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Mathematical Talent is Linked to Autism

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Abstract A total of 378 mathematics undergraduates (selected for being strong at "systemizing") and 414 students in other (control) disciplines at Cambridge University were surveyed with two questions: (1) Do you have a diagnosed autism spectrum condition? (2) How many relatives in your immediate family have a diagnosed autism spectrum condition? Results showed seven cases of autism in the math group (or 1.85%) vs one case of autism in the control group (or 0.24%), a ninefold difference that is significant. Controlling for sex and general population sampling, this represents a three- to sevenfold increase for autism spectrum conditions among the mathematicians. There were 7 of 1,405 (or 0.5%) cases of autism in the immediate families of the math group vs 2 of 1,669 (or 0.1%) cases in the immediate families of the control group, which again is a significant difference. These results confirm a link between autism and systemizing, and they suggest this link is genetic given the association between autism and first-degree relatives of mathematicians.

Keywords Autism · Broader autism phenotype · Genetic risk · Mathematical talent · Systemizing

The empathizing-systemizing theory claims the two core (universal) features of the autistic spectrum are impaired empathizing concurrent with intact or even superior systemizing (Baron-Cohen 2002). Empathizing is a familiar concept. Systemizing is the drive to analyze and/or build a system (of any kind) based on identifying input-operation-output rules. Engineering, mathematics, music, architecture, librarianism (library science), and biology are all clear examples of systemizing. In this study we test for evidence of any association between talent at systemizing and autism.

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The predicted link between autism and systemizing is based on eight pieces of evidence:

1. Obsessions in autism cluster in the domain of systems; for example, children with autism may become obsessed by train timetables, traffic systems, electrical light switches, collections of objects, or spinning objects (Baron-Cohen 2002).
2. People with Asperger syndrome (a subgroup on the autistic spectrum) score higher than average on the systemizing quotient (SQ), a self-report questionnaire measuring one's interest in a range of systems from mechanical (machines) to abstract (numbers) to natural (geology; Baron-Cohen et al. 2003).
3. Fathers and grandfathers of children with autism are twice as likely to work in the occupation of engineering (a profession in which systemizing ability is a prerequisite) compared with men in the general population, a correlation which is assumed to reflect a genetic association (Baron-Cohen et al. 1997).
4. Students in the natural sciences (engineering, mathematics, physics) have more relatives with autism than do students in the humanities (Baron-Cohen et al. 1998).
5. Scientists score higher than non-scientists on the autism spectrum quotient (AQ), a self-report questionnaire which measures how many autistic traits an individual has (Baron-Cohen et al. 2001b). The AQ has been validated with clinical diagnosis (Woodbury-Smith et al. 2005), and AQ scores are elevated among parents of children with autism (Bishop et al. 2004), suggesting it is clinically related to autism and may be an index of the broader phenotype.
6. Within the sciences, mathematicians score highest of all on the AQ (Baron-Cohen et al. 2001b), possibly reflecting that mathematics entails pure systemizing, whereas other sciences (such as medicine) may entail a mix of systemizing and empathy (e.g., for alleviating patients' distress and suffering).
7. People with Asperger syndrome perform at a normal or high level on tests of systemizing such as those involving engineering problems or "folk physics" (Baron-Cohen et al. 2001a; Lawson et al. 2004).
8. Asperger syndrome is not a barrier to achieving maximum potential in systemizing domains such as mathematics, physics, or computer science (Baron-Cohen et al. 1999).

We therefore tested whether mathematical talent (as a pure example of systemizing) carries an increased risk of developing autism, and if so, whether mathematical talent is genetically linked to autism.

Sample

We surveyed 792 students in Cambridge University: 378 mathematics undergraduates and 414 students in control disciplines (medicine, law, social science). The sex ratio in the math group was 280 males vs 98 females (or 74.1% male), and in the control group, 163 males vs 251 females (or 39.4% male). These sex ratios were significantly different (Fisher's exact test, p=0.0001). The groups were matched for age (math group mean=20.16 years, SD=1.4; control group mean=20.02, SD=1.5; t=1.58, df=774, p=0.12); parental occupation (professional parents in the math group=88.7% and in controls=89.4%, Fisher's exact test, p=0.1); and handedness (left-handed mathematicians=14.4%, left-handed controls=11.4%, Fisher's exact test, $p=0.117$).

