STUDIES OF THEORY OF MIND:

Are Intuitive Physics and Intuitive Psychology Independent?

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Abstract. *According to the framework of evolutionary psychology, the human mind should be considered in terms of its evolved adaptedness to the environment (Karmiloff-Smith, Grant, Bellugi & Baron-Cohen, 1995). Two postulated neurocognitive adaptations are intuitive (or folk) psychology, for inferring social causality; and intuitive (or folk) physics, for inferring physical causality. In this paper we test these two aspects of our causal cognition in children with Asperger Syndrome (AS). To do this, we employ new tests of intuitive physics and intuitive psychology. Results show that children with AS are impaired in folk psychology whilst being superior in folk physics. Future work needs to test if intuitive psychology and physics are truly independent of one another (implying separate underlying mechanisms) or are inversely related to one another (implying a single underlying mechanism for both).*

The Evolutionary Framework

The model guiding this study holds that there are specialized neurocognitive mechanisms that have evolved to enable rapid discrimination of two classes of entity: agents vs. non-agents (Baron-Cohen, 1994; Leslie, 1995; Premack, 1990). This follows from the classical view that in this universe there are only two

Acknowledgments: SBC and SW were supported by the MRC and the McDonnell-Pew Foundation during the period of this work. VS was supported by the Anglia and Oxford NHS. JL was supported by the Isaac Newton Trust. Steve Cooter, Rachel Treadaway, Becky Hannon, and Nic Alexander carried out invaluable pilot studies for this study, as part of their final year undergraduate project, for which we are grateful. We are also indebted to Southlands School, Hampshire, and Wolverhampton Grammar School for their co-operation. Special thanks to Maggi Rigg, Ann Wakeling, and Tony Bennett for opening their schools to us.

kinds of entity: those that have intentionality, and those that do not (Brentano, 1874/1970)[1]. The animate-inanimate distinction doesn't quite cover the intentional/non-intentional distinction in that plants are of course alive, so the distinction is better covered by the concept of agency (Premack, 1990). Agents have intentionality, whereas non-agents do not. This also means that when agents and non-agents move, their motion has different causes (Csibra, Gergely, Biro, Koos & Brockbanck, 1999; Gelman & Hirschfield, 1994). Agents can move by self-propulsion, which we naturally interpret as driven by their goals and desires, whilst non-agents can reliably be expected not to move unless acted upon by another object (e.g., following a collision).

We assume that the task for hominids as information-processors, over millions of years, has been to compute the causes of these two distinct classes of motion rapidly, since to fail to do so would be self-evidently maladaptive. Dennett's claim is that humans from infancy onwards use *folk (or intuitive) psychology* to deduce the cause of an agent's actions, and use *folk (or intuitive) physics*[2] to deduce the cause of a non-agent's movement (Dennett, 1987). Thus, if we see a rock rolling down the hill, and an agent is present then the event could be interpreted as having been caused by an intention (e.g. to throw it, roll it, kick it, etc.,). If no agent is present, the event could be interpreted in terms of a physical causal force (e.g. it was hit by another object, gravity, etc.,). Sperber, et. al., suggest that humans alone have the reflective capacity to be concerned about causality, and that "causal cognition" broadly falls into at least these two types (Sperber, Premack & Premack, 1995).

It may be that aptitudes in folk psychology and folk physics are independent of one another, or are inversely related to one another. The experiments reported below are relevant to these possibilities, since they investigate if some individuals are impaired in their folk psychology but not in their folk physics, and if others show the opposite pattern.

Folk psychology and folk physics may also be under some degree of genetic control. That is, they may comprise modules in a minimally innate sense (Baron-Cohen, 1999). One way one can test if such mechanisms are under some degree of genetic control is by testing for dissociations in individuals who are known to have a genetic disability. In the studies to be reported, we take this approach by investigating folk psychology and folk physics in children with Asperger Syndrome (AS). Before turning to AS, it is necessary to define folk psychology and folk physics, and to consider the evidence from normal development which points to these being "core domains of cognition" (Wellman & Inagaki, 1997).

[1] Intentionality is defined as the capacity of something to refer or point to things other than itself. A rock cannot point to anything. It just is. In contrast, a mouse can "look" at a piece of cheese, and can "want" the piece of cheese.

[2] We use the terms "folk psychology" "intuitive psychology", and "theory of mind" interchangeably. We also intend the terms "folk physics" and "intuitive physics" to be interchangeable.

Defining Folk Psychology and Folk Physics

We define folk psychology as comprising both low-level social perception, and higher-level social intelligence. Low-level here broadly refers to skills present in human infancy (Johnson, 2000). These include being able to judge (a) if something is an agent or not (Premack, 1990); (b) if another agent is looking at you or not (Baron-Cohen, 1994); (c) if an agent is expressing a basic emotion (Ekman, 1992), and if so, what type. It also includes (d) engaging in shared attention, for example by following gaze or pointing gestures (Mundy & Crowson, 1997; Scaife & Bruner, 1975; Tomasello, 1988); (e) showing concern or basic empathy at another's distress, or responding appropriately to another's basic emotional state (Yirmiya, Sigman, Kasari & Mundy, 1992); (f) being able to judge an agent's goal or basic intention (Premack, 1990). Higher-level here refers to skills present from early childhood and which continue to develop throughout the lifespan. These include the following: (i) Attribution of the range of mental states to oneself and others, including pretence, deception, belief (Leslie, 1987). (ii) Being able to recognize and respond appropriately to complex emotions, not just basic ones (Harris, Johnson, Hutton, Andrews & Cooke, 1989). (iii) Being able to link such mind-reading to action, including language, and therefore to understand and produce pragmatically appropriate language (Tager-Flusberg, 1993). (iv) Using mind-reading not only to make sense of others' behaviour, but also to predict it, and even manipulate it (Whiten, 1991). (v) Our sense of what is appropriate in different social contexts, based on what others will think of our own behaviour. (v) Empathic understanding of another mind. In short, it includes the skills that are involved in normal reciprocal social relationships (including intimate ones) and in communication. We recognise that we have defined folk psychology broadly, such that it is unlikely to hinge on a single cognitive process. However, we argue that the domain is quite focused and narrowly defined, namely, ***understanding social causality.***

We define folk physics as comprising both low-level perception of physical causality, and higher-level understanding of physical-causality. Low-level here refers broadly to skills present in human infancy, such as the perception of physical causality (Leslie & Keeble, 1987) and expectations concerning the motion and properties of physical objects. Higher-level here refers to skills present from early childhood and which continue to develop throughout the lifespan. These include concepts relating to mechanics (Karmiloff-Smith, 1992). Like folk psychology, folk physics is unlikely to hinge on a single cognitive process. However, like folk psychology, we argue that the domain is quite focused and narrowly defined, namely, ***understanding how things work.***

Both folk physics and folk psychology have been proposed as "core domains of human cognition" because they share seven features (Carey, 1985; Gelman & Hirschfield, 1994; Sperber et al., 1995; Wellman & Inagaki, 1997). Both domains (1) are aspects of our causal cognition, (2) demonstrate precocity in human infancy, (3) are acquired or develop universally, (4) show little if any cultural variability, (5) have a specific but universal ontogenesis, (6) are adaptive, and (7) may be open to neurological dissociation. The first of these features (causal cognition) is definitional: folk psychology involves searching for the mental or intentional causes behind agentive events, whilst folk physics involves searching for the physical causes of non-agentive event. Evidence for features 2–5 applying to folk physics and folk psychology comes from studies in developmental psychology, reviewed in the next section. The sixth feature (adaptiveness) may not be directly testable but has inherent plausibility and we imagine is non-contentious. The final feature (neurological dissociability) is tested with respect to these two domains in the experiment reported later in this paper.

