Toward Brief "Red Flags" for Autism Screening: The Short Autism Spectrum Quotient and the Short Quantitative Checklist in 1,000 Cases and 3,000 Controls

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Objective: Frontline health professionals need a "red flag" tool to aid their decision making about whether to make a referral for a full diagnostic assessment for an autism spectrum condition (ASC) in children and adults. The aim was to identify 10 items on the Autism Spectrum Quotient (AQ) (Adult, Adolescent, and Child versions) and on the Quantitative Checklist for Autism in Toddlers (Q-CHAT) with good test accuracy. **Method:** A case sample of more than 1,000 individuals with ASC (449 adults, 162 adolescents, 432 children and 126 toddlers) and a control sample of 3,000 controls (838 adults, 475 adolescents, 940 children, and 754 toddlers) with no ASC diagnosis participated. Case participants were recruited from the Autism Research Centre's database of volunteers. The control samples were recruited through a variety of sources. Participants completed full-length versions of the measures. The 10 best items were selected on each instrument to produce short versions. **Results:** At a cut-point of 6 on the AQ-10 adult, sensitivity was 0.88, specificity was 0.91, and positive predictive value (PPV) was 0.85. At a cut-point of 6 on the AQ-10 adolescent, sensitivity was 0.93, specificity was 0.95, and PPV was 0.86. At a cut-point of 6 on the AQ-10 child, sensitivity was 0.95, specificity was 0.97, and PPV was 0.94. At a cut-point of 3 on the Q-CHAT-10, sensitivity was 0.91, specificity was 0.89, and PPV was 0.58. Internal consistency was >0.85 on all measures. **Conclusions:** The short measures have potential to aid referral decision making for specialist assessment and should be further evaluated. J. Am. Acad. Child Adolesc. Psychiatry, 2012;51(2):202–212. **Key Words:** autism spectrum conditions, red flags, referral, screening, questionnaires

Autism spectrum conditions (ASC) are characterized by difficulties in social interaction, communication, and adapting to change, alongside unusually narrow interests and strongly repetitive behavior. The diagnostic classification systems define ASC to include autistic disorder, Asperger's syndrome (AS), atypical autism, and pervasive developmental disorder not otherwise specified (PDD-NOS).[1, 2] ASC are currently behaviorally defined. There is much research evidence suggesting that etiology is strongly (although not exclusively) genetic[3-6] and neurological[7] in origin. To date, no clear biological, neurological, or genetic marker can define ASC. Prospective population screening studies indicate that approximately 1% of the child and adult population is affected by ASC.[8-10] In recent years, there has been a shift in the conceptualization of ASC from a categorical to a dimensional model, and the development of dimensional measures that can measure autistic traits as individual differences that run right through the general population.[11]

Diagnosis of ASC can be a lengthy process because it varies greatly across individuals.[12] The age at which symptoms first appear also differs across individuals,[13] and changes in symptom

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profiles occur across the lifespan. Diagnosis is often delayed because ASC can be difficult to detect in very young children. Parents may raise concerns about their child by 18 months,[14] but there is frequently a significant delay between the point of first concern and an eventual diagnosis. This may in part be due to community pediatricians or primary care providers not being sufficiently informed about the more subtle manifestations of ASC. The average age of a diagnosis for individuals with AS is 11 years.[15] However, it is clear that there are individuals with undetected ASC in the population[9] who may be struggling and would benefit from support.

ASC costs the United Kingdom approximately £28 billion sterling each year,[16] and similar health economic estimates have been reported in the United States.[17] Health and social care services have a key responsibility to recognize ASC, yet levels of awareness and understanding of ASC among health care and social care agencies differ greatly from one area to another. For example, the UK National Audit Office asked General Practitioners (GP) to estimate how many adults they had seen with suspected ASC in their practice over the previous 6-month period. The average response was two patients.[18] Given the average size of GP practices is 6,500 patients,[19] one would have expected them to see approximately 65 cases of ASC per year. If we assume that half of these might be in the adult age range, this suggests underdetection could be 16-fold. In addition, 80% of GPs indicated that they require guidance to identify persons who may be on the autistic spectrum. GPs or family physicians may be the first point of contact for parents of children with concerns about autistic traits, as well as for adults with concerns that they themselves possibly have "high functioning" ASC or AS. Family physicians need to be able to identify children and adults who may require a specialist diagnostic assessment and therefore need to make an appropriate referral. Furthermore, child care workers (e.g., nursery staff) have many opportunities to observe children in their care and, over time, will develop a sound knowledge of what counts as typical development. One recent study demonstrated that screening measures designed for child care workers performed equally well to detect ASC as parent-report screening instruments.[20]

To improve diagnosis, brief instruments would be useful for frontline clinicians and social care professionals as "red flags" to alert them to make a referral for a full diagnostic assessment. Glascoe[21] recommends that standards for the identification of a screened condition (sensitivity) on a single administration should be between 70% and 80%. Furthermore, to avoid over-referral, specificity should be close to 80%. Over the past 20 years, most efforts have gone into developing screening measures for ASC in early childhood. The first attempt was by our group which evaluated the Checklist for Autism in Toddlers (CHAT) in a large population.[22-24] Key domains assessed by the CHAT are absence of joint attention and pretend play in a child at 18 months of age. A large population study (n = 16,000) identified 10 of 12 (83.3%) children who consistently failed to show these key behaviors at 18 months went on to develop autism[23]. However, the CHAT had poor sensitivity (<40%), despite good specificity (>90%). The Social Communication Questionnaire (SCQ)[25] is a parent-rated questionnaire that can be completed in approximately 10 minutes, with a binary response format. Allen et al.[26] found that sensitivity and specificity were 0.60 and 0.70 respectively when the SCQ was assessed in a sample of 81 preschool children, whereas investigators in another study[27] found sensitivity and specificity both to be 0.71 in a much larger sample. The Modified Checklist for Autism in Toddlers (M-CHAT)[28] is a modified version of the CHAT, designed to be used in the American health care system. Robins et al.[28] reported sensitivity was 0.97, specificity was 0.99, and PPV was 0.68. However, these psychometric calculations were based on the assumption that there were no cases of ASC in those who screened negative on the M-CHAT, so these findings should be treated with caution. There are a great many other instruments designed to detect ASC, including the Early Screen for Autistic Traits,[29,30] the Social Responsiveness Scale,[31] and the First Year Inventory,[32,33] and have been validated in different settings and at different ages. However, there are no fully validated measures to detect possible ASC in primary care and social care settings.

The majority of measures developed to detect ASC have focused on young children. There is also a need for an instrument to measure autistic traits in adulthood. Barnard et al.[34] found that 46% of those individuals with a diagnosis of Asperger's syndrome did not receive the diagnosis until late adolescence or adulthood. The Au-

tism Spectrum Quotient (AQ)[11] was developed to measure the degree to which adults with average intelligence exhibit autistic traits. The 50-item AQ is structured around five subdomains that are characteristic of individuals with ASC. The subdomains are social interaction, communication, attention to detail, attention switching and imagination. Individuals diagnosed with ASC score significantly higher on the AQ than persons in the general population. The AQ has been used extensively in research studies. It has good discriminative validity and screening properties at a threshold score of 26 in a clinical sample[35] and excellent discriminative validity and screening properties at a threshold score of 32 in a case-control sample.[11] It is normally distributed, and 80% of people with ASC score above 32 out of a maximum of 50, compared with only 2% of controls. Child[36] and adolescent[37] parent-report versions of the AQ have been developed. Both of these versions also discriminate between individuals with a diagnosis on the autism spectrum, in a cross-sectional sample. In this paper we consider whether the AQ—in these three different versions—can be adapted for use in primary and social care as 'red flags' and assist with referral decision making.

The AQ has produced consistent results across time[38] and culture,[39-41] and scores are highly heritable, as demonstrated in a twin study.[42] Evidence suggests that the AQ is also correlated with biological factors such as salivary testosterone levels,[43] decreased neural white matter volume in the posterior superior temporal sulcus,[44] brain functional activity in the superior frontal gyrus[45] and medial prefrontal cortex,[46] and single nucleotide polymorphisms in candidate genes.[5] Prenatal testosterone levels have also been shown to predict child AQ scores.[47]

An early developmental version of the AQ is the Quantitative Checklist for Autism in Toddlers (Q-CHAT), which is a revision of the CHAT. The Q-CHAT enables parents to quantify autistic traits in children 18 to 30 months of age and to discriminate children who may be on a developmental trajectory for ASC from those who are developing typically. A large-scale population screening study (n = 4,000) is underway to assess the validity of the Q-CHAT, but the 25-item Q-CHAT has already shown excellent power to discriminate young children with an ASC diagnosis from unselected toddlers at 18 to 24 months.[48] The key difference between the CHAT and the Q-CHAT is to move from categorical to dimensional screening (Q denotes "quantitative"). Use of a quantitative measure confers upon the instrument the power to detect more subtle manifestations of ASC. Like the AQ, the Q-CHAT has good test–retest reliability and adequate internal consistency. The Q-CHAT is also normally distributed.[48] The Q-CHAT score also reflects biological processes; for example, it correlates with fetal testosterone levels in typically developing toddlers[49] and atypical electrophysiological response in response to social stimuli in infant siblings of children with ASC.[50]

For all of these reasons, the three versions of the AQ and the Q-CHAT are strong candidates for being useful "red flag" instruments for ASC. However, the AQ and Q-CHAT are 50 and 25 items, respectively. Arguably these are too lengthy to be used in a busy primary care practice in which the average appointment time is 11 minutes,[51] as the full-length versions take 10 minutes to complete. Although the full-length versions can be used comfortably at home or online by families or individuals, the aim of the present study is to adapt these for use in clinics by developing short (10-item) versions of these measures. These would fill the gap for health care professionals in making quick decisions in real clinic time about whether to refer patients to specialist services for ASC, without sacrificing the excellent psychometric properties of these instruments. The objective of the study was to identify which 10 items from each of the adult AQ, adolescent AQ, child AQ, and Q-CHAT would show the same levels of excellent sensitivity and specificity as the full-length versions of these instruments in available case and control samples. This study therefore represents the first step in developing the measures, rather than testing the instruments in the context in which they may have the most clinical utility.

