.72	44	3.77	.82	.73	.71	.70	.140	.76
2) M ₂	139.89	43	3.25	.85	.77	.75	.76	.130	.81
3) M ₃	107.06	41	2.61	.89	.82	.81	.83	.099	.87
4) M _{3D}	106.58	40	2.66	.89	.81	.81	.82	.100	.87
5) M _{3SI}	133.86	41	3.26	.86	.77	.76	.75	.120	.82
6) M _{4PC}	88.12	38	2.32	.90	.82	.84	.86	.094	.90
7) M _{4C}	101.73	38	2.68	.89	.82	.82	.82	.099	.87

^aM₁ = one-factor model; M₂ = two-factor model; M₃ = three-factor model; M_{3D} = three-factor model with Digit Symbol specified to load on PO and FFD factors; M_{3SI} = three-factor model with Picture Arrangement and Picture Completion specified to load on a Social Intelligence factor; M_{4PC} = four-factor model with Picture Arrangement and Picture Completion on factor 4; M_{4C} = four-factor model

with Picture Arrangement and Comprehension on factor 4. WISC-R = Wechsler Intelligence Scale for Children – Revised standardization sample 11.5 year old age group ($n = 200$); WISC-III = Wechsler Intelligence Scale for Children – III standardization sample 11 year old age group ($n = 200$); Autism = Children with high-functioning autism ($n = 137$).

^b GFI = Goodness of Fit Index; AGFI = Adjusted GFI; RMSEA = Root Mean Square Error of Approximation; NFI = Normed Fit Index; T-LI = Tucker-Lewis Index; CFI = Comparative Fit Index.

^c NFI and T-LI calculated using an independent null model: WISC-R $\chi^2 = 1061.32$; $df = 55$; $n = 200$; WISC-III $\chi^2 = 922.28$; $df = 55$; $n = 200$; Autism $\chi^2 = 563.28$; $df = 55$, $n = 137$.

Table 4

Goodness of Fit Indexes for all Models in Adult samples

Models ^a	Fit Indexes ^b									
	X ²	df	X ² /df	GFI	AGFI	NFI	T-LI	RMSEA	CFI	
WISC-R										
1) M ₁	236.20	44	5.37	.86	.80	.88	.88	.130	.90	
2) M ₂	142.07	43	3.30	.92	.88	.93	.94	.089	.95	
3) M ₃	116.90	41	2.85	.93	.90	.94	.95	.077	.96	
4) M _{3D}	114.22	40	2.86	.94	.89	.94	.95	.078	.96	
5) M _{3SI}	137.15	41	3.35	.92	.87	.93	.93	.090	.95	
6) M _{4PC}	97.71	38	2.57	.94	.89	.95	.96	.072	.97	
7) M _{4C}	120.24	38	3.16	.94	.89	.92	.94	.082	.96	
WISC-III										
1) M ₁	191.90	44	4.36	.83	.75	.86	.86	.140	.89	
2) M ₂	115.26	43	2.68	.90	.85	.91	.93	.093	.94	
3) M ₃	81.23	41	1.98	.93	.89	.94	.96	.067	.97	
4) M _{3D}	80.74	40	2.02	.93	.89	.94	.96	.069	.97	
5) M _{3SI}	105.58	41	2.58	.91	.86	.92	.93	.089	.95	
6) M _{4PC}	63.11	38	1.66	.95	.91	.95	.97	.055	.98	
7) M _{4C}	67.01	38	1.76	.94	.90	.95	.97	.059	.98	
Autism										
1) M ₁	153.83	44	3.50	.81	.71	.79	.80	.150	.84	
2) M ₂	117.65	43	2.74	.84	.76	.84	.86	.120	.89	
3) M ₃	75.60	41	1.89	.91	.85	.90	.93	.072	.95	
4) M _{3D}	75.47	40	1.84	.91	.85	.90	.93	.072	.95	
5) M _{3SI}	109.51	41	2.67	.85	.76	.85	.87	.120	.90	
6) M _{4PC}	62.60	38	1.65	.92	.86	.92	.95	.062	.96	
7) M _{4C}	79.07	38	2.08	.90	.83	.89	.91	.082	.94	

^aM₁ = one-factor model; M₂ = two-factor model; M₃ = three-factor model; M_{3D} = three-factor model with Digit Symbol specified to load on PO and FFD factors; M_{3SI} = three-factor model with Picture Arrangement and Picture Completion specified to load on a Social Intelligence factor; M_{4PC} = four-factor model with Picture Arrangement and Picture Completion on factor 4; M_{4C} = four-factor model

with Picture Arrangement and Comprehension on factor 4. WAIS-R = Wechsler Adult Intelligence Scale – Revised standardization sample 25 – 34 year old age group ($n = 300$); WAIS-III = Wechsler Adult Intelligence Scale – III standardization sample 25 – 29 year old age group ($n = 200$); Autism = Adults with high-functioning autism ($n = 118$).

^b GFI = Goodness of Fit Index; AGFI = Adjusted GFI; RMSEA = Root Mean Square Error of Approximation; NFI = Normed Fit Index; T-LI = Tucker-Lewis Index; CFI = Comparative Fit Index.

^b NFI and T-LI calculated using an independent null model: WAIS-R₂ = 2038.28; $df = 55$; $n = 300$; WAIS-III₂ = 1345.04; $df = 55$; $n = 200$; Autism₂ = 742.32; $df = 55$, $n = 118$.