Developmental Evidence

Folk psychology appears to be present from at least 12 months of age (Baron-Cohen, 1994; Premack, 1990). Thus, infants show dishabituation to actions of "agents" who appear to violate goal-directedness (Gergely, Nadasdy, Gergely & Biro, 1995; Rochat, Morgan & Carpenter, 1997). They also expect agents to "emote" (express emotion), and expect this to be consistent across modalities (between face and voice) (Walker, 1982). They are also highly sensitive to where another person is looking, and by 14 months will strive to establish joint attention (Butterworth, 1991; Hood, Willen & Driver, 1997; Scaife & Bruner, 1975). By 14 months they also start to produce and understand pretence (Bates, Benigni, Bretherton, Camaioni & Volterra, 1979; Leslie, 1987). By 18 months they begin to show concern at the distress of others (Yirmiya et al., 1992). By 2 years old they begin to use mental state words in their speech (Wellman & Bartsch, 1988). By 3 years old they can understand relationships between mental states such as seeing leads to knowing (Pratt & Bryant, 1990). By 4 years old they can understand that people can hold false beliefs (Wimmer & Perner, 1983). By 5–6 years old they can understand that people can hold beliefs about beliefs (Perner & Wimmer, 1985). By 7 years old they begin to understand what not to say in order to avoid offending others (Baron-Cohen, O'Riordan, Stone, Jones & Plaisted, 1999a). With age, mental state attribution becomes increasingly more complex (Baron-Cohen, Jolliffe, Mortimore & Robertson, 1997a; Happe, 1993).

Folk physics is also present very early in human ontogeny as manifested in the infant's sensitivity to apparent violations of the laws of physics. Thus, infants show dishabituation to the unexpected events of larger objects going into smaller ones, objects being unsupported, two objects occupying the same space, one object passing through another, or one inanimate object moving without being touched by another (Baillargeon, Kotovsky & Needham, 1995; Leslie & Keeble, 1987; Spelke, Phillips & Woodward, 1995). That is, even in infancy, humans appear to be sensitive to physical causality. With age, children's understanding of mechanics grows (Karmiloff-Smith, 1992), but again the precocity of folk physics argues strongly for its status as a core domain. The little cross-cultural evidence that exists suggests a similar picture in very different cultures (Avis & Harris, 1991).

These data have been interpreted in terms of two innate, independent modules being part of the infant cognitive architecture: a theory of mind mechanism (ToMM) and a theory of bodies mechanism (ToBy) (Leslie, 1995). A theory of mind takes several years to develop, but a more restricted Intentionality Detector (or ID) (Baron-Cohen, 1994; Premack, 1990) may be part of the starting state of our causal cognition in infancy. The studies reported in this paper are not concerned with whether folk psychology and folk physics are modular systems; rather, they are concerned with these two core domains of cognition in children with Asperger Syndrome. Asperger Syndrome is conceptualised as a variant on the autistic spectrum. This group of children are chosen for two reasons: previous work suggests that a dissociation between these core domains might characterise them; and that this might occur for genetic and neurodevelopmental reasons. We elaborate on these points next.

Asperger Syndrome

Asperger Syndrome (AS) was first described by Asperger (Asperger, 1944), and the descriptions of the children he documented overlapped considerably with the accounts of childhood autism (Kanner, 1943). Little was published on AS in English until relatively recently (Frith, 1991; Wing, 1981). Current diagnostic practice recognises AS as meeting the same criteria for autism but with no history of language or communication delay, and with no cognitive delay (APA, 1994; ICD-10, 1994). Although some studies have claimed a distinction between AS and high-functioning autism (HFA) (Klin, Volkmar, Sparrow, Cicchetti & Rourke, 1995), the majority of studies have not demonstrated any significant differences between these. For this reason we use the term AS (for present purposes) as overlapping with HFA. In the experiment reported below, we test folk psychology and folk physics in these children. But first, why should one suspect a dissociation between these two domains will be found in such individuals?

Since the first test of folk psychology in children with autism (Baron-Cohen, Leslie & Frith, 1985), there have been more than 30 experimental tests, the vast majority revealing profound impairments in the development of their folk psychological understanding. These are reviewed elsewhere (Baron-Cohen, 1995; Baron-Cohen, Tager-Flusberg & Cohen, 1993) but include deficits in: joint attention (Baron-Cohen, 1989d; Sigman, Mundy, Ungerer & Sherman, 1986); use of mental state terms in language (Tager-Flusberg, 1993); production and comprehension of pretence (Baron-Cohen, 1987; Wing & Gould, 1979); understanding that "seeing-leads-to-knowing" (Baron-Cohen & Goodhart, 1994; Leslie & Frith, 1988); distinguishing mental from physical entities (Baron-Cohen, 1989a; Ozonoff, Pennington & Rogers, 1990); making the appearance-reality distinction (Baron-Cohen, 1989a); understanding false belief (Baron-Cohen et al., 1985); understanding beliefs about beliefs (Baron-Cohen, 1989b); and understanding complex emotions (Baron-Cohen, 1991). Some adults with AS only show their deficits on age-appropriate adult tests of folk psychology (Baron-Cohen et al., 1997a; Baron-Cohen, Wheelwright & Jolliffe, 1997b). This deficit in their folk psychology is thought to underlie the difficulties such children have in social and communicative development (Baron-Cohen, 1988; Tager-Flusberg, 1993), and the development of imagination (Baron-Cohen, 1987; Leslie, 1987).

The above evidence points to an impairment in folk psychology, but it says nothing about how circumscribed this is. Does it leave their folk physics intact? Or might their folk physics even be super-developed? We predicted the latter, for reasons explained next.

Autism and Folk Physics

If children with autism had an impairment in their folk physics, this might suggest that the cause of their problems in the intentional domain was a problem in "theory-building" per se (Carey, 1985). However, there are reasons to suspect that not only is their folk physics intact but may even be *superior*, relative to normally developing children.

First, there is no shortage of clinical descriptions of children with autism being fascinated by machines (the paragon of non-intentional systems). One of the earliest clinical accounts was by Bettelheim (Bettelheim, 1968) who describes the case of "Joey, the mechanical boy". This child with autism was obsessed with drawing pictures of machines (both real and fictitious), and with explaining his own behaviour and that of others in purely mechanical terms. On the face of it, this would suggest he had a well-developed folk-physics. The clinical literature reveals hundreds of cases of children obsessed by machines. Parents' accounts (Hart, 1989; Lovell, 1978; Park, 1967) are a rich source of such descriptions. Indeed, it is hard to find a clinical account of autism that does *not* involve the child being obsessed by some machine or another. Typical examples include extreme fascinations with electricity pylons, burglar alarms, vacuum cleaners, washing machines, video players, trains, planes, and clocks. Sometimes the machine that is the object of the child's obsession is quite simple (e.g., the workings of drainpipes, or the design of windows, etc.,).