METHOD

Measures

Full details of the construction of all versions of the AQ and the Q-CHAT can be found elsewhere.[11,36,37,48] The AQ consists of a series of 50 statements to which participants or parents have to indicate the degree to which they agree or disagree with the statement. There are four response options: strongly agree, slightly agree, slightly disagree, strongly disagree. On half the

TABLE 1 Participant Characteristics

Measure	Group				Total
	Control Derivation Sample	Case Derivation Sample	Control Validation Sample	Case Validation Sample	
AQ Adult					
Sex					
Female	249	103	260	106	718
Male	170	121	159	119	569
Total	419	224	419	225	1287
Mean age in years (SD)	33.53 (12.48)	35.08 (12.55)	32.93 (12.20)	35.62 (13.04)	
AQ Adolescent					
Sex					
Female	134	20	145	16	315
Male	104	61	92	65	322
Total	238	81	237	81	637
Mean age in years (SD)	13.46 (1.05)	13.33 (1.07)	13.52 (1.06)	13.59 (1.05)	
AQ Child					
Sex					
Female	256	38	254	35	583
Male	214	178	216	181	789
Total	470	216	470	216	1372
Mean age in years (SD)	9.26 (1.30)	7.29 (2.32)	9.21 (1.27)	7.15 (2.21)	
Q-CHAT					
Sex					
Female	180	12	192	12	396
Male	197	51	185	51	484
Total	377	63	377	63	880
Mean age in months (SD)	20.85 (2.15)	36.38 (7.62)	20.81 (2.12)	35.29 (7.67)	

Note: AQ = Autism Spectrum Quotient; Q-CHAT = Quantitative Checklist for Autism in Toddlers.

items, the autistic trait requires a response of slightly agree or strongly agree, and on half the items slightly disagree or strongly disagree is the response that identifies an autistic trait. Each autistic trait endorsed scores one point, regardless of whether the individual indicated slightly or strongly agree or disagree. The Child AQ was originally scored in a Likert 0, 1, 2, 3 format, but for consistency, all versions of the AQ were scored in a binary format. A total score is determined by summing all the items. The adult AQ is self-report, whereas the child and adolescent versions are parent-report.

The Q-CHAT consists of 25 questions focusing on behaviors that reflect autistic traits in very early childhood. Each item has five response options based on frequency to which the child exhibits the behavior. A high frequency of an autistic trait scores 4, and a low frequency of an autistic trait scores 0. Half the items are reverse scored. For consistency of the method to determine the best 10 items, the Likert rating scale was converted to a binary scoring system so that a score of 0 or 1 would score 0, and a score of 2, 3, or 4 would score 1.

Participants

This study tested a group of cases and a group of controls for each of the four measures. Analysis for each measure was further split into derivation case and control and validation case and control samples. Therefore a total of 16 participant groups participated. A summary of participant characteristics is given in Table 1.

Adult Sample. Adults with a diagnosis of ASC registered as volunteers on our Web site (www.autismresearchcentre.com). They provided details about their diagnosis, including information about who made the diagnosis, where it was made, and when. Only cases diagnosed at a recognized clinic by a recognized medic or clinical psychologist using *DSM-IV* criteria were included. After registration, volunteers completed an online version of the AQ. Altogether, there were 449 adults with ASC (n = 402 with AS, n = 47 with HFA), of which approximately half formed the derivation sample and half formed the validation sample.

Adult control data were collected at the Cambridge Psychology Web site for volunteers (www.cambridge

psychology.com). This site is for people from the general population who are interested in taking part in research. The registration procedure for control volunteers is identical to the procedure for adults with an ASC diagnosis. Control adults also completed the AQ online. Only adults more than 16 years of age who did not report any neurodevelopmental diagnosis were included in the study. The derivation and validation control samples comprised a total of 838 adults.

Adolescent Sample. Parents of adolescents between the ages of 12 and 15 with a diagnosis of ASC registered on our Web site and completed the AQ-adolescent. Again, parents provided details about their child's diagnosis, including information about who made the diagnosis, where it was made, and when. Only cases diagnosed at a recognized clinic by a recognized medic or clinical psychologist using *DSM-IV* criteria were included. Altogether, there were 162 adolescents with ASC (n = 91 with AS, n = 26 with HFA, n = 37 with autism, n = 4 with PDD, and n = 4 with atypical autism). n = 81 formed the derivation case sample, and n = 81 formed the validation case sample.

Parents of adolescents who were participating in a large epidemiological study of social communication skills[9] were sent the AQ-adolescent through the post. Only adolescents (aged 12-15 years) whose parents did not report any neurodevelopmental diagnosis were included in the study. The derivation and validation control samples comprised 475 adolescents.

Child Sample. Recruitment for the child samples was the same as for the adolescent samples. Altogether, there were 432 children (aged 4-11 years) with ASC (n = 158 with AS, n = 81 with HFA, n = 160 with autism, n = 26 with PDD, and n = 7 with atypical autism). n = 216 formed the derivation case sample and n = 216 formed the case validation sample. Only control children, who were 4-11 years of age, taken from the dataset published in Auyeung et al.[36] and whose parents did not report any neurodevelopmental diagnosis were included. The derivation and validation control samples comprised 940 children.

Preschool Sample. Parents of preschool children between the ages of 15 and 47 months with a diagnosis of ASC registered on our Web site (www.autismresearchcentre.com) and completed the Q-CHAT. Altogether, there were 126 preschool children with ASC (n = 10 with AS, n = 11 with HFA, n = 90 with autism, n = 11 with PDD, and n = 4 with atypical autism) for whom Q-CHAT data were available. Again, parents provided details about who made the diagnosis, where it was made and when. Only cases diagnosed at a recognized clinic by a recognized medic or clinical psychologist using *DSM-IV* criteria were included. n = 63 formed the derivation case sample and n = 63 formed the validation case sample. The sample (N = 754) published by Allison et al.[48] comprised the control derivation and validation samples.

Procedure

Participants were randomly allocated to derivation and validation samples. The best 10 items from each measure were determined from the derivation samples by calculating a discrimination index (DI) for each item.[52] This is calculated by subtracting the proportion of participants who scored 1 (autism trait positive response) on each item in the control group from the proportion of participants who scored 1 in the ASC group. Good items on a measure are indicated by a discrimination index of 0.3 to 0.7. On all versions of the AQ, the two items with the highest DI within each subscale were chosen. On the Q-CHAT, the 10 items with the highest DI were chosen.

Receiver operating characteristic (ROC) curves comprising the 10 most discriminating items for each measure were produced on the validation samples. ROC curves plots sensitivity and 1-specificity of all possible scores on the measure. The presence of a diagnosis of ASC was the dependent variable and AQ or Q-CHAT score was the independent predictor variable. The area under the curve (AUC) is a measure of the overall predictive validity, where an AUC = 0.50 indicates random prediction of the independent variable. An AUC of >0.90 indicates excellent validity. The AUC was calculated for each 10-item measure, and compared with the AUC for the full versions.

Independent-samples t tests were conducted to compare the 10-item measures between case individuals and controls. Internal consistency (Cronbach's alpha) was calculated for each measure. Correlations were examined between total scores on the short and long forms of all questionnaires. The collection of the AQ and Q-CHAT online at our Web sites received a favorable ethical opinion from the University of Cambridge Psychology Research Ethics Committee.

RESULTS

Results from the item analysis for all measures are presented in Tables S1 to S4, available online. The 10 items with the highest DI are presented in Table 2 (AQ) and Table 3 (Q-CHAT). The AUC for all the measures (long and short versions) is shown in Table 4, indicating that all the short versions all had AUC of >0.90. The AUC value was marginally higher for the short version on the Q-CHAT and Child AQ than the long version. ROC curves for the long and short versions of each measure are displayed in Figure S1, available online. The coordinates of the curve indicating the score at various sensitivities and specificities are shown in Table S5, available online.