Method

We asked each individual two questions via a screening survey: (1) Do you have a formally diagnosed autism spectrum condition? (2) How many relatives in your *immediate* family (excluding yourself) have a formally diagnosed autism spectrum condition? "Excluding yourself" was included in order to avoid any risk of double counting. "Formally diagnosed" was defined as a diagnosis by a trained professional in one of the relevant clinical fields, using internationally established criteria [e.g., DSM-III (APA 1980) or DSM-IV (APA 1994) or equivalent ICD-10, WHO (1994)]. Autism spectrum condition included classic autism (or autistic disorder), Asperger syndrome, and high-functioning autism but excluded "autistic traits," pervasive developmental disorder not otherwise specified (PDD-NOS), atypical autism, nonverbal learning disorder, Rett's syndrome, or childhood disintegrative disorder so as to be a conservative estimate. "Immediate family" was defined as first-degree relatives (siblings or parents) and excluded adoptive parents, or adoptive, step-, or half-siblings.

Anyone reporting a diagnosis on the autistic spectrum for themselves or a first-degree relative was contacted to confirm that the diagnosis met the above criteria. This was achieved by asking *who* had made the diagnosis, and *when* and *where* the diagnosis had been made. Only a diagnosis by a clinical psychologist, psychiatrist, or allied medical professional (e.g., pediatrician or neurologist) was accepted, and only if this diagnosis was given in a recognized clinic that employed established international criteria (e.g., a hospital or specialist assessment center).

Surveys were distributed by hand and completed at the end of a lecture while the investigators were observing and were available for any questions. The surveys also contained questions about demographic and background variables, such as age, handedness, parental occupation, subject of study, and other medical diagnoses.

Results

A total of 490 questionnaires were handed out to math students, of which 378 were returned completed. This represents a response rate of 77.1%. A total of 580 questionnaires were handed out to the control disciplines, of which 414 were returned completed (a response rate of 71.4%). These good response rates may reflect the fact that the surveys took place in a lecture theater, where there were no other distractions. There is unlikely to have been a response bias in return rates between the math and control groups.

There were seven independent cases of autism in the math group (or 1.85%)—that is, coming from seven different families. In contrast, there was only one case of autism in the control group (or 0.24%). This ninefold difference between groups is significant (Fisher's exact test, $p=0.026$). Even when the rate of high-functioning autism in the math group is compared with the most elevated general population prevalence rate of 0.65% (Baird et al. 2006; Betrand et al. 2001; Chakrabarti and Fombonne 2001), the rate among mathematicians is at least three times greater than one would expect.

The sex ratios in the math group and the control group were not equated (74% male in the math group vs 39% male in the control group). This is inevitable in any study of mathematicians since this field has a high male/female sex ratio, estimated at 13:1 (Benbow et al. 2000). Because autism is more common in general in males, the elevated rate of autism found in the math group could simply reflect a higher rate of autism among males. Although this is unlikely (because it is still much higher than the rate seen among males in the general population), further analysis looked at the rates of autism found in each group among just the males. All seven cases in the math group were male (representing a rate of autism of 7 of 280 male mathematicians, or 2.5%) whereas the one (male) case out of 263 males in the control group represents a rate of 0.38%. This is still a sixfold difference and is highly significant (Fisher's exact test, $p < 0.05$).

Finally, there were 7 of 1,405 (or 0.5%) cases of autism in the siblings of the math group vs 2 of 1,669 (or 0.1%) cases in the siblings of the control group, which again is a significant difference (Fisher's exact test, $p < 0.05$).

Discussion

In this study we tested the prediction that autism spectrum conditions would be more common among a sample of individuals selected for being talented systemizers, mathematics being assumed to be a clear example of systemizing. This prediction was confirmed. The rate of autism spectrum conditions among the mathematicians was 1.85%, and this was nine times greater than the rate among controls (0.24%). Controlling for sex, by analyzing this rate just among males, yielded a result of 2.5% among the math students compared with 0.38% among the male controls, which is still a sixfold increase. However, testing this association just within males reduced the sample size, thereby reducing statistical power.