Of course, a fascination with machines need not necessarily imply that the child *understands* the machine, but in fact most of these anecdotes also reveal that children with autism have a precocious understanding too. The child (with enough language, such as is seen in children with AS) may be described as holding forth, like a "little professor", on their favourite subject or area of expertise, often failing to detect that their listener may have long since become bored of hearing more on the subject. The apparently precocious mechanical understanding, whilst being relatively oblivious to their listener's level of interest, suggests that their folk physics might be outstripping their folk psychology in development. The anecdotal evidence includes not just an obsession with machines, but with other kinds of physical systems. Examples include obsessions with the weather (meteorology), the formation of mountains (geography), motion of the planets (astronomy), and the classification of lizards (taxonomy).

Clinical/anecdotal evidence must however be left to one side, as this may not prove anything. More convincing is that experimental studies converge on the same conclusion: children with autism not only have an intact folk physics, they have accelerated or superior development in this domain (relative to their folk psychology and relative to their mental age, both verbal and nonverbal). First, using a picture sequencing paradigm, children with autism performed significantly better than mental-age matched controls in sequencing physical-causal stories (Baron-Cohen, Leslie & Frith, 1986). The children with autism also produced more physical-causal justifications in their verbal accounts of the picture sequences they made, compared to intentional accounts[3].

Second, two studies found children with autism showed good understanding of a camera (Leekam & Perner, 1991; Leslie & Thaiss, 1992). In these studies, the child is shown a scene where an object is located in one position (A). The child is encouraged to take a photo of this scene, using a Polaroid camera. Whilst the experimenter and the child are waiting for the photo to develop, the scene is changed: the object is now moved to a new position (B). The experimenter then turns to the child and asks where in the photo the object will be. These studies found that children with autism could accurately infer what would be depicted in a photograph, even though the photograph was at odds with the current visual scene. Again, this contrasted with their poor performance on False Belief tests.

These "false photo" tasks (Zaitchik, 1990) closely parallel the structure of the false belief task. The key difference is that in the (folk psychological) false belief test, a *person* sees the scene, and then the object is moved from A to B whilst that person is absent. Hence the person holds a belief that is at odds with the current visual scene. In the false photo task a *camera* records the scene, and then the object is moved from A to B whilst the camera is not in use. Hence the camera contains a picture that is at odds with the current visual scene. The pattern of results by the children with autism on these two tests was interpreted as showing that whilst their understanding of mental representations was impaired, their understanding of physical representations was not. This pattern has been found in other domains (Charman & Baron-Cohen, 1992; Charman & Baron-Cohen, 1995). But the False Photo Test is also evidence of their folk physics outstripping their folk psychology and being superior to mental age (MA) matched controls.

Family studies add to this picture. Parents of children with Asperger Syndrome (AS) also show mild but significant deficits on an adult folk psychology task (the adult version of the "Reading the Mind in the Eyes" task). This mirrors the deficit in folk psychology seen in patients with autism or AS (Baron-Cohen & Hammer, 1997). This familial resemblance at the cognitive level is assumed to reflect genetic factors, since autism and AS appear to have a strong heritable component (Bailey et al., 1995; Bolton et al., 1994; Folstein & Rutter, 1977; Le Couteur et al., 1996). One should also expect that parents of children with autism or AS to be over-represented in occupations in which possession of superior folk physics is an advantage, whilst a deficit in folk psychology would not necessarily be a disadvantage. The paradigm occupation for such a cognitive profile is engineering.

[3] This study however did not involve a chronological age (CA) matched control group, so the apparent superiority in folk physics in autism may simply have reflected their higher CA.

A recent study of 1000 families found that fathers and grandfathers (patri- and matrilineal) of children with autism or AS were more than twice as likely to work in the field of engineering, compared to fathers and grandfathers of children with other disabilities (Baron-Cohen, Wheelwright, Stott, Bolton & Goodyer, 1997c). Indeed, 28.4% of children with autism or AS had at least one relative (father and/or grandfather) who was an engineer. Related evidence comes from a survey of students at Cambridge University, studying either sciences (physics, engineering, or maths) or humanities (English or French literature). When asked about family history of a range of psychiatric conditions (schizophrenia, anorexia, autism, Down's Syndrome, or manic depression), the students in the science group showed a six-fold increase in the rate of autism in their families, and this was specific to autism (Baron-Cohen et al., 1998).

This raises the possibility that the cognitive phenotype of autism spectrum conditions may involve superiority in folk physics alongside a relative deficit in folk psychology, relative of course to MA. In this paper we report an experimental test of the prediction that children with AS will have superior folk physics in the presence of impaired folk psychology.

The Experiment

Subjects

We tested 2 groups of subjects.

Group 1 comprised 15 children (all male) with a clear diagnosis of Asperger Syndrome (AS), defined according to internationally recognised, established criteria (APA, 1994; ICD-10, 1994). They were all attending a special school for Asperger Syndrome (the only one in the UK). This is a residential provision, reflecting the severity of their symptoms and the disruptive impact these had had on their previous schooling and on their family life. They were aged between 8 and 14 years of age, and were all of at least average intelligence. They had all received an IQ test within the previous 2 years, with a standard instrument (WISC-R). Their ages and IQ data are shown in Table 1. They had a range of obsessional interests, consistent with their diagnosis, and these included military tanks, explosives, the periodic table, historical dates, football, electricity, relativity, vehicles, and machines. They had all received a special educational needs statement specifying that they needed special provision as a result of their AS.

Group 2 were pupils attending state primary and secondary schools in Cambridge and Wolverhampton, selected at random. They comprised n=63 male and n=40 female pupils, age range 12–13 (see Table 1), and n=53 children, age 6–10 yrs (see Table 2). The children in the 12–13 yr age group (in Table 1) were given the Folk Physics Test, whilst the children in the 6-10 yr age group (in Table 2) were given the Folk Psychology Test (see below). None had been statemented for having special educational needs. They were not given any IQ test because of time

TABLE 1
Subjects Participating in the Folk Physics Test.

				IQ				
	AGE		VIQ		PIQ		FULLSCALE	
GROUP	x	(sd)	x	(sd)	x	(sd)	x	(sd)
AS (n=15 males)	13.35	(1.18)	102.4	(10.1)	93.6	(8.8)	96.9	(9.9)
Normal								
Males (n=63)	12.4	(0.3)	–					
Females (n=40)	12.8	(0.3)	–					

VIQ=Verbal IQ
PIQ=Performance IQ

TABLE 2
Subjects Participating in the Folk Psychology Test.

				IQ				
	AGE		VIQ		PIQ		FULLSCALE	
GROUP	x	(sd)	x	(sd)	x	(sd)	x	(sd)
AS (n=15 males)	13.35	(1.18)	102.4	(10.1)	93.6	(8.8)	96.9	(9.9)
Normals (n=53)								
6-8 yr. olds								
Males (n=9)	7.3	(0.7)						
Females (n=11)	6.8	(0.6)						
8-10 yr. olds								
Males (n=8)	8.9	(0.6)						
Females (n=6)	9.0	(0.3)						
10-12 yr. olds								
Males (n=9)	11.0	(0.5)						
Females (n=10)	10.7	(0.6)						

constraints but were assumed to have normal intelligence by virtue of their educational placement.

Method

The children with AS were all given two tests:

1. The *Folk Physics Test* (see full test in **Appendix A**): This comprises 20 questions drawn from a variety of sources, with multiple choice format. This was piloted with a range of age groups of normal subjects, revealing meaningful results only above age 10 years. We consider it as a test of folk physics for two reasons. (a) All the problems could be solved from everyday real world experience of the physical-causal world. (b) The teachers of physics in the schools where our subjects were studying confirmed that these problems had not been taught as part of any school curriculum.