Case-Control Comparisons. Adult AQ. There was a significant difference in AQ-10 Adult scores for

TABLE 2 Most Discriminating 10 Items on All Versions of the Autism Spectrum Quotient (AQ), Including Positive Predictive Value (PPV)

Subscale	AQ Adult	AQ Adolescent	AQ Child
Attention to Detail	I often notice small sounds when others do not (5). PPV = 0.46	S/he notices patterns in things all the time (23). PPV = 0.48	S/he often notices small sounds when others do not (5). PPV = 0.49
	I usually concentrate more on the whole picture, rather than the small details (28). PPV = 0.53	S/he usually concentrates more on the whole picture, rather than the small details (28). PPV = 0.50	S/he usually concentrates more on the whole picture, rather than the small details (28). PPV = 0.51
Attention Switching	I find it easy to do more than one thing at once (32). PPV = 0.61	In a social group, s/he can easily keep track of several different people's conversations (10). PPV = 0.67	In a social group, s/he can easily keep track of several different people's conversations (10). PPV = 0.68
	If there is an interruption, I can switch back to what I was doing very quickly (37). PPV = 0.57	If there is an interruption, s/he can switch back to what s/he was doing very quickly (37). PPV = 0.65	S/he finds it easy to go back and forth between different activities (32). PPV = 0.74
Communication	I find it easy to 'read between the lines' when someone is talking to me (27). PPV = 0.70	S/he frequently finds that s/he doesn't know how to keep a conversation going (26). PPV = 0.65	S/he does not know how to keep a conversation going with his/her peers (26). PPV = 0.87
	I know how to tell if someone listening to me is getting bored (31). PPV = 0.76	S/he is good at social chit-chat (38). PPV = 0.70	S/he is good at social chit-chat (38). PPV = 0.82
Imagination	When I'm reading a story I find it difficult to work out the characters' intentions (20). PPV = 0.76	When s/he was younger, s/he used to enjoy playing games involving pretending with other children (40). PPV = 0.66	When s/he is reading a story, s/he finds it difficult to work out the characters' intentions or feelings (20). PPV = 0.73
	I like to collect information about categories of things (e.g., types of car, types of bird, types of train, types of plant, etc) (41). PPV = 0.56	S/he finds it difficult to imagine what it would be like to be someone else (42). PPV = 0.63	When s/he was in preschool, she used to enjoy playing games involving pretending with other children (40). PPV = 0.73
Social	I find it easy to work out what someone is thinking or feeling just by looking at their face (36). PPV = 0.70	S/he finds social situations easy (11). PPV = 0.66	S/he finds it easy to work out what someone is thinking or feeling just by looking at their face (36). PPV = 0.77
	I find it difficult to work out people's intentions (45). 0.63	S/he finds it hard to make new friends (22). PPV = 0.63	S/he finds it hard to make new friends (22). PPV = 0.74

Note: Numbers in parentheses indicate item number.

case individuals (mean = 7.93, standard deviation [SD] = 1.93) and controls (mean = 2.77, SD = 2.00); t(642) = −31.71, $p < .0001$ (equal variances assumed). The magnitude of the differences in the means was large (eta squared = 0.62). Cronbach's alpha for the AQ-10 (Adult) was 0.85. The AQ-10 (Adult) significantly correlated with the AQ-50 (Adult) (r = 0.92, $p < .0001$).

Adolescent AQ. There was a significant difference in AQ-10 adolescent scores for case individuals (mean = 8.40, SD = 1.69) and controls (mean = 1.78, SD = 1.80); t(146.52) = −29.96, $p < .0001$ (equal variances not assumed). The magnitude of the differences in the means was large (eta squared = 0.74). Cronbach's alpha for the AQ-10 (Adolescent) was 0.89. The AQ-10 (Adolescent)

TABLE 3 Most Discriminating 10 Items on the Quantitative Checklist for Autism in Toddlers (Q-CHAT)

Q-CHAT
Does your child look at you when you call his/her name? (1). PPV = 0.80
How easy is it for you to get eye contact with your child? (2). PPV = 0.78
Does your child point to indicate that s/he wants something (eg, a toy that is out of reach) (5). PPV = 0.55
Does your child point to share interest with you (eg, pointing at an interesting sight)? (6). PPV = 0.55
Does your child pretend (e.g., care for dolls, talk on a toy phone)? (9). PPV = 0.51
Does your child follow where you're looking? (10). PPV = 0.55
If you or someone else in the family is visibly upset, does your child show signs of wanting to comfort them? (eg, stroking their hair, hugging them)? (15). PPV = 0.28
Would you describe your child's first words as (typical): (17). PPV = 0.70
Does your child use simple gestures (eg, wave goodbye)? (19). PPV = 0.76
Does your child stare at nothing with no apparent purpose? (25). PPV = 0.48

Note: Numbers in parentheses indicate item number. PPV = Positive Predictive Value.

significantly correlated with the AQ-50 (Adolescent) (r = 0.95, $p < 0.0001$).

Child AQ. There was a significant difference in AQ-10 child scores for case individuals (mean = 8.64, SD = 1.43) and controls (mean = 1.81, SD = 1.57); t(684) = −54.33, $p < .0001$ (equal variances assumed). The magnitude of the differences in the means was large (eta squared = 0.81). Cronbach's alpha for the AQ-10 (Child) was 0.90. The AQ-10 (Child) significantly correlated with the AQ-50 (Child) (r = 0.94, $p < .0001$).

Q-CHAT. There was a significant difference in Q-CHAT-10 scores for case individuals (M = 6.90, SD = 2.70) and controls (mean = 1.03, SD = 1.32); t(67.01) = −16.94, $p < .0001$ (equal variances not assumed). The magnitude of the differences in the means was large (eta squared = 0.40). Cronbach's alpha for the Q-CHAT-10 was 0.88. The Q-CHAT-10 significantly correlated with the Q-CHAT-25 (r = 0.79, $p < .0001$).

Cut-Points on the Short Screeners. All versions of the AQ and the Q-CHAT had very high test accuracy properties in their short (10 item) forms. On all versions of the AQ, the cut-point that best balanced sensitivity and specificity was 6, and on the Q-CHAT it was 3. At a cut-point of 6 on the AQ-10 adult, sensitivity was 0.88, specificity was 0.91, and positive predictive value (PPV) was 0.85 (pretest odds = 0.54). At a cut-point of 6 on the AQ-10 adolescent, sensitivity was 0.93, specificity was 0.95 and PPV was 0.86 (pretest odds = 0.33). At a cut-point of 6 on the AQ-10 child, sensitivity was 0.95, specificity was 0.97 and PPV was 0.94 (pretest odds = 0.85). At a cut-point of 3 on the Q-CHAT-10, sensitivity was 0.91, specificity was 0.89, and PPV was 0.58 (pretest odds = 0.16). Internal consistency was high on all measures (>0.85).

DISCUSSION

This study set out to adapt the AQ (child, adolescent, and adult versions) and the Q-CHAT into short versions for use in primary or social care settings by busy frontline health care professionals as rapid screeners or "red flags" to serve as guides for referral. The study demonstrated that all versions of the AQ and the Q-CHAT have very high test accuracy properties in their short (10-item) forms. Internal consistency was high on all measures (>0.85). Anastasi[53] suggested that Cronbach's alpha should be at least 0.85 if an instrument is to be used to draw inferences concerning an individual. These results demonstrate that the short versions are as good (if not

TABLE 4 Area Under the Curve for All Measures (Short and Long Versions)

				Asymptotic 95% CI	
	Area	SE	Asymptotic Sig.	Upper Bound	Lower Bound
AQ-10 Adult	0.951	0.008	0.000	0.934	0.967
AQ-50 Adult	0.959	0.008	0.000	0.943	0.975
AQ-10 Adolescent	0.982	0.011	0.000	0.960	1.003
AQ-50 Adolescent	0.984	0.009	0.000	0.966	1.002
AQ-10 Child	0.993	0.002	0.000	0.989	0.997
AQ-50 Child	0.991	0.003	0.000	0.986	0.996
Q-CHAT-10	0.965	0.011	0.000	0.943	0.987
Q-CHAT-25	0.920	0.023	0.000	0.875	0.965

Note: AQ = Autism Spectrum Quotient; CI = confidence interval; SE = standard error; Sig. = significance; Q-CHAT = Quantitative Checklist for Autism in Toddlers.

better in the cases of the AQ-10 child and Q-CHAT-10) than the long versions.

The items that were selected for the short forms of the questionnaires were derived and tested on independent samples. That is, the items were derived in one sample and test accuracy was assessed on a separate, nonoverlapping, independent sample, to avoid circularity. The same items appeared in the short forms on at least two of the three versions of the AQ, with the exception of one of the items in the imagination subdomain that was different for all three versions of the AQ. This suggests that autistic traits are stable across the lifespan.

The Q-CHAT cut-point is lower compared with the cut-point for the versions of the AQ. Since the control sample of Q-CHAT data were collected when the child was 18 to 24 months, it is likely that there are children within this sample with high scores who may have subsequently received a diagnosis. If anything, this would have served to reduce the size of the group differences. This may also apply to the control samples for the versions of the AQ but to a lesser extent, as we would expect autistic traits to become more stable with age. Diagnoses are less stable in high-functioning children under the age of 2 years.[54-56] Möricke et al.[54] argue that transience may exist for subtle subclinical autistic traits in very young infants that may go unnoticed, but these traits may become more visible with the increasing demands for reciprocal social interaction with others in adolescence. Alternatively, these traits may remain subclinical, reduce over time, or resolve altogether, which could potentially explain the somewhat lower positive predictive value of the Q-CHAT as compared with the other measures presented.

