Evidence for a grammar-specific deficit in children

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Background: Specific language impairment (SLI) is a disorder in which language acquisition is impaired in an otherwise normally developing child. SLI affects around 7% of children. The existence of a purely grammatical form of SLI has become extremely controversial because it points to the existence and innateness of a putative grammatical subsystem in the brain. Some researchers dispute the existence of a purely grammatical form of SLI. They hypothesise that SLI in children is caused by deficits in auditory and/or general cognitive processing, or social factors. There are also claims that the cognitive abilities of people with SLI have not yet been sufficiently characterised to substantiate the existence of SLI in a pure grammatical form.

Results: We present a case study of a boy, known as AZ, with SLI. To investigate the claim for a primary grammatical impairment, we distinguish between grammatical abilities, non-grammatical language abilities and non-verbal cognitive abilities. We investigated AZ's abilities in each of these areas. AZ performed normally on auditory and cognitive tasks, yet exhibited severe grammatical impairments. This is evidence for a developmental grammatical deficit that cannot be explained as a by-product of retardation or auditory difficulties.

Conclusions: The case of AZ provides evidence supporting the existence of a genetically determined, specialised mechanism that is necessary for the normal development of human language.

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Background

Language is a specialised cognitive ability which is uniquely human. Children with specific language impairment (SLI) provide a rare insight into the development of specialised systems in the human brain. SLI is a disorder in which language acquisition is impaired in an otherwise normally developing child; it affects around 7% of children [1]. It is highly controversial whether a purely grammatical form of SLI exists because, if it does, it provides evidence for a genetically determined grammatical subsystem in the brain [2,3]. The controversy surrounds the nature of the interaction between genes and environmental experience in the development of specialised cognitive abilities. Some researchers claim that specialised cognitive systems develop from genetically determined specialised mechanisms, which underlie different domains of cognitive abilities [2,3]. If this is so, a pure primary impairment of a specialised system should exist. Alternatively, other researchers claim that a more general-purpose system underlies specialised cognitive abilities. This general system becomes specialised in the course of processing sensory input [4]. Thus, genes do not directly determine any particular specialised cognitive ability. The implication of this latter position is that a pure impairment of a specialised system should not exist.

Previous research of the large 'KE' family, half of whose members were language impaired, provided support for the genetic inheritance of language impairment [5,6]. Other researchers, however, subsequently disputed how circumscribed the family's 'language impairment' really was [4,7]. They claim that SLI in this family and in children generally is caused by deficits in auditory and/or general cognitive processing, or social factors [1,4,7–11]. Moreover, there are also claims that the cognitive abilities of people with SLI have not yet been sufficiently characterised to substantiate the existence of SLI in a pure grammatical form.

To address this issue, we present a case study of a boy, known as AZ, with SLI. We distinguish between grammatical abilities, non-grammatical language abilities and non-verbal cognitive abilities. Our tests investigated AZ's competence in each of these areas. When testing non-verbal abilities, we paid particular attention to assessing abilities claimed by some to cause SLI.

Results and discussion

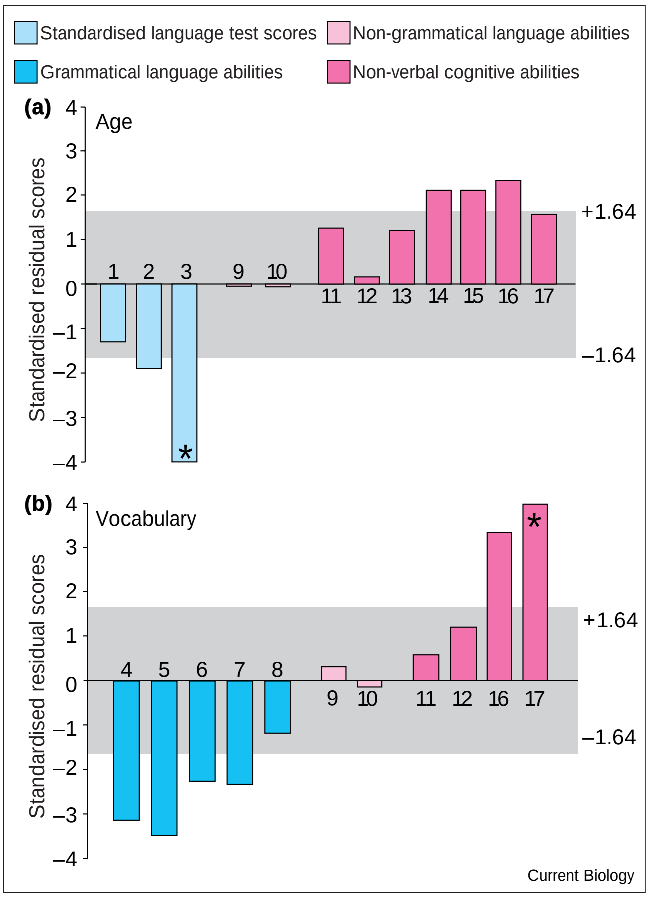
AZ was late in speaking and has received intensive remedial help from four years of age. He appeared normal in non-verbal intelligence, however. An assessment at six years of age revealed a non-verbal intelligence quotient (IQ) of 119 — an above average ability (Figure 1a, test 13). Previous research suggests that language impairment is largely inherited [5,12–14]. AZ's father and paternal uncle reported a history of language impairment. This is consistent with an inherited, genetic basis to AZ's impairment. At the beginning of the study, AZ (age 10 years 3 months) was diagnosed as receptive-expressive SLI using standardised language tests (Figure 1a, scores 1–3). On tests that assess aspects of grammatical and non-grammatical language abilities — such as a test for understanding sentences [15] (for example, 'The boy is pushed by the elephant') and an expressive test of sentence completion [16] (for example, 'There is milk in this glass. It is a glass …') — AZ showed a severe impairment, scoring at a level expected for a child of 5 years 10 months. AZ's comprehension and expression of single word vocabulary [17,18] is less severely impaired; he performed at a level equivalent to a child of 7 years 10 months. A digital tape recording of AZ, analysed by a phonetician, confirmed that his speech is clear and without articulation errors.