Since the folk physics task was visual, as a control test for perceptual processing the children with AS were also give the Raven's Coloured Matrices (Raven, 1956).

2. The *Folk Psychology Test:* this comprised the children's version of the Reading the Mind in the Eyes Test, adapted from the adult version (Baron-Cohen et al., 1997a, 2001). Examples are shown in **Appendix B**. This comprises 28 photographs of the eye region of the face. The subject is asked to pick which of 4 words best describes what the person in the photo is thinking or feeling. The test is the result of piloting with normal children. 3 of the 4 words are foil mental state terms, and the other word is deemed "correct". (See below for how "correct" was established). Position of the 4 words are randomised for each item. This is not simply a complex test of emotion recognition (although it is this in part) because the mental state words included both affective and non-affective (cognitive) mental state terms.

The Eyes task included a control for non-mentalistic social intelligence: the children were asked to judge the person in the photo's gender, from their eyes alone. Mental state words were not displayed on this control task, and instead the words "male" and "female" appeared as a forced choice. This latter control test was given in full to the children with AS, but because of limited testing time with the normal children, just a random selection of 8 items were given to the normal subjects, all of whom performed at ceiling on this control test. While we do not claim that the Gender Recognition task is matched for complexity with the mentalizing condition, it nevertheless involves a (non-mentalistic) social judgement from the eyes, and attention to the relevant stimuli.

Regarding children in Group 2 (normal controls), only children over 12 were given the folk physics test, as piloting showed that prior to this age normal performance is poor. Thus, only children in the age groups 6-10 were given the Eyes test, in order to obtain normative developmental data on this test from this age range.

Results

Folk Physics Test

A one-way ANOVA was used to compare the AS group with the control males and females. There was a significant difference between the groups, $F(2, 117)=30.4$, $p<0.0001$. Post hoc Student Newman-Keuls tests, with significance set at $p<0.05$, indicated that the AS group performed significantly better than both the control males and the control females, who did not differ from each other. See Table 3 for

TABLE 3
Results of the Folk Physics Test: Means and Standard Deviations

GROUP	x	(sd)
AS (n=15 males)	16.3	(3.1)
Normal		
Males (n=63)	10.6	(2.8)
Females (n=40)	9.9	(2.8)

TABLE 4
Folk Physics Test:
Item Analysis (Normal group only)

ITEM	PERCENT OF CHILDREN PASSING ITEM
1	60.4
2	76.4
3	73.6
4	16.0
5	73.6
6	89.6
7	46.2
8	18.9
9	69.8
10	50.0
11	83.0
12	67.9
13	25.5
14	61.3
15	13.2
16	44.3
17	42.5
18	19.8
19	39.6
20	65.1

results. An item analysis was carried out. This did not reveal any specific item was failed significantly more often than any other item, in the AS group. In the normal group, there was more variability. (Table 4 shows the item analysis for the normal group.) On the Raven's Coloured Matrices, the AS group performed in line with (but not significantly above) their mental age (scores, x=30, sd=4).

Folk Psychology Test

The test was first developed to parallel the (revised) Adult Version[4] with 36 items, but using child-level vocabulary. It was piloted on a small group of normal children (n=6) age 8-12, to identify candidate target and foil words. In the larger sample tested here (n=53), all 36 items were screened in two ways. (a) By checking that in all cases the majority of normal subjects (more than 50%) in the 10-12 yr. age group (n=19) identified the target word as correct (more than 10 children out of 19 identifying this word). (b) By checking that the second word most commonly identified was chosen by no more than a third of normal subjects in this age group (i.e. no more than 5 children). This was true for all items analysed below (i.e., for 28 items). The remaining 8

[4] The published version of this test (Baron-Cohen et al., 1997a) has 25 items. The revised version of this test improves on this by having 36 items. "(Baron-Cohen et al, 2001)."

items failed to meet these criteria and were therefore dropped from any further analysis. Table 5 shows the item analysis for these remaining 28 items.

In a test of 28 items, with 4 response options, scoring 9 or more out of 28 is above chance (Binomial Test, $p<0.05$). 4 normal children in the 6-8 yr. age group (all girls) failed to score above chance. In the AS group, 2/15 boys failed to score above chance. A one-way ANOVA comparing performance of the AS group and the 3 groups of normal children on the Eyes Test was significant, $F(3, 64)=16.0$, $p<0.0001$. Post hoc Student Newman-Keuls tests, with significance set at $p<0.05$, indicated that the two oldest groups of normal children scored significantly higher than both the AS group and the youngest group of normal children. This was the only significant difference found in the post hoc analysis. The AS group scored close to ceiling on the Gender Judgement Control Test ($x=25.3$, $sd=0.3$).

TABLE 5
Item Analysis from the Normal Group on the Folk Psychology Test (Data from 10–12 Year Olds Only). Group 3 Correct Answers Shown in Bold
n=19

	ANSWER A	ANSWER B	ANSWER C	ANSWER D
1	26.3	0.0	**57.9**	15.8
2	0.0	5.3	5.3	**89.5**
3	**63.2**	5.3	0.0	31.6
4	0.0	**100.0**	0.0	0.0
5	36.8	**63.2**	0.0	0.0
6	5.3	0.0	**63.2**	31.6
7	10.5	15.8	**68.4**	5.3
8	**78.9**	0.0	0.0	21.1
9	5.3	0.0	0.0	**94.7**
10	21.1	21.1	**57.9**	0.0
11	0.0	**84.2**	0.0	15.8
12	10.5	0.0	0.0	**89.5**
13	**84.2**	15.8	0.0	0.0
14	5.3	**94.7**	0.0	0.0
15	**52.6**	5.3	21.1	21.1
16	**57.9**	0.0	15.8	26.3
17	5.3	0.0	5.3	**89.5**
18	**89.5**	5.3	5.3	0.0
19	5.3	31.6	5.3	**57.9**
20	5.3	0.0	**94.7**	0.0
21	**52.6**	0.0	26.3	21.1
22	0.0	0.0	5.3	**94.7**
23	21.1	**68.4**	0.0	10.5
24	**68.4**	15.8	15.8	0.0
25	15.8	15.8	10.5	**57.9**
26	10.5	5.3	**63.2**	21.1
27	31.6	0.0	**52.6**	15.8
28	5.3	0.0	**73.7**	21.1

TABLE 6
Results of Folk Psychology Test: means and standard deviations.

GROUP	EYES TEST x	EYES TEST (sd)	GENDER CONTROL TEST x	GENDER CONTROL TEST (sd)
AS (n=15 males)	12.6	(3.3)	26.5	(2.3)
Normals (n=53)				
6–8 yr. olds				
Males (n=9)	14.6	(5.1)		
Females (n=11)	12.5	(5.6)		
8–10 yr. olds				
Males (n=8)	18.1	(4.7)		
Females (n=6)	17.7	(3.5)		
10–12 yr. olds				
Males (n=9)	20.2	(2.4)		
Females (n=10)	21.0	(2.4)		

Results are shown in Table 6. An Age by Gender ANOVA in the normal group alone, on the Eyes Scores, found a significant main effect of Age ($F(2,52)=13.9$, $p<0.0001$), with the youngest age group scoring significantly lower on the Eyes Test compared to the older two age groups, who did not differ from each other (Student Newman-Keuls Test, $p<0.05$). There was no effect of Gender ($F(1, 52)=0.3$, $p=0.62$), and no Age by Gender interaction ($F(2,52)=0.6$, $p=0.60$).