There are limitations to this study that must be acknowledged. First, the analyses presented here were conducted retrospectively. That is, all individuals (or their parents) in the case groups for whom AQ or Q-CHAT data were available provided the data following diagnosis. Increased awareness about ASC may have led respondents to answer in the expected direction (i.e., endorsing the presence of the autistic trait). Future research should repeat this study using a prospective design, aiming to replicate our results in differently ascertained samples, particularly in settings where children and adults interface with nonspecialists who have limited knowledge and experience of ASC. Measurement equivalence (the comparability of data obtained from different groups[57]) is a discussion beyond the scope of this article, but we acknowledge that this should be addressed in future studies. Second, the method of administration across samples was not consistent; with the exception of the AQ adult samples, all case data were completed online, and control data by post. Although we do not think that this will have had a significant effect on the results, this issue too could be addressed in future studies.

Third, because of resource limitations, it was not possible to independently validate diagnostic status in either the case or control groups. However, we adopted a strict and conservative approach; individuals were included as case individuals in this study only if sufficient information was available about their diagnosis. This limitation is balanced by the large samples of individuals diagnosed with ASC that we were able to include in this study; in total, more than 1,000 individuals with ASC and 3,000 controls were included. Given the lengthy process required to make an independent research diagnosis of ASC, this study would not have been possible without taking the reported diagnosis on trust. A recent study in the United States found that 98% of individuals who had reported a diagnosis of ASC were validated through medical record checks.[58] Furthermore, the accuracy of a Web-based approach to autism phenotyping implemented within the Interactive Autism Network (IAN) has been examined. This study directly assessed participants with a diagnosis of ASC on their network. The clinician's best-estimate diagnosis agreed with the diagnosis reported by the families in 98% of cases.[59] Support for using the Internet for data collection is provided by Gosling et al.,[60] who found that data provided by Internet methods are of at least as good quality as those provided by traditional methods. Taken together these findings suggest that scientists can confidently recruit participants for autism research through Web-based databases. As Daniels et al.[58] point out, participants in voluntary research projects do not represent the entire population of children with ASC and their families. However, all of the participants included in this study share something in common with nonresearch participants with a diagnosis of ASC, that is, they have all at some stage had concern expressed about them, been referred,

assessed, and diagnosed by a suitably qualified health professional.

A final limitation is that there are unequal proportions of individuals with different subtype diagnoses within the case groups. For example, in the adult case sample, 90% of the participants have a diagnosis of Asperger syndrome, compared with 37% in the child case sample. Adults with autism and learning disability are underrepresented in the adult volunteers who register on the Web site. Therefore, it must be acknowledged that the composition of the case samples differ by age which may reflect systematic bias in relation to the participants who register on the Web site to be volunteers.

We are not proposing that these instruments be used as population screening instruments, as taking that step would require evaluation in an unselected population, and this has not yet been done. We believe that it is unlikely that general population screening will ever be a practical solution to detection for ASC across the lifespan. There are many costs associated with population screening, including the psychological impact for an incorrect positive screening result, a delay in accessing help for an incorrect negative screening result, and a potentially costly increased demand for diagnostic and intervention services. Rather, at this stage, we propose that these may be used as referral tools that is, where concern has already been expressed, and/or the individual is experiencing difficulties, as a guide for primary care health or social care professionals (including GPs, family physicians, social workers, nursery workers and Health Visitors) to help them to decide whether a referral to a specialist service for ASC is appropriate. The current decision-making process of primary health, social care, and early education practitioners with regard to referral for specialist ASC assessment is unknown and should be investigated. In reality, decision making is most likely dependent on knowledge, training, and prior experience in relation to ASC, meaning that many individuals who warrant a referral may not be referred. The predictive value of measures such as these can be increased by applying them in contexts where concerns have already been raised.[61] It must be cautioned that the psychometric properties obtained in these samples may not be generalizable. It is not known how the samples derived for this study differ not just from referred samples but also from samples where a decision is being made about whether to make a referral. The performance of any measure is dependent on the prevalence of the disorder being measured in the sample. The predictive value of the measure will change as a function of the prevalence in the sample being assessed, given the known sensitivity and specificity of the instruments (even if these are high).[62,63] The proportion of cases in each validation sample ranged from 14% to 46%. To illustrate an example using the adult AQ data, the proportion of cases of ASC in the validation sample was 35% and the resulting PPV was 0.85 (197 true positives, 36 false positives). However, in a true population sample in which the prevalence of ASC is approximately 1%,[8,9] the PPV would have been 0.09 (given the sensitivity and specificity of 0.88 and 0.91 respectively, values that do not vary). Therefore, screening for ASC in a sample enriched by individuals for whom there are concerns about possible ASC may result in a substantially higher predictive value than if the measure is tested in a population sample in which the prevalence is substantially lower. Similarly, it is inevitable that screening the general population for a rare condition will result with many test false-positive results and therefore a low PPV.[64]

This study represents the first step in the development of short instruments designed to help health care and social care professionals in the referral pathway for ASC. The short forms are more suitable for busy health care professionals than the long forms when time is limited. Respondent burden is also reduced with the short forms. Further work is required to examine how these tools perform in primary and social care, by tracking individuals who are referred to specialist diagnostic services and determining their outcome by independent expert diagnostic observations. &

Accepted November 14, 2011.

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Funding was made possible from grants from the Big Lottery Fund, the Medical Research Council, the Three Guineas Trust, and the National Institute for Health Research Collaboration for Leadership in Applied Health Research and Care.

We are grateful to all of the individuals and families that completed the questionnaires. This study was conducted in association with National Institute of Health Research (NIHR) Collaborations for Leadership in Applied Health Research and Care (CLAHRC) for Cambridgeshire and Peterborough. We thank Carol Brayne, Fiona Matthews, and Liliana

Ruta of the University of Cambridge; Tony Charman and Greg Pasco of the Institute of Education; Sally Wheelwright of the University of Southampton and Rosa Hoekstra of the Open University, for valuable discussions. We thank the anonymous reviewers for their helpful comments.

Disclosure: Drs. Allison, Auyeung, and Baron-Cohen report no biomedical financial interests or potential conflicts of interest.

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0890-8567/$36.00/©2012 American Academy of Child and Adolescent Psychiatry