The conclusion that autism is elevated among mathematicians should also be considered in the context of Cambridge University mathematics students being a special population. Since the controls were also Cambridge University students, however, they can be considered matched to the math group on variables such as age, IQ, social class (broadly), educational level, and level of awareness of a neurological condition such as autism.

The controls were students in medicine, law, and social science, and all we can say about their status as controls is that *they* had not chosen to be mathematicians. We did not test their mathematical ability, so whilst it is likely that math ability would have been higher in the math group, this is only an assumption. In an independent sample of math students tested more recently, we have confirmed that on a math test of speed and accuracy, math students do perform better than students registered for other degree subjects. So this assumption is likely to be a safe one.

It is also important to recognize that the controls were not non-systemizers, since students of law are studying the legal system, students of medicine are studying different systems (the cardiovascular system, the endocrine system, the digestive and respiratory systems, etc.), and even those who opt to study social science are in effect trying to systemize human behavior. Truly non-systemizing controls might have been better selected from a discipline such as English literature, or from a non-academic profession such as emotional counseling (e.g., the Samaritans in the UK).

The controls in this study were included for comparative purposes since previous studies had shown that mathematicians score higher on the autism spectrum quotient (AQ) relative to students in other sciences, such as medicine or social science (Baron-Cohen et al. 2001b). If anything, we were testing for differences in rates of autism between a group of very strong or pure systemizers (mathematicians) vs. less strong systemizers, since it is at least possible that among medical students or social scientists or law students, motivation for study would be driven not only by a desire to understand the system, but also to help people (empathy).

Even when comparing the rate of high-functioning autism among the math students with the most elevated prevalence rates for autism spectrum conditions that have been reported in the general population (0.65%; Chakrabarti and Fombonne 2001), autism spectrum conditions were still at least three times greater among the mathematicians than one would expect from chance. These results need to be treated with caution until larger samples have been studied, and replications have been attempted, but the first conclusion to be drawn is that talent at systemizing increases the likelihood of developing an autism spectrum condition. This is consistent with other studies that have found a link between mathematical talent and number of autistic traits as measured on the AQ (Baron-Cohen et al. 2001b).

The second prediction that this study tested was that any link found between mathematical (systemizing) talent and autism spectrum conditions would reflect *genetic* factors. Specifically, we predicted that the rate of autism spectrum conditions would be higher in the first-degree relatives of mathematicians relative to the first-degree relatives of controls (students in other disciplines). This second prediction was also confirmed: 0.5% of the siblings of the math students had a formal diagnosis of autism spectrum conditions, compared with only 0.1% of siblings of controls. This fivefold difference confirms an earlier finding (Baron-Cohen et al. 1998). Such family evidence now needs direct genetic tests (e.g., using twin studies or molecular studies) as a next step, as well as replication in a larger sample. The rate of autism spectrum conditions is no higher among siblings than the most elevated prevalence rate in the general population of 0.65%. However, the latter rate includes all subgroups on the autistic spectrum, whereas the rate reported among the mathematicians includes just the major subgroups of classic autism, high-functioning autism, and Asperger syndrome. The most elevated estimate of the population prevalence of just these major subgroups is likely to be close to that found among the relatives of the controls in this study (0.1–0.2%). As such, the results may well be indicating that among first-degree relatives of mathematicians, the rate of autism is indeed elevated.

We conclude that a non-mathematician carries the same risk of autism as does any individual randomly selected in the general population (0.2%; Ehlers and Gillberg 1993; Scott et al. 2002), whereas a mathematician carries an increased risk of autism (1.9%). Strong systemizing might be an important aspect of the cognitive phenotype of the genes for autism. Given clues that autism may result from assortative mating (Baron-Cohen and Hammer 1997; Baron-Cohen et al. 1997; Bishop et al. 2004;

Constantino and Todd 2005), future work should test if assortative mating of systemizers in particular carries the highest risk for having a child with autism (Baron-Cohen 2003, 2006a,b).

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