Correlation Between Folk Physics and Folk Psychology in AS

A test of correlation between folk psychology and folk physics in the normal group was not possible since different groups of children were given each of these tests. In the group with AS, the two tasks were strongly inversely correlated ($r=-0.63$, $p=0.001$).

Discussion

The experiments in this paper derive from the model that the human brain has evolved at least two independent modes of causal cognition: folk psychology and folk physics. In the extreme case, severe autism may be characterised by almost no folk psychology (and thus “mindblindness”). Autism spectrum conditions come by degrees, so different points on the autistic spectrum may involve degrees of deficit in folk psychology (Baron-Cohen, 1995). We predicted that in those individuals who have no accompanying mental handicap (i.e., whose intelligence is in the normal range), the child’s folk physics would develop not only normally, but even at a superior level. This was tested in a group of children with Asperger Syndrome (AS). This prediction was confirmed: children with AS were functioning significantly above their mental age (MA) in terms of folk physics, but significantly below their MA in terms of folk psychology.

The control tasks in this experiment enable us to conclude that children with AS are not superior in all visuo-spatial tasks (since they were normal but not above average on the Raven's Matrices). On the Eyes Task they were clearly attending to the eyes well enough to judge gender. This pattern of results suggests their understanding in folk physics may represent an islet of ability; and that their difficulties on the Eyes Task may be specifically linked to mind-reading.

We take seriously the notion that this profile in AS (impaired folk psychology, together with superior folk physics) might be partly the result of a genetic liability. This is because AS appears to be heritable (Gillberg, 1991), and because there is every reason to expect that individuals with such a cognitive profile could have been selected for in hominid evolution. Good folk physics would have conferred important advantages to an individual's inclusive fitness (e.g., tool use, hunting skills, construction skills, etc.,), even if that individual's folk psychology skills were less proficient.

Note that a genetic factor could operate in at least two different ways: (a) An individual might have a genetically-based impairment in folk psychology; or (b) a genetically-based talent for folk physics. This second alternative derives from the idea of an independent module for folk physics (Leslie, 1995). It is possible that in autism spectrum conditions we see the *twin* genetic anomalies of impaired folk psychology co-occurring with superior folk physics. But whether the present results reflect (a) or (b) above, or both, such genotypes would lead the individual to spend less time interacting with the social environment, and more time interacting with the physical environment, since he or she would understand the latter better. A gene-environment interaction could then explain why such a brain, developing along an abnormally one-sided trajectory, would lead to a superiority in folk physics.

What is the extra explanatory scope of documenting superior folk physics in autism spectrum conditions, over and above the (now standard) demonstration of a theory of mind deficit in autism? The theory of mind account has been virtually silent on why such children should show "repetitive behaviour", a strong desire for routines, and a "need for sameness". To date, the only cognitive account to attempt to explain this aspect of the syndrome is the executive dysfunction theory (Ozonoff, Rogers, Farnham & Pennington, 1994; Pennington et al., 1997; Russell, 1997). This paints an essentially negative view of this behaviour, assuming that it is a form of "frontal lobe" perseveration or inability to shift attention.

Whilst some forms of repetitive behaviour in autism, such as "stereotypies" (e.g., twiddling the fingers rapidly in peripheral vision) may be due to executive deficits, the executive account has traditionally ignored the *content* of "repetitive behaviour". The current account draws attention to the fact that much repetitive behaviour involves the child's "obsessional"[5] or strong interests with mechanical systems (such as light switches or water faucets) or other systems that can be understood in physi-

[5] Elsewhere (Baron-Cohen, 1989c) we review the argument for why the term "obsession" can only be used in the context of autism with some qualifications. This centers on the traditional definition of an obsession being "egodystonic" (or unwanted). In autism, there is no evidence that the child's strong interests are unwanted. Rather, those individuals with autism or AS who can report on why they engage in these activities report that they often derive some pleasure from them. They are therefore probably egosyntonic.

cal-causal terms. Rather than these behaviours being a sign of executive dysfunction, these may reflect the child's intact or even superior development of their folk physics. The child's obsession with machines and systems, and what is often described as their "need for sameness" in attempting to hold the environment constant, might be signs of the child as a superior folk-physicist: conducting mini-experiments in his or her surroundings, in an attempt to identify physical-causal principles underlying events. Certainly, our recent study of obsessions suggests that these are not random with respect to content (which would be predicted by the content-free executive dysfunction theory), but that these test to cluster in the domain of folk physics (Baron-Cohen & Wheelwright, 1999).

In this paper we have not presented a task analysis of folk physics, and it could be argued that the good folk physics skills seen here are simply an expression of an anomaly previously documented, namely "weak" central coherence (Frith, 1989; Happe, 1996). Weak central coherence refers to the individual's preference for local detail over global processing. This has been demonstrated in terms of an autistic superiority on the Embedded Figures Task (EFT) and the Block Design Subtest (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983; Shah & Frith, 1993). Both of these are interpreted as evidence of good segmentation skills, and superior attention to detail. The latter has also been demonstrated on visual search tasks (Plaisted, O'Riordan & Baron-Cohen, 1998a; Plaisted, O'Riordan & Baron-Cohen, 1998b). The question is whether superior folk physics, like weak central coherence, might simply reflect this superior attention to detail. This is a strong possibility, and merits direct testing in the future. If confirmed, this would not invalidate the usefulness of studying folk physics in autism spectrum conditions. Rather, it may show strong folk physics as an upstream benefit of weak central coherence.

Developing a New Model

If folk psychology and folk physics are independent dimensions it is possible to plot on orthogonal axes possible scores from possible tests assessing these two abilities. Figure 1 provides a visual representation of this model of the relationship between folk psychology and folk physics. It suggests appropriate labels for different possible patterns of scores. The axes show number of standard deviations from the mean. The scale of the diagram is less important than the principle underlying it.

We have used the terms *Balanced Brain, Social Brain, Technical Brain, Extreme Social Brain* and *Extreme Technical Brain* as short-hand to describe these different possible patterns of scores. The terms describe the discrepancy between the folk psychology score and the folk physics score. In the Balanced Brain, there is no difference between scores. In the Social Brain, folk psychology is one or two standard deviations higher than folk physics. In the Extreme Social Brain, this discrepancy is greater than two standard deviations. The same pattern is used for the Technical Brain and the Extreme Technical Brain. In the Technical Brain, folk physics is one or two standard deviations higher than folk psychology whilst for the Extreme Technical Brain, this discrepancy is greater than two standard deviations.