DOI: 10.1016/j.jaac.2011.11.003

REFERENCES

1. World Health Organisation. The ICD-10 Classification of Mental and Behavioural Disorders: Diagnostic Criteria for Research. Geneva: World Health Organisation; 1993.
2. American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders (DSM-IV). 4th ed. Washington, DC: American Psychiatric Association; 1994.
3. Bailey A, Le Couteur A, Gottesman I, *et al.* Autism as a strongly genetic disorder: evidence from a British twin study. Psychol Med. 1995;25:63-77.
4. Bolton P, Macdonald H, Pickles A, *et al.* A case-control family history study of autism. J Child Psychol Psychiatry. 1994;35:877-900.
5. Chakrabarti B, Dudbridge F, Kent L, *et al.* Genes related to sex steroids, neural growth, and social-emotional behavior are associated with autistic traits, empathy, and Asperger syndrome. Autism Res. 2009;2:157-177.
6. Geschwind DH. Autism: many genes, common pathways? Cell. 2008;135:391-395.
7. Courchesne E, Carper R, Akshoomoff N. Evidence of brain overgrowth in the first year of life in autism. JAMA. 2003;290:337-344.
8. Baird G, Simonoff E, Pickles A, *et al.* Prevalence of disorders of the autism spectrum in a population cohort of children in South Thames: the Special Needs and Autism Project (SNAP). Lancet. 2006;368:210-215.
9. Baron-Cohen S, Scott FJ, Allison C, *et al.* Prevalence of autism-spectrum conditions: UK school-based population study. Br J Psychiatry. 2009;194:500-509.
10. Brugha T, McManus S, Meltzer H, *et al.* Autism spectrum disorders in adults living in households throughout England: report from the Adult Psychiatric Morbidity Survey 2007. Leeds, UK: Health and Social Care Information Centre, Social Care Statistics; 2009.
11. Baron-Cohen S, Wheelwright S, Skinner R, Martin J, Clubley E. The autism-spectrum quotient (AQ): evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. J Autism Dev Disord. 2001;31:5-17.
12. Wing L. The continuum of autistic characteristics. In: Schopler E, Mesibov G, eds. Diagnosis and Assessment in Autism. New York: Plenum; 1988.
13. Charman T. What does the term 'working diagnosis' mean? J Autism Dev Disord. 2005;35:539-540.
14. Wing L. The Autistic Spectrum. Oxford: Pergamon; 1997.
15. Howlin P, Asgharian A. The diagnosis of autism and Asperger syndrome: findings from a survey of 770 families. Dev Med Child Neurol. 1999;41:834-839.
16. Knapp M, Romeo R, Beecham J. Economic cost of autism in the UK. Autism. 2009;13:317-336.
17. Ganz M. The costs of autism. In: Moldin S, Rubenstein J, eds. Understanding Autism: From Basic Neuroscience to Treatment. Boca Raton, FL: Taylor & Francis; 2006.
18. National Audit Office. Supporting People with Autism Through Adulthood. London: Stationery Office; 2009.
19. Information Centre for Health and Social Care. Average Practice List Sizes in the UK NHS Technical Steering Committee; 2008.
20. Dereu M, Raymaekers R, Warreyn P, Schietecatte I, Meirsschaut M, Roeyers H. Can child care workers contribute to the early detection of autism spectrum disorders? A comparison between screening instruments with child care workers versus parents as informants. [published online ahead of print June 21 2011]. J Autism Dev Disord. 2011. Available at: http://www.springerlink.com/content/mk01522176825656/. Accessed August 23, 2011.
21. Glascoe FP. Screening for developmental and behavioral problems. Ment Retard Dev Disabil Res Rev. 2005;11:173-179.
22. Baron-Cohen S, Allen J, Gillberg C. Can autism be detected at 18 months? The needle, the haystack, and the CHAT. Br J Psychiatry. 1992;161:839-843.
23. Baron-Cohen S, Cox A, Baird G, *et al.* Psychological markers in the detection of autism in infancy in a large population. Br J Psychiatry. 1996;168:158-163.
24. Baird G, Charman T, Baron-Cohen S, *et al.* A screening instrument for autism at 18 months of age: a 6-year follow-up study. J Am Acad Child Adolesc Psychiatry. 2000;39:694-702.
25. Berument SK, Rutter M, Lord C, Pickles A, Bailey A. Autism screening questionnaire: diagnostic validity. Br J Psychiatry. 1999;175:444-451.
26. Allen CW, Silove N, Williams K, Hutchins P. Validity of the social communication questionnaire in assessing risk of autism in preschool children with developmental problems. J Autism Dev Disord. 2007;37:1272-1278.
27. Corsello C, Hus V, Pickles A, *et al.* Between a ROC and a hard place: decision making and making decisions about using the SCQ. J Child Psychol Psychiatry. 2007;48:932-940.
28. Robins DL, Fein D, Barton ML, Green JA. The Modified Checklist for Autism in Toddlers: an initial study investigating the early detection of autism and pervasive developmental disorders. J Autism Dev Disord. 2001;31:131-144.
29. Swinkels SH, Dietz C, van Daalen E, Kerkhof IH, van Engeland H, Buitelaar JK. Screening for autistic spectrum in children aged 14 to 15 months. I: the development of the Early Screening of Autistic Traits Questionnaire (ESAT). J Autism Dev Disord. 2006;36:723-732.
30. Dietz C, Swinkels S, van Daalen E, van Engeland H, Buitelaar JK. Screening for autistic spectrum disorder in children aged 14-15 months. II: population screening with the Early Screening of Autistic Traits Questionnaire (ESAT). Design and general findings. J Autism Dev Disord. 2006;36:713-722.
31. Constantino JN, Davis SA, Todd RD, *et al.* Validation of a brief quantitative measure of autistic traits: comparison of the social responsiveness scale with the autism diagnostic interview-revised. J Autism Dev Disord. 2003;33:427-433.
32. Reznick JS, Baranek GT, Reavis S, Watson LR, Crais ER. A parent-report instrument for identifying one-year-olds at risk for an eventual diagnosis of autism: the first year inventory. J Autism Dev Disord. 2007;37:1691-1710.
33. Watson LR, Baranek GT, Crais ER, Steven Reznick J, Dykstra J, Perryman T. The first year inventory: retrospective parent responses to a questionnaire designed to identify one-year-olds at risk for autism. J Autism Dev Disord. 2007;37:49-61.
34. Barnard J, Harvey V, Prior A, Potter D. Ignored or Ineligible? The Reality for Adults with Autistic Spectrum Disorders. London: National Autistic Society; 2001.
35. Woodbury-Smith MR, Robinson J, Wheelwright S, Baron-Cohen S. Screening adults for Asperger syndrome using the AQ: a preliminary study of its diagnostic validity in clinical practice. J Autism Dev Disord. 2005;35:331-335.
36. Auyeung B, Baron-Cohen S, Wheelwright S, Allison C. The Autism Spectrum Quotient: Children's Version (AQ-Child). J Autism Dev Disord. 2008;38:1230-1240.
37. Baron-Cohen S, Hoekstra RA, Knickmeyer R, Wheelwright S. The Autism-Spectrum Quotient (AQ)—Adolescent Version. J Autism Dev Disord. 2006;36:343-350.
38. Wheelwright S, Baron-Cohen S, Goldenfeld N, *et al.* Predicting Autism Spectrum Quotient (AQ) from the Systemizing Quo-

tient—Revised (SQ-R) and Empathy Quotient (EQ). Brain Res. 2006;1079:47-56.
39. Hoekstra RA, Bartels M, Cath DC, Boomsma DI. Factor structure, reliability and criterion validity of the Autism-Spectrum Quotient (AQ): a study in Dutch population and patient groups. J Autism Dev Disord. 2008;38:1555-1566.
40. Wakabayashi A, Baron-Cohen S, Wheelwright S, Tojo Y. The Autism-Spectrum Quotient (AQ) in Japan: a cross-cultural comparison. J Autism Dev Disord. 2006;36:263-270.
41. Ruta L, Mazzone D, Mazzone L, Wheelwright S, Baron-Cohen S. The Autism-Spectrum Quotient—Italian Version: a cross-cultural confirmation of the broader autism phenotype [published online ahead of print May 28 2011]. J Autism Dev Disord. 2011. Available at: http://www.springerlink.com/content/n71j631157373513/. Accessed August 23, 2011.
42. Hoekstra RA, Bartels M, Verweij CJH, Boomsma DI. Heritability of autistic traits in the general population. Arch Pediatr Adolesc Med. 2007;161:372-377.
43. Takagishi H, Takahashi T, Yamagishi T, *et al.* Salivary testosterone levels and autism-spectrum quotient in adults. Neuro Endocrinol Lett. 2011;31:837-841.
44. von dem Hagen EA, Nummenmaa L, Yu R, Engell AD, Ewbank MP, Calder AJ. Autism spectrum traits in the typical population predict structure and function in the posterior superior temporal sulcus. Cereb Cortex. 2011;21:493-500.
45. Gomot M, Belmonte MK, Bullmore ET, Bernard FA, Baron-Cohen S. Brain hyper-reactivity to auditory novel targets in children with high-functioning autism. Brain. 2008;131:2479-2488.
46. Lombardo MV, Barnes JL, Wheelwright SJ, Baron-Cohen S. Self-referential cognition and empathy in autism. PLoS ONE. 2007;2:e883.
47. Auyeung B, Baron-Cohen S, Ashwin E, Knickmeyer R, Taylor K, Hackett G. Fetal testosterone and autistic traits. Br J Psychol. 2009;100:1-22.
48. Allison C, Baron-Cohen S, Wheelwright S, *et al.* The Q-CHAT (Quantitative CHecklist for Autism in Toddlers): a normally distributed quantitative measure of autistic traits at 18-24 months of age: preliminary report. J Autism Dev Disord. 2008;38:1414-1425.
49. Auyeung B, Taylor K, Hackett G, Baron-Cohen S. Foetal testosterone and autistic traits in 18 to 24-month-old children. Mol Autism. 2010;1:11.
50. Elsabbagh M, Mercure E, Hudry K, *et al.* The utility of ERP measures as putative intermediate phenotypes in infancy. Paper presented at the International Meeting for Autism Research (IMFAR) 2010; Philadelphia.
51. Stones R, Janvier N, Robbins K. 2006/7 UK General Practice Workload Survey. Leeds, UK: The Information Centre; 2007.
52. Gillis JM, Callahan EH, Romanczyk RG. Assessment of social behavior in children with autism: the development of the Behavioral Assessment of Social Interactions in Young Children. Res Autism Spectrum Disord. 2011;5:351-360.
53. Anastasi A. Psychological Testing. 6th ed. New York: Macmillan; 1990.
54. Möricke E, Swinkels S, Beuker K, Buitelaar J. Predictive value of subclinical autistic traits at age 14–15 months for behavioral and cognitive problems at age 3–5 years. Eur Child Adolesc Psychiatry. 2010;19:659-668.
55. Kleinman JM, Ventola PE, Pandey J, *et al.* Diagnostic stability in very young children with autism spectrum disorders. J Autism Dev Disord. 2008;38:606-615.
56. Landa RJ. Diagnosis of autism spectrum disorders in the first 3 years of life. Nat Clin Pract Neurol. 2008;4:138-147.
57. Kankaras M, Vermunt JK, Moors GBD. Measurement equivalence of ordinal items: a comparison of factor analytic, item response theory, and latent class approaches. Sociol Methods Res. 2011;40:279-310.
58. Daniels AM, Rosenberg RE, Anderson C, Law JK, Marvin AR, Law PA. Verification of parent-report of child autism spectrum disorder diagnosis to a Web-based autism registry [published online ahead of print April 6 2011]. J Autism Dev Disord. 2011. Available at: http://www.springerlink.com/content/r3102357gg7rt30p/. Accessed April 23, 2011.
59. Lee H, Marvin AR, Watson T, *et al.* Accuracy of phenotyping of autistic children based on Internet implemented parent report. Am J Med Genet B Neuropsychiatr Genet. 2010;153B:1119-1126.
60. Gosling SD, Vazire S, Srivastava S, John OP. Should we trust Web-based studies? A comparative analysis of six preconceptions about Internet questionnaires. Am Psychologist. 2004;59:93-104.
61. Williams J, Scott F, Allison C, Bolton P, Baron- Cohen S, Brayne C. The CAST (Childhood Asperger Syndrome Test): test accuracy. Autism. 2005:45-68.
62. Clark A, Harrington R. On diagnosing rare disorders rarely: appropriate use of screening instruments. J Child Psychol Psychiatry. 1999;40:287-290.
63. O'Toole BI. Screening for low prevalence disorders. Aust N Z J Psychiatry. 2000;34(Suppl):S39-S46.
64. Altman DG, Bland JM. Diagnostic tests 2: predictive values. Br Med J. 1994;309:102.