Table 5

Incremental Fit for Confirmatory Factor Analyses for Child Autism Samples and the Wechsler Scales Normative Samples

Model Comparisons	χ^2 difference	df	NFI
WISC-R			
M ₁ M ₂	55.12***	1	.35
M ₁ M ₃	77.29***	3	.50
M ₁ M _{4PC}	85.43***	6	.55
M ₂ M ₃	22.17***	2	.22
M ₂ M _{4PC}	30.31***	5	.30
M ₃ M _{4PC}	8.14*	3	.10
WISC-III			
M ₁ M ₂	57.92***	1	.39
M ₁ M ₃	84.20***	3	.57
M ₁ M _{4PC}	99.63***	6	.67
M ₂ M ₃	26.28***	2	.29
M ₂ M _{4PC}	41.71***	5	.46
M ₃ M _{4PC}	11.78***	3	.18
Autism			
M ₁ M ₂	25.83***	1	.16
M ₁ M ₃	58.66***	3	.35
M ₁ M _{4PC}	77.60***	6	.47
M ₂ M ₃	32.83***	2	.23
M ₂ M _{4PC}	51.77***	5	.37
M ₃ M _{4PC}	18.94***	3	.18

^aM₁ = one-factor model; M₂ = two-factor model; M_{4PC} = four-factor model with Picture Arrangement and Picture Completion specified to load on factor 4.

WISC-R = Wechsler Intelligence Scale for Children – Revised standardization sample 11.5 year old age group ($n = 200$); WISC-III = Wechsler Intelligence Scale for Children – III standardization sample 11 year old age group ($n = 200$); Autism = Children with high-functioning autism ($n = 137$).

*
 $p < .05$,

 $p < .001$

Table 6

Incremental Fit for Confirmatory Factor Analyses for Adult Autism Samples and the Wechsler Scales Normative Samples

Model Comparisons ^a	χ^2 difference	<i>df</i>	NFI
WISC-R			
M ₁ M ₂	94.13***	1	.40
M ₁ M ₃	119.30***	3	.51
M ₁ M _{4PC}	138.49***	6	.59
M ₂ M ₃	25.17***	2	.18
M ₂ M _{4PC}	44.36***	5	.31
M ₃ M _{4PC}	19.19***	3	.16
WISC-III			
M ₁ M ₂	76.64***	1	.40
M ₁ M ₃	110.67***	3	.58
M ₁ M _{4PC}	128.79***	6	.67
M ₂ M ₃	34.03***	2	.30
M ₂ M _{4PC}	52.15***	5	.45
M ₃ M _{4PC}	18.20***	3	.22
Autism			
M ₁ M ₂	36.18***	1	.24
M ₁ M ₃	78.23***	3	.51
M ₁ M _{4PC}	91.23***	6	.59
M ₂ M ₃	42.05***	2	.36
M ₂ M _{4PC}	55.05***	5	.47
M ₃ M _{4PC}	13.00**	3	.17

^aM₁ = one-factor model; M₂ = two-factor model; M_{4PC} = four-factor model with Picture Arrangement and Picture Completion specified to load on factor 4.

WAIS-R = Wechsler Adult Intelligence Scale – Revised standardization sample 25 – 34 year old age group (*n* = 300); WAIS-III = Wechsler Adult Intelligence Scale – III standardization sample 25 – 29 year old age group (*n* = 200); Autism = Adults with high-functioning autism (*n* = 118).

**
p < .01,

p < .001

Table 7

Optimal Maximum Likelihood Factor Solutions for Child and Adult Autism Samples in Comparison to the WISC-R and WAIS-R Standardization Samples for the Four Factor Model (M_{4PC})^a

Subtests ^b	Wechsler Factor Loadings ^e									
	Autism Samples					Wechsler III Samples				
	VC	PO	FFD	SI	VC	PO	FFD	SI	VC	PO
Child ^c										
I	.79	--	--	--	--	.78	--	--	--	--
V	.83	--	--	--	--	.82	--	--	--	--
C	.62	--	--	--	--	.70	--	--	--	--
S	.75	--	--	--	--	.84	--	--	--	--
BD	--	.77	--	--	--	.79	--	--	--	--
OA	--	.59	--	--	--	.68	--	--	--	--
D	--	--	.50	--	--	--	.57	--	--	--
A	--	--	.92	--	--	--	.92	--	--	--
C/D	--	--	.43	--	--	--	.32	--	--	--
PC	--	--	--	.46	--	--	--	.74	--	--
PA	--	--	--	.46	--	--	--	.50	--	--
Adult ^d										
I	.84	--	--	--	--	.85	--	--	--	--
V	.93	--	--	--	--	.93	--	--	--	--
C	.90	--	--	--	--	.84	--	--	--	--
S	.82	--	--	--	--	.83	--	--	--	--
BD	--	.94	--	--	--	.89	--	--	--	--
OA	--	.59	--	--	--	.74	--	--	--	--
D	--	--	.74	--	--	--	.69	--	--	--
A	--	--	.83	--	--	--	.85	--	--	--
C/D	--	--	.56	--	--	--	.49	--	--	--
PC	--	--	--	.69	--	--	--	.65	--	--
PA	--	--	--	.61	--	--	--	.75	--	--

^aModel M4PC = four-factor model with Picture Arrangement and Picture Completion specified to load on factor 4.

^bI = Information, V = Vocabulary, C = Comprehension, S = Similarities, BD = Block Design, OA = Object Assembly, D = Digit Span, A = Arithmetic, C/D = Coding/Digit Symbol, PA = Picture Arrangement, PC = Picture Completion.

^cChild = Children with autism ($n = 137$) or children in the WISC-III 11 year old standardization sample age group ($n = 200$)

^dAdult = Adults with autism ($n = 118$) or adults in the WAIS-III 25–29 year old standardization sample age group ($n = 200$).

^eVC = Verbal Comprehension, PO = Perceptual Organization, FFD = Freedom From Distractibility, SI = Social Intelligence.