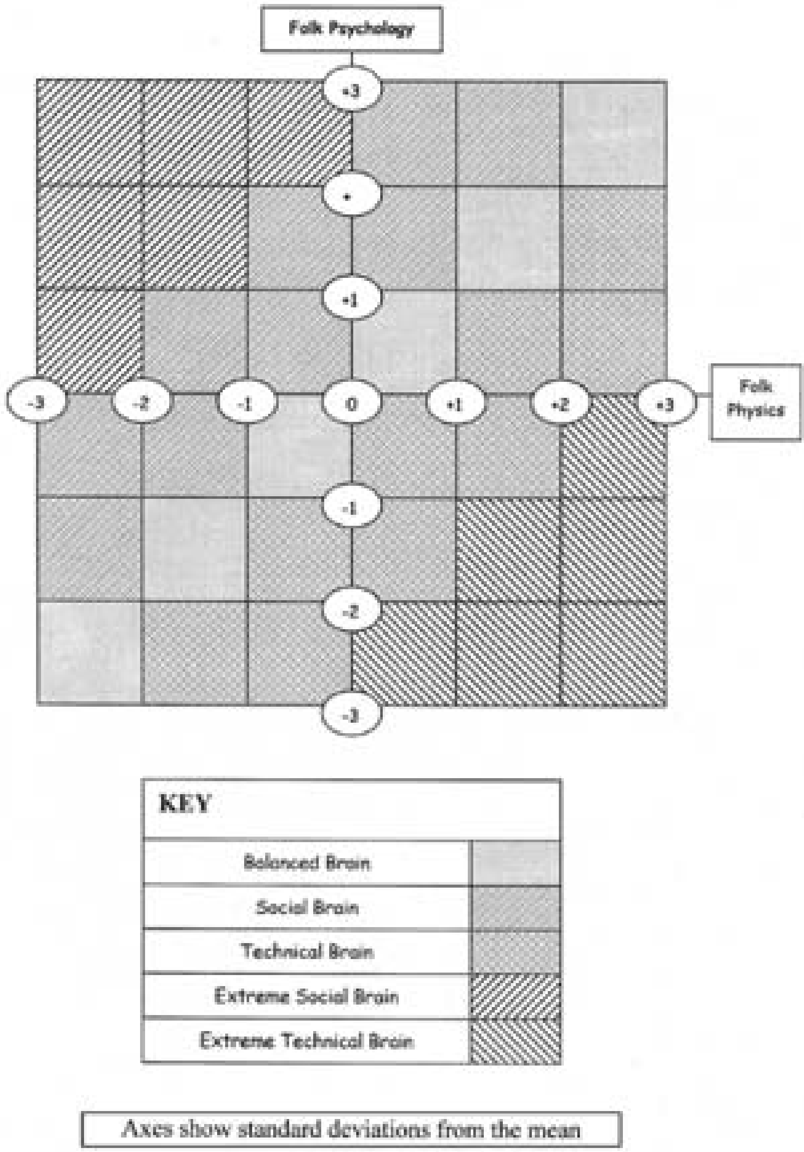


FIGURE 1. Folk psychology–folk physics dimensions.

It is worth underlining the fact that the key point is the discrepancy between the scores rather than the absolute scores themselves. For example, someone could score two standard deviations above the mean on folk psychology (a very high score) but if they scored three standard deviations above the mean on folk physics, they would be described as having the Technical Brain. Thus, the key issue is possible asymmetries of ability.

Our ongoing work is testing this model. If folk physics and folk psychology are truly independent, then it should be possible to find individuals in every square within the diagram (no correlation). If there is some trade-off between abilities in folk physics and folk psychology, then the majority of individuals should have results which fit into the top left quadrant or bottom right quadrant of the diagram (negative correlation). If folk physics and folk psychology abilities are subserved by the same underlying system, then the majority of individuals should have results which fit into the top right quadrant or bottom left quadrant (positive correlation). It is important to clarify that we conceptualise folk physics and folk psychology will both vary with mental age (MA). Therefore, standardised norms will need to be obtained for each level of MA.

Evidence from sex difference research (Kimura, 1992) suggests that the Technical Brain type is more commonly found in males whilst the Social Brain type is more frequent in females. For this reason we can also use the terminology *Female* Brain and *Male Brain types* as synonyms for the Social and Technical Brains, respectively. This claim is also being tested as part of ongoing work, using a wider variety of tests and assessments.

Autism has been described as the extreme form of the male brain (Baron-Cohen & Hammer, 1997). Figure 2 illustrates where we predict the vast majority of people with autism will be located in this (MA-matched) framework. Although this area overlaps with the Extreme Technical brain they are not exactly the same. This is because we predict that people with autism will always score more than one standard deviation below the mean on folk psychology and also that they will always score more than one standard deviation above the mean folk physics. We tested this prediction using the AS group data and control data from above. The scores for the AS group on the Eyes test were transformed to z-scores using the mean and standard deviation from the eldest group of control children (so the children were as closely matched on MA as possible). All the scores from the control children who did the folk physics test were used to produce the mean and standard deviation to standardise the AS group on the folk physics test. Figure 3 shows the relationship between the standardised folk physics and folks psychology scores in the AS group. Note that all but one of the children appear in the bottom right quadrant. Obviously, the number of subjects in this test is limited and in future studies, a battery of tests is likely to be used to make up the folk physics and folk psychology scores. However, this first test of the model is encouraging.

It is important to stress that this approach is in no way diagnostic. We do not intend to imply that someone who scores in the Extreme Technical Brain area should be diagnosed with autism. Rather, we are simply predicting that people with autism are more likely to score in the Extreme Technical Brain area than in any other area.

Figure 2 also illustrates where the contrast case to autism is located. This area is the exact opposite of the predicted autism area, overlapping with the Extreme Social Brain, but not matching it exactly. Some people have speculated as to whether people with Williams syndrome might have the Extreme Social Brain, (Karmiloff-Smith et al., 1995), though this is debated (Tager-Flusberg, Boshart & Baron-Cohen, 1998).

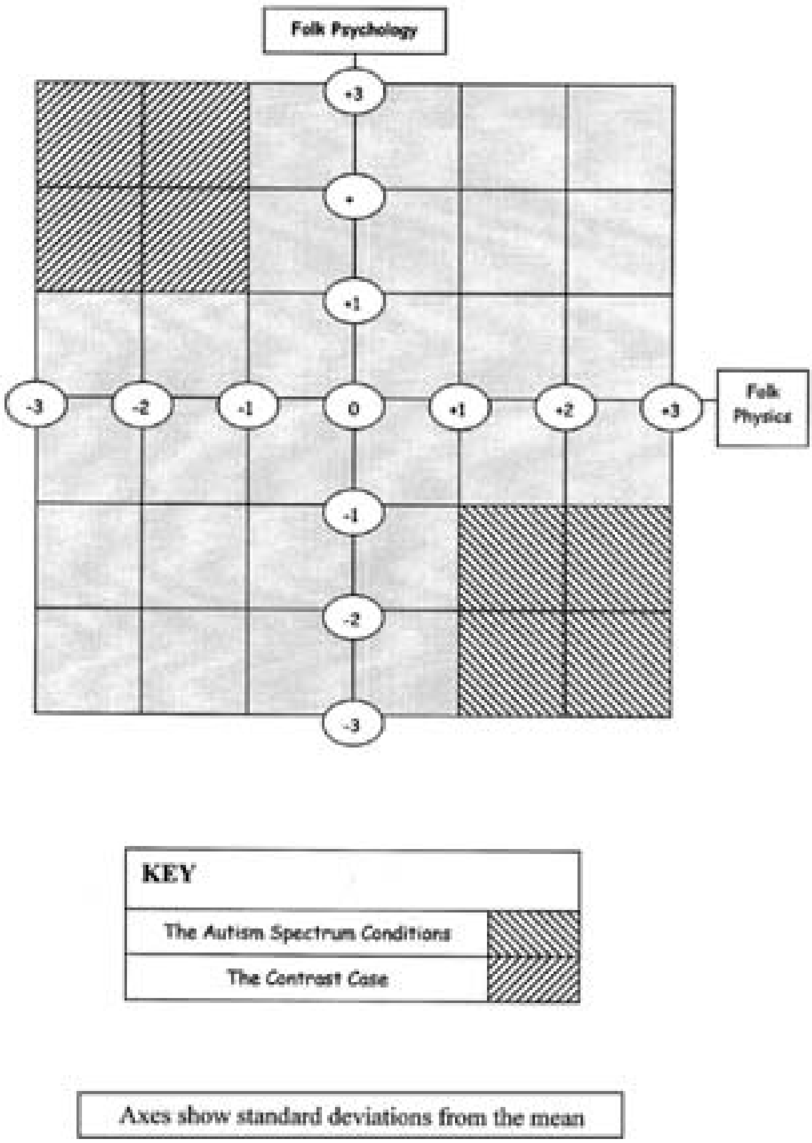


FIGURE 2. The predicted location for autism spectrum conditions and the contrast case.