TABLE S1 Item Analysis Showing Discrimination Index (DI) for Autism Spectrum Quotient (AQ) 50-Item Adult Version

		Cases		Controls		
Item	Subscale	0 n (%)	1 n (%)	0 n (%)	1 n (%)	DI
01	Social	51 (22.77)	173 (77.23)	238 (56.8)	181 (43.2)	0.34
02	Attention Switching	34 (15.18)	190 (84.82)	215 (51.31)	204 (48.69)	0.36
03	Imagination	140 (62.5)	84 (37.5)	349 (83.29)	70 (16.71)	0.21
04	Attention Switching	8 (3.57)	216 (96.43)	150 (35.8)	269 (64.2)	0.32
05	Attention to Detail	20 (8.93)	204 (91.07)	193 (46.06)	226 (53.94)	0.37
06	Attention to Detail	36 (16.07)	188 (83.93)	203 (48.45)	216 (51.55)	0.32
07	Communication	47 (20.98)	177 (79.02)	321 (76.61)	98 (23.39)	0.56
08	Imagination	88 (39.29)	136 (60.71)	359 (85.68)	60 (14.32)	0.46
09	Attention to Detail	93 (41.52)	131 (58.48)	323 (77.09)	96 (22.91)	0.36
10	Attention Switching	32 (14.29)	192 (85.71)	265 (63.25)	154 (36.75)	0.49
11	Social	13 (5.8)	211 (94.2)	246 (58.71)	173 (41.29)	0.53
12	Attention to Detail	8 (3.57)	216 (96.43)	87 (20.76)	332 (79.24)	0.17
13	Social	34 (15.18)	190 (84.82)	241 (57.52)	178 (42.48)	0.42
14	Imagination	95 (42.41)	129 (57.59)	256 (61.1)	163 (38.9)	0.19
15	Social	28 (12.5)	196 (87.5)	257 (61.34)	162 (38.66)	0.49
16	Attention Switching	9 (4.02)	215 (95.98)	212 (50.6)	207 (49.4)	0.47
17	Communication	22 (9.82)	202 (90.18)	261 (62.29)	158 (37.71)	0.52
18	Communication	65 (29.02)	159 (70.98)	275 (65.63)	144 (34.37)	0.37
19	Attention to Detail	71 (31.7)	153 (68.3)	251 (59.9)	168 (40.1)	0.28
20	Imagination	76 (33.93)	148 (66.07)	364 (86.87)	55 (13.13)	0.53
21	Imagination	120 (53.57)	104 (46.43)	333 (79.47)	86 (20.53)	0.26
22	Social	24 (10.71)	200 (89.29)	257 (61.34)	162 (38.66)	0.51
23	Attention to Detail	19 (8.48)	205 (91.52)	167 (39.86)	252 (60.14)	0.31
24	Imagination	52 (23.21)	172 (76.79)	260 (62.05)	159 (37.95)	0.39
25	Attention Switching	37 (16.52)	187 (83.48)	254 (60.62)	165 (39.38)	0.44
26	Communication	20 (8.93)	204 (91.07)	253 (60.38)	166 (39.62)	0.51
27	Communication	35 (15.63)	189 (84.38)	319 (76.13)	100 (23.87)	0.61
28	Attention to Detail	51 (22.77)	173 (77.23)	259 (61.81)	160 (38.19)	0.39
29	Attention to Detail	101 (45.09)	123 (54.91)	198 (47.26)	221 (52.74)	0.02
30	Attention to Detail	97 (43.3)	127 (56.7)	149 (35.56)	270 (64.44)	−0.08
31	Communication	66 (29.46)	158 (70.54)	366 (87.35)	53 (12.65)	0.58
32	Attention Switching	38 (16.96)	186 (83.04)	298 (71.12)	121 (28.88)	0.54
33	Communication	57 (25.45)	167 (74.55)	337 (80.43)	82 (19.57)	0.55
34	Attention Switching	75 (33.48)	149 (66.52)	325 (77.57)	94 (22.43)	0.44
35	Communication	70 (31.25)	154 (68.75)	337 (80.43)	82 (19.57)	0.49
36	Social	32 (14.29)	192 (85.71)	318 (75.89)	101 (24.11)	0.62
37	Attention Switching	32 (14.29)	192 (85.71)	280 (66.83)	139 (33.17)	0.53
38	Communication	18 (8.04)	206 (91.96)	247 (58.95)	172 (41.05)	0.51
39	Communication	34 (15.18)	190 (84.82)	293 (69.93)	126 (30.07)	0.55
40	Imagination	60 (26.79)	164 (73.21)	321 (76.61)	98 (23.39)	0.50
41	Imagination	35 (15.63)	189 (84.38)	299 (71.36)	120 (28.64)	0.56
42	Imagination	44 (19.64)	180 (80.36)	284 (67.78)	135 (32.22)	0.48
43	Attention Switching	31 (13.84)	193 (86.16)	156 (37.23)	263 (62.77)	0.23
44	Social	36 (16.07)	188 (83.93)	314 (74.94)	105 (25.06)	0.59
45	Social	32 (14.29)	192 (85.71)	312 (74.46)	107 (25.54)	0.60
46	Attention Switching	15 (6.7)	209 (93.3)	158 (37.71)	261 (62.29)	0.31
47	Social	61 (27.23)	163 (72.77)	303 (72.32)	116 (27.68)	0.45
48	Social	68 (30.36)	156 (69.64)	308 (73.51)	111 (26.49)	0.43
49	Attention to Detail	112 (50)	112 (50)	234 (55.85)	185 (44.15)	0.06
50	Imagination	48 (21.43)	176 (78.57)	276 (65.87)	143 (34.13)	0.44

TABLE S2 Item Analysis Showing Discrimination Index (DI) for Autism Spectrum Quotient (AQ) 50-Item Adolescent Version

		Case		Control		
Item	Subscale	0 n (%)	1 n (%)	0 n (%)	1 N (%)	DI
01	Social	31 (38.27)	50 (61.73)	182 (76.47)	56 (23.53)	0.38
02	Attention Switching	13 (16.05)	68 (83.95)	162 (68.07)	76 (31.93)	0.52
03	Imagination	37 (45.68)	44 (54.32)	215 (90.34)	23 (9.66)	0.45
04	Attention Switching	3 (3.7)	78 (96.3)	93 (39.08)	145 (60.92)	0.35
05	Attention to Detail	14 (17.28)	67 (82.72)	136 (57.14)	102 (42.86)	0.40
06	Attention to Detail	29 (35.8)	52 (64.2)	150 (63.03)	88 (36.97)	0.27
07	Communication	18 (22.22)	63 (77.78)	208 (87.76)	29 (12.24)	0.66
08	Imagination	22 (27.16)	59 (72.84)	223 (94.49)	13 (5.51)	0.67
09	Attention to Detail	53 (65.43)	28 (34.57)	202 (85.59)	34 (14.41)	0.2
10	Attention Switching	11 (13.58)	70 (86.42)	200 (84.39)	37 (15.61)	0.71
11	Social	2 (2.47)	79 (97.53)	207 (86.97)	31 (13.03)	0.85
12	Attention to Detail	16 (19.75)	65 (80.25)	90 (38.14)	146 (61.86)	0.18
13	Social	37 (45.68)	44 (54.32)	218 (92.37)	18 (7.63)	0.47
14	Imagination	28 (34.57)	53 (65.43)	182 (76.79)	55 (23.21)	0.42
15	Social	15 (18.52)	66 (81.48)	187 (78.57)	51 (21.43)	0.60
16	Attention Switching	6 (7.41)	75 (92.59)	137 (57.56)	101 (42.44)	0.50
17	Communication	16 (19.75)	65 (80.25)	220 (92.44)	18 (7.56)	0.73
18	Communication	26 (32.1)	55 (67.9)	144 (60.5)	94 (39.5)	0.28
19	Attention to Detail	49 (60.49)	32 (39.51)	178 (74.79)	60 (25.21)	0.14
20	Imagination	20 (24.69)	61 (75.31)	216 (90.76)	22 (9.24)	0.66
21	Imagination	32 (39.51)	49 (60.49)	192 (81.01)	45 (18.99)	0.42
22	Social	3 (3.7)	78 (96.3)	204 (86.08)	33 (13.92)	0.82
23	Attention to Detail	21 (25.93)	60 (74.07)	176 (73.95)	62 (26.05)	0.48
24	Imagination	28 (34.57)	53 (65.43)	174 (73.42)	63 (26.58)	0.39
25	Attention Switching	15 (18.52)	66 (81.48)	179 (75.21)	59 (24.79)	0.57
26	Communication	7 (8.64)	74 (91.36)	203 (85.29)	35 (14.71)	0.77
27	Communication	8 (9.88)	73 (90.12)	191 (80.25)	47 (19.75)	0.70
28	Attention to Detail	20 (24.69)	61 (75.31)	182 (76.79)	55 (23.21)	0.52
29	Attention to Detail	41 (50.62)	40 (49.38)	81 (34.18)	156 (65.82)	−0.16
30	Attention to Detail	39 (48.15)	42 (51.85)	60 (25.32)	177 (74.68)	−0.23
31	Communication	8 (9.88)	73 (90.12)	196 (83.4)	39 (16.6)	0.74
32	Attention Switching	16 (19.75)	65 (80.25)	165 (69.92)	71 (30.08)	0.50
33	Communication	26 (32.1)	55 (67.9)	213 (89.5)	25 (10.5)	0.57
34	Attention Switching	23 (28.4)	58 (71.6)	191 (80.93)	45 (19.07)	0.53
35	Communication	24 (29.63)	57 (70.37)	192 (81.36)	44 (18.64)	0.52
36	Social	17 (20.99)	64 (79.01)	201 (84.81)	36 (15.19)	0.64
37	Attention Switching	23 (28.4)	58 (71.6)	209 (87.82)	29 (12.18)	0.59
38	Communication	8 (9.88)	73 (90.12)	215 (90.34)	23 (9.66)	0.80
39	Communication	8 (9.88)	73 (90.12)	168 (70.59)	70 (29.41)	0.61
40	Imagination	8 (9.88)	73 (90.12)	202 (84.87)	36 (15.13)	0.75
41	Imagination	25 (30.86)	56 (69.14)	196 (82.35)	42 (17.65)	0.51
42	Imagination	9 (11.11)	72 (88.89)	194 (81.86)	43 (18.14)	0.71
43	Attention Switching	25 (30.86)	56 (69.14)	113 (47.48)	125 (52.52)	0.17
44	Social	33 (40.74)	48 (59.26)	223 (93.7)	15 (6.3)	0.53
45	Social	4 (4.94)	77 (95.06)	184 (77.64)	53 (22.36)	0.73
46	Attention Switching	6 (7.41)	75 (92.59)	123 (51.68)	115 (48.32)	0.44
47	Social	31 (38.27)	50 (61.73)	208 (87.39)	30 (12.61)	0.49
48	Social	13 (16.05)	68 (83.95)	205 (86.5)	32 (13.5)	0.70
49	Attention to Detail	45 (55.56)	36 (44.44)	93 (39.24)	144 (60.76)	−0.16
50	Imagination	13 (16.05)	68 (83.95)	198 (83.9)	38 (16.1)	0.68