Note that in the same way that autism can be considered either from the perspective of difficulties (folk psychology) or strengths (folk physics), so can the contrast case. In the latter case, the difficulties are predicted to be in folk physics (we could think of this as technical-blindness) whilst the strengths are remarkable empathy. Such a case is predicted by this model but has not yet been documented. Our ongoing work will go out to test for such cases.

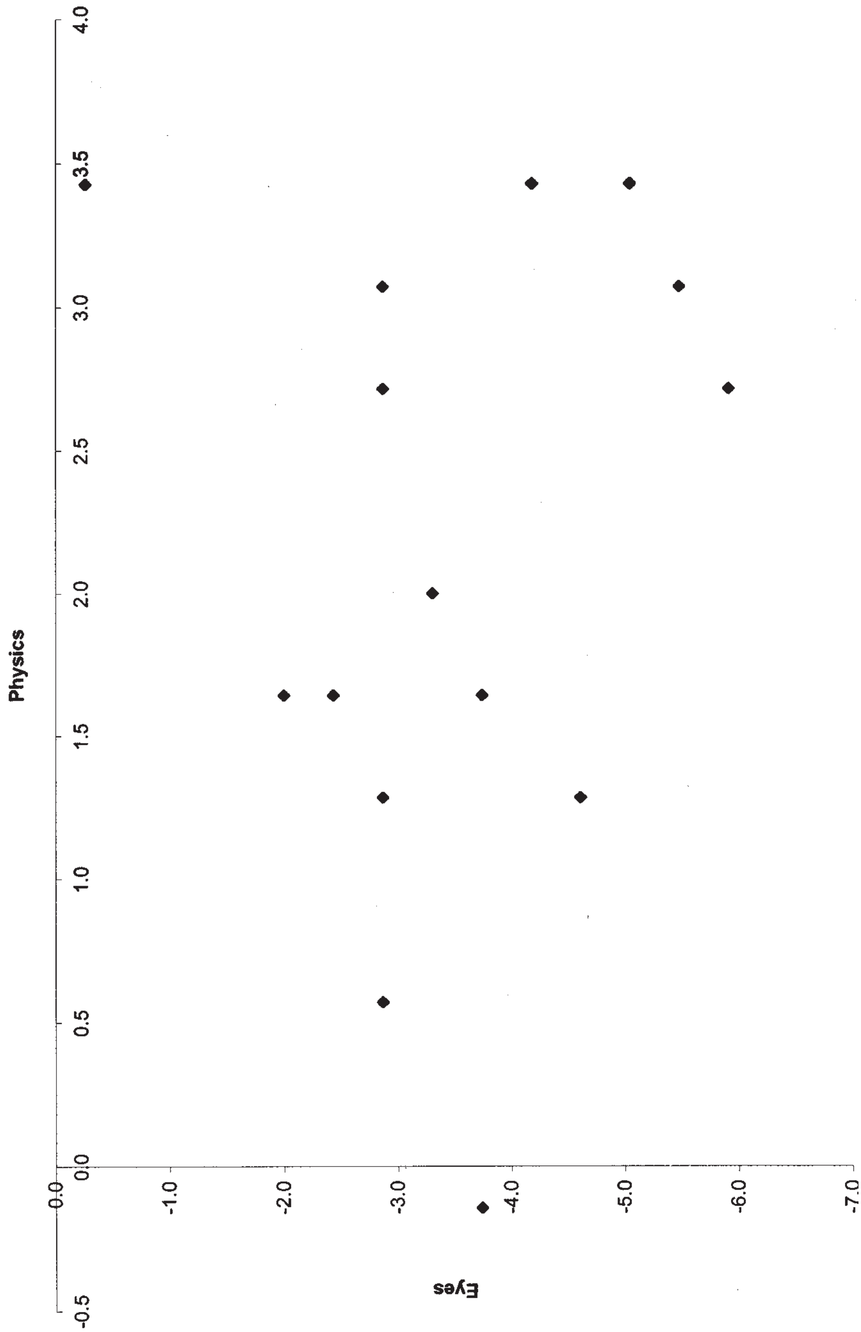


FIGURE 3. Distribution of standardised scores on the physics and eyes tests in the AS group.

Note that the two dimensions of folk psychology and folk physics are conceptualised as independent of IQ. We certainly know of cases in individuals with Asperger syndrome whose IQ is in the superior range but who perform in the low range on empathy (folk psychology) tests (Baron-Cohen et al., 1999c). We speculate that whilst IQ may influence folk physics ability to a greater extent, there may be individuals whose folk physics is out of keeping with their IQ. The children with Asperger syndrome in the above study are an example of this, since they were normal on the Raven's matrices.

This article has focused on folk physics and folk psychology, because they are two forms of causal cognition. As has been discussed by others (Hatano & Inagaki, 1994; Sperber et al., 1995; Wellman, 1990), other universal cognitive domains may also exist. The principal other candidates are folk mathematics (counting) and folk biology (classification of the animate world into species, predators, prey, etc.). We remain to be persuaded that these are independent domains, since it is plausible that folk mathematics is simply part of folk physics, for example. However, in the same way that a deficit in folk psychology should leave folk physics either unaffected or superior in autism, the same arguments should lead to unaffected or superior development of folk mathematics and folk biology in such individuals.

This model of the independence of folk physics and folk psychology (or social and non-social intelligence) also predicts the existence of very high functioning individuals with AS, who may be extreme high achievers in domains such as mathematics and physics–equivalent to Nobel Prize winners even - but who have deficits in folk psychology. Our recent case studies are beginning to identify such very high-functioning individuals (Baron-Cohen et al., 1999c).

In conclusion, the present data suggest folk psychology is impaired in individuals with AS, whilst their folk physics is superior. This is consistent with recent neurological reports of the effects of specific lesions to the amygdala causing specific impairments in social perception (Damasio, Tranel & Damasio, 1990). It is of some interest that using functional magnetic resonance imaging (fMRI) the normal brain shows activation of the amygdala when performing the Eyes Task, whilst individuals with AS show significantly reduced amygdala activity (Baron-Cohen et al., 1999b). Whilst the brain basis of folk psychology is gradually being unravelled, the brain basis of folk physics is as yet unknown.

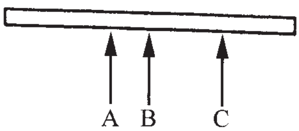
Appendix A: The Folk Physics Test

This section aims to find out whether you can easily understand how things work and function.

Each question has a diagram by it, from which the answer can be worked out. After each question there is a choice of answers. Only one is correct. When you think you have found the correct answer, please indicate your choice by putting a circle around it. An example is shown below.

The section should not take any more than 10 minutes. Please try to answer all the questions as quickly and as accurately as you can, and then enter the *total time taken to complete this section* in the box at the end.

Example

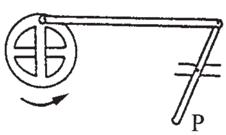


Which arrow will balance the beam?
(a) A (b) B (c) C (d) all equal

NOTE THE TIME BEFORE YOU START!

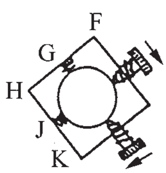
Questions

1.



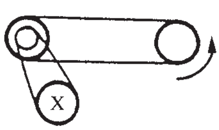
If the wheel rotates as shown, P will
(a) move to the right and stop
(b) move the left and stop
(c) move to and fro
(d) none of these

2.



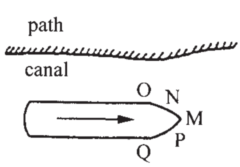
When the two screws are turned the same amount as shown, the ball will move towards
(a) F (b) G (c) H (d) J (e) K

3.

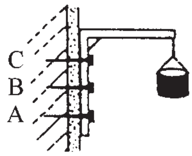


Which way does wheel X move?
(a) either (b) ↶ (c) ↷ (d) stays still

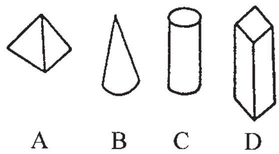
4.



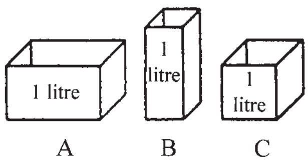
To move the boat easily in the direction shown, the rope would be best attached to
(a) M (b) N (c) O (d) P (e) Q

5. 

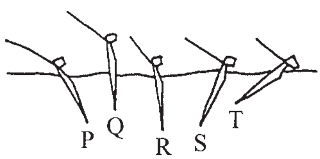
Which nail is most likely to pull out of the wall?
(a) A (b) B (c) C (d) all equally likely

6. 

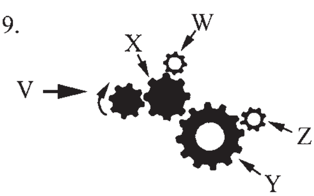
If each block weighs the same, which one will be most difficult to push over?
(a) A (b) B (c) C (d) D

7. 

Which tank will cool the water fastest?
(a) A (b) B (c) C (d) all equal

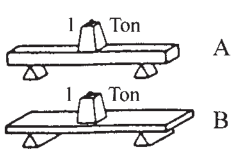
8. 

Which tent peg will give the best hold in soft ground?
(a) P (b) Q (c) R (d) S (e) T

9. 

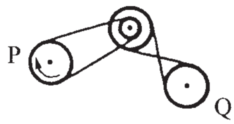
Which gear wheel goes in the same direction as the driver, V?
(a) X (b) Y (c) Z

10. In question 9, which gear goes round fastest?
(a) W (b) X (c) Y (d) Z

11. 

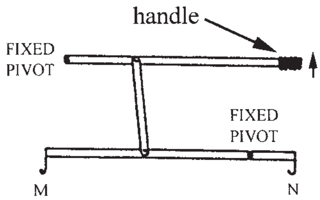
Which plank is more likely to break?
(a) A (b) B (c) either

12.



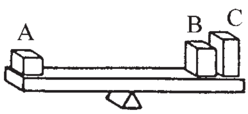
Which way will wheel Q turn when wheel P rotates as shown?
(a) ↶ (b) ↷ (c) either

13.



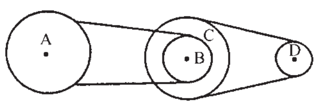
If the handle is moved as shown, how will the hooks M and N move?
(a) M up, N down
(b) M down, N up
(c) M up, N up
(d) M down, N down
(e) M up, N still

14.



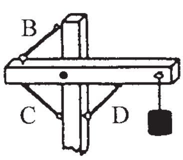
Which box is the heaviest?
(a) A (b) B (c) C (d) all equal

15. The diameter of pulleys A and C is 10cm and the diameter of pulleys B and D is 5cm. When pulley A makes a complete turn, pulley D will turn
(a) once (b) twice (c) 4 times (d) 6 times (e) 8 times



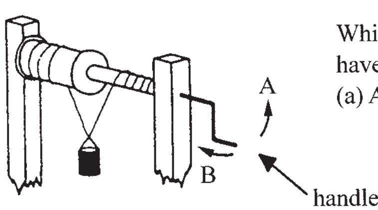
16. If pulley D is the driver, (i.e. pulley D rotates) which pulley turns slowest?
(a) A (b) B (c) C (d) all the same

17.



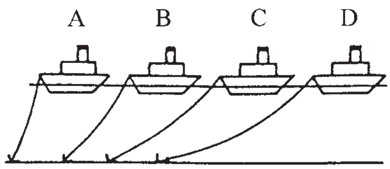
Which chain would support the weight by itself?
(a) any equally (b) B (c) C (d) D

18.



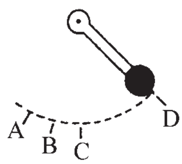
Which way would the handle have to turn to raise the bucket?
(a) A (b) B (c) either

19.



Which boat has the safest anchorage?
(a) A (b) B (c) C (d) D

20.



Where is the pendulum moving fastest?
(a) A (b) B (c) C (d) D

NOTE THE TIME AT THIS POINT

Time taken to complete this section [ ] mins [ ] secs

Appendix B: Folk Physics Test Answers

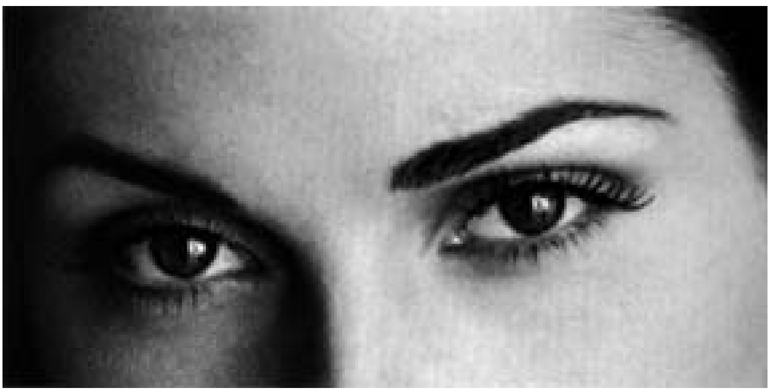
1. c
2. c
3. b
4. b
5. c
6. a
7. a
8. d
9. b
10. a
11. b
12. a
13. a
14. a
15. c
16. a
17. c
18. a
19. d
20. c

Appendix C: Examples from the Children's Version of the Reading the Mind in the Eyes (Folk Psychology) Test (Revised).

1. Female

Correct answer=sure about something

surprised sure about something



joking happy

Appendix C: Examples from the Children's Version of the Reading the Mind in the Eyes (Folk Psychology) Test (Revised).

2. Male

Correct answer=Friendly

friendly sad

surprised worried

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