TABLE S3 Item Analysis Showing Discrimination Index (DI) for Autism Spectrum Quotient (AQ) 50-Item Child Version

		Cases		Controls		
Item	Subscale	0 n (%)	1 n (%)	0 n (%)	1 n (%)	DI
01	Social	82 (37.96)	134 (62.04)	368 (78.3)	102 (21.7)	0.40
02	Attention Switching	23 (10.65)	193 (89.35)	331 (70.58)	138 (29.42)	0.60
03	Imagination	90 (41.67)	126 (58.33)	408 (87.37)	59 (12.63)	0.46
04	Attention Switching	12 (5.56)	204 (94.44)	188 (40.17)	280 (59.83)	0.35
05	Attention to Detail	27 (12.5)	189 (87.5)	291 (62.05)	178 (37.95)	0.50
06	Attention to Detail	43 (19.91)	173 (80.09)	272 (57.87)	198 (42.13)	0.38
07	Communication	22 (10.19)	194 (89.81)	421 (89.96)	47 (10.04)	0.80
08	Imagination	70 (32.41)	146 (67.59)	435 (92.75)	34 (7.25)	0.60
09	Attention to Detail	125 (57.87)	91 (42.13)	381 (81.06)	89 (18.94)	0.23
10	Attention Switching	18 (8.33)	198 (91.67)	364 (77.78)	104 (22.22)	0.69
11	Social	32 (14.81)	184 (85.19)	397 (84.65)	72 (15.35)	0.70
12	Attention to Detail	24 (11.11)	192 (88.89)	173 (36.81)	297 (63.19)	0.26
13	Social	116 (53.7)	100 (46.3)	448 (95.32)	22 (4.68)	0.42
14	Imagination	67 (31.02)	149 (68.98)	390 (83.16)	79 (16.84)	0.52
15	Social	47 (21.76)	169 (78.24)	367 (78.25)	102 (21.75)	0.56
16	Attention Switching	17 (7.87)	199 (92.13)	233 (49.68)	236 (50.32)	0.42
17	Communication	33 (15.28)	183 (84.72)	426 (90.83)	43 (9.17)	0.76
18	Communication	63 (29.17)	153 (70.83)	238 (50.64)	232 (49.36)	0.21
19	Attention to Detail	82 (37.96)	134 (62.04)	314 (66.95)	155 (33.05)	0.29
20	Imagination	40 (18.52)	176 (81.48)	423 (90.19)	46 (9.81)	0.72
21	Imagination	123 (56.94)	93 (43.06)	419 (89.34)	50 (10.66)	0.32
22	Social	31 (14.35)	185 (85.65)	401 (85.5)	68 (14.5)	0.71
23	Attention to Detail	49 (22.69)	167 (77.31)	312 (66.38)	158 (33.62)	0.44
24	Imagination	113 (52.31)	103 (47.69)	370 (79.06)	98 (20.94)	0.27
25	Attention Switching	57 (26.39)	159 (73.61)	391 (83.19)	79 (16.81)	0.57
26	Communication	25 (11.57)	191 (88.43)	436 (92.77)	34 (7.23)	0.81
27	Communication	9 (4.17)	207 (95.83)	351 (74.68)	119 (25.32)	0.71
28	Attention to Detail	37 (17.13)	179 (82.87)	321 (68.44)	148 (31.56)	0.51
29	Attention to Detail	98 (45.37)	118 (54.63)	142 (30.28)	327 (69.72)	−0.15
30	Attention to Detail	81 (37.5)	135 (62.5)	113 (24.04)	357 (75.96)	−0.13
31	Communication	17 (7.87)	199 (92.13)	345 (73.72)	123 (26.28)	0.66
32	Attention Switching	44 (20.37)	172 (79.63)	408 (86.81)	62 (13.19)	0.66
33	Communication	34 (15.74)	182 (84.26)	416 (88.51)	54 (11.49)	0.73
34	Attention Switching	66 (30.56)	150 (69.44)	430 (91.68)	39 (8.32)	0.61
35	Communication	40 (18.52)	176 (81.48)	386 (82.3)	83 (17.7)	0.64
36	Social	36 (16.67)	180 (83.33)	417 (88.91)	52 (11.09)	0.72
37	Attention Switching	58 (26.85)	158 (73.15)	410 (87.23)	60 (12.77)	0.60
38	Communication	22 (10.19)	194 (89.81)	426 (90.64)	44 (9.36)	0.80
39	Communication	32 (14.81)	184 (85.19)	315 (67.02)	155 (32.98)	0.52
40	Imagination	33 (15.28)	183 (84.72)	401 (85.32)	69 (14.68)	0.70
41	Imagination	69 (31.94)	147 (68.06)	305 (64.89)	165 (35.11)	0.33
42	Imagination	34 (15.74)	182 (84.26)	359 (76.38)	111 (23.62)	0.61
43	Attention Switching	74 (34.26)	142 (65.74)	251 (53.75)	216 (46.25)	0.19
44	Social	88 (40.74)	128 (59.26)	452 (96.38)	17 (3.62)	0.56
45	Social	12 (5.56)	204 (94.44)	343 (73.29)	125 (26.71)	0.68
46	Attention Switching	22 (10.19)	194 (89.81)	235 (50)	235 (50)	0.40
47	Social	80 (37.04)	136 (62.96)	403 (85.93)	66 (14.07)	0.49
48	Social	37 (17.13)	179 (82.87)	414 (88.27)	55 (11.73)	0.71
49	Attention to Detail	127 (58.8)	89 (41.2)	194 (41.36)	275 (58.64)	−0.17
50	Imagination	45 (20.83)	171 (79.17)	426 (90.64)	44 (9.36)	0.70

TABLE S4 Item Analysis Showing Discrimination Index (DI) for Quantitative Checklist for Autism in Toddlers (Q-CHAT) 25-Item Version

	Cases		Controls		
Item	0 n (%)	1 n (%)	0 n (%)	1 n (%)	DI
01	12 (19.05)	51 (80.95)	363 (96.29)	14 (3.71)	0.772
02	25 (39.68)	38 (60.32)	372 (98.94)	4 (1.06)	0.593
03	26 (41.27)	37 (58.73)	156 (41.49)	220 (58.51)	0.002
04	12 (19.05)	51 (80.95)	213 (56.8)	162 (43.2)	0.378
05	27 (42.86)	36 (57.14)	349 (93.07)	26 (6.93)	0.502
06	9 (14.29)	54 (85.71)	342 (90.96)	34 (9.04)	0.767
07	34 (53.97)	29 (46.03)	293 (78.13)	82 (21.87)	0.242
08	29 (46.03)	34 (53.97)	133 (35.37)	243 (64.63)	−0.107
09	12 (19.05)	51 (80.95)	339 (90.16)	37 (9.84)	0.711
10	8 (12.7)	55 (87.3)	335 (89.1)	41 (10.9)	0.764
11	22 (34.92)	41 (65.08)	219 (58.24)	157 (41.76)	0.233
12	11 (17.46)	52 (82.54)	140 (37.43)	234 (62.57)	0.200
13	24 (38.1)	39 (61.9)	207 (55.05)	169 (44.95)	0.170
14	29 (46.03)	34 (53.97)	348 (92.31)	29 (7.69)	0.463
15	4 (6.35)	59 (93.65)	225 (60)	150 (40)	0.537
16	9 (14.29)	54 (85.71)	159 (42.29)	217 (57.71)	0.280
17	27 (42.86)	36 (57.14)	351 (93.1)	26 (6.9)	0.502
18	23 (36.51)	40 (63.49)	37 (9.84)	339 (90.16)	−0.267
19	25 (39.68)	38 (60.32)	369 (97.88)	8 (2.12)	0.582
20	29 (46.03)	34 (53.97)	335 (89.57)	39 (10.43)	0.435
21	11 (17.46)	52 (82.54)	219 (58.24)	157 (41.76)	0.408
22	31 (49.21)	32 (50.79)	213 (57.57)	157 (42.43)	0.084
23	29 (46.03)	34 (53.97)	294 (78.61)	80 (21.39)	0.326
24	17 (26.98)	46 (73.02)	281 (74.54)	96 (25.46)	0.476
25	16 (25.4)	47 (74.6)	321 (85.83)	53 (14.17)	0.604

FIGURE S1 Receiver operating characteristic (ROC) curves. Note: (A) Autism Spectrum Quotient (AQ) Adult. (B) Autism Spectrum Quotient (AQ) Adolescent. (C) Autism Spectrum Quotient (AQ) Child. (D) Quantitative Checklist for Autism in Toddlers (Q-CHAT).

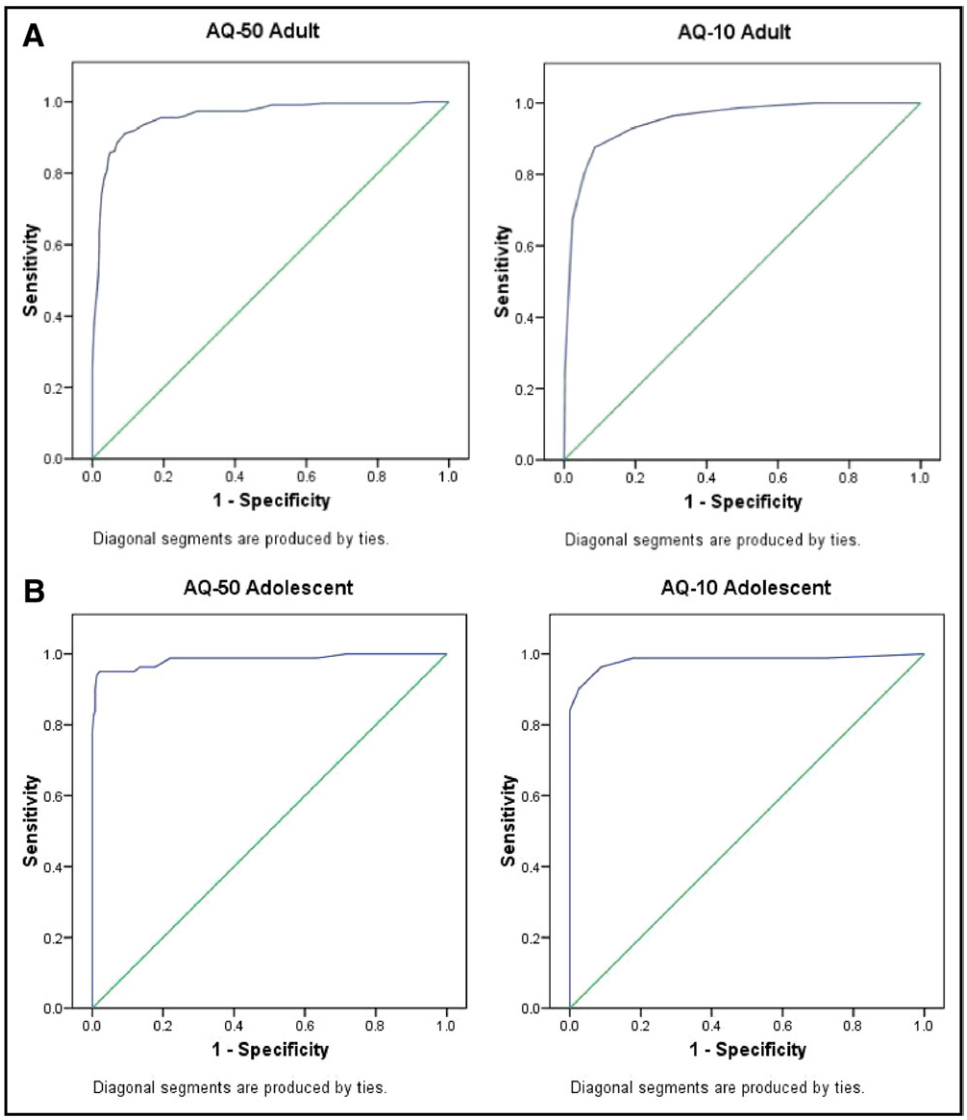

FIGURE S1 Continued

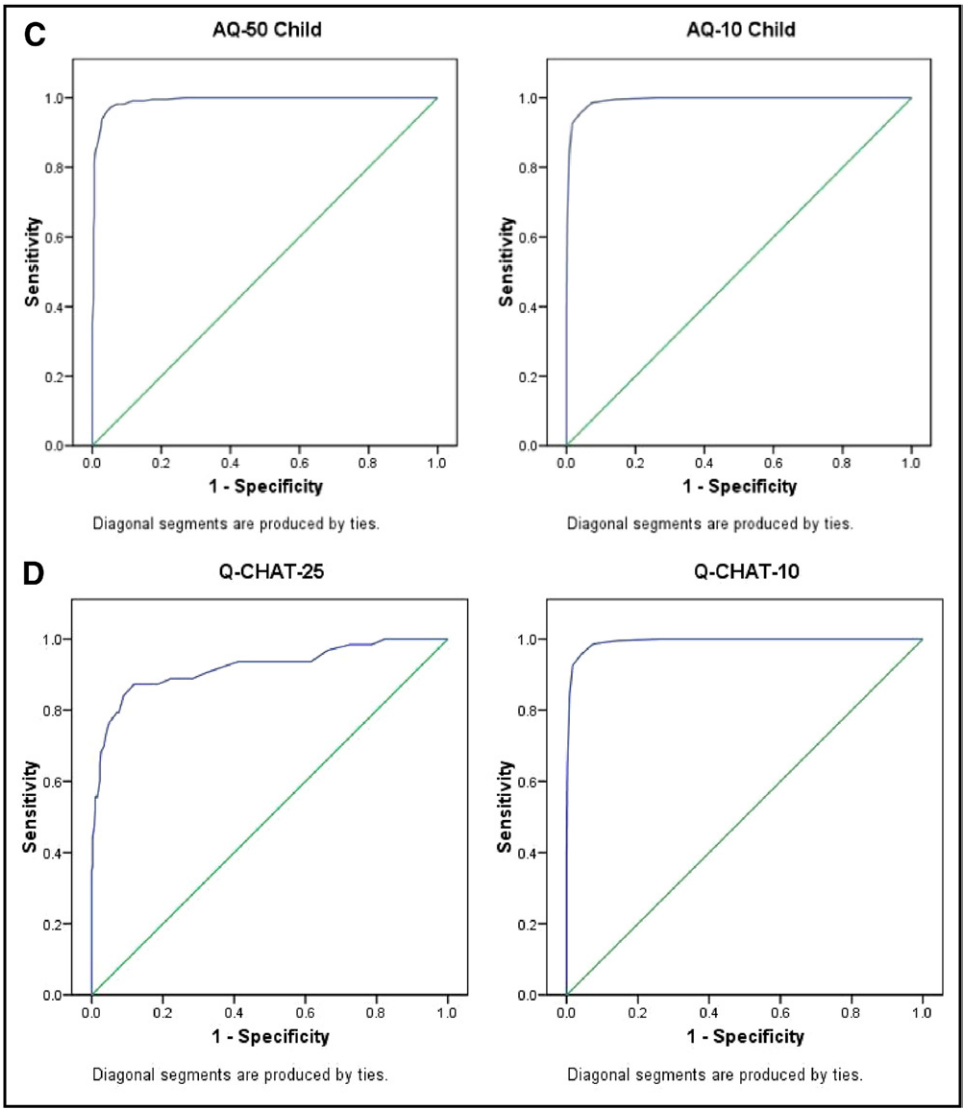

TABLE S5 Sensitivity and Specificity for the Short Measures

Measure	Score	Sensitivity	Specificity
AQ-10 Adult	1	1.00	0.11
	2	1.00	0.30
	3	0.99	0.51
	4	0.96	0.70
	5	0.93	0.81
	6	0.88	0.91
	7	0.80	0.94
	8	0.68	0.98
	9	0.45	0.99
	10	0.25	1.00
AQ-10 Adolescent	1	0.99	0.28
	2	0.99	0.57
	3	0.99	0.71
	4	0.99	0.82
	5	0.96	0.91
	6	0.93	0.95
	7	0.90	0.98
	8	0.84	1.00
	9	0.58	1.00
	10	0.24	1.00
AQ-10 Child	1	1.00	0.20
	2	1.00	0.48
	3	1.00	0.74
	4	1.00	0.87
	5	0.98	0.94
	6	0.95	0.97
	7	0.94	0.98
	8	0.83	0.99
	9	0.60	1.00
	10	0.35	1.00
Q-CHAT-10	1	1.00	0.42
	2	0.97	0.76
	3	0.91	0.89
	4	0.84	0.96
	5	0.78	0.97
	6	0.71	0.98
	7	0.65	0.99
	8	0.49	0.99
	9	0.37	1.00
	10	0.19	1.00

Note: AQ = Autism Spectrum Quotient; Q-CHAT = Quantitative Checklist for Autism in Toddlers.