The first set of investigations assessed AZ's grammatical abilities; that is, composing or analysing words, phrases and sentences using unconscious combinatorial rules [2,3]. An analysis of AZ's spontaneous and elicited speech revealed that he communicated in short sentences. He frequently made grammatical errors such as omitting the inflection '–s' (for example, 'My mum make_ the breakfast'; 'My dad go_ to work') 70% to 80% of the time, or omitting phrases in sentences (for example, 'The dog was poking [his head] in[-to the jar]'). These grammatical characteristics are not found in his local dialect.

Children from around four years of age use complex or embedded phrases such as 'The small black dog', or 'The cat with the blanket'; subordinate sentences such as 'Can you ask mum if I can have an ice cream?'; as well as grammatically well-formed questions [19]. In a story-telling test [20], AZ did not use such complex phrases or subordinate sentences in 29 sentences at age 10 years 3 months (test score: < 4 years). He used just two subordinate sentences out of 26 sentences at age 12 years 2 months (test score: 4 years 8 months). An elicitation test assessed whether AZ (at age 15 years 6 months) could produce 'who', 'what' and 'which' questions, such as 'Which cat did Mrs White stroke?'. AZ had severe problems producing such questions, with 83% (15 out of 18) of his questions containing grammatical errors, for example omitting 'did' ('Which cat Mrs White stroked?'), substituting 'was' for 'did' ('What coat was Professor Plum weared?') and overusing the '-ed' inflection ('What did Mrs Brown dropp*ed*?'). The overuse of '-ed' shows that AZ is not making the grammatical relationship, needed for the tense marking rule, between the auxiliary 'did' and the verb 'dropped' (compare and contrast, 'What has Mrs Brown dropped?').

Two further experiments compared AZ's grammatical ability with 36 younger control children, aged 5 years 5 months to 8 years 9 months (see Materials and methods). The first, a test of inflectional morphology, assessed his ability to produce the past tense form of 64 verbs, which

Figure 1



AZ's standardised residual scores for the grammatical and non-grammatical language tests and non-verbal tests, computed from the expected score for his **(a)** age and **(b)** vocabulary score [17]. A bar below the shaded area (–1.64, $p < 0.05$) indicates a significant impairment. The standardised language test scores were: 1, British picture vocabulary scale (BPVS) [17]; 2, test of reception of grammar (TROG) [15]; 3, grammatical closure subtest, Illinois test of psycholinguistic abilities (GCITPA) [16]. The tests of grammatical language abilities were: 4, inflectional morphology – real verbs, total correct; 5, inflectional morphology – regular verbs, total correct; 6, inflectional morphology – novel verbs, regular response; 7, syntax test – name–pronoun mismatch condition; 8, syntax test – name–reflexive mismatch condition. The tests of non-grammatical language abilities were: 9, pragmatic inference test – total correct; 10, verbal analogy test – total correct. The tests of non-verbal cognitive abilities were: 11, transitive inference test (TINT) – mean overall reaction time to bars labelled A to E; 12, TINT– mean reaction time to the BD pair of bars in the sequence; 13, British ability scale (BAS) [18] – non-verbal performance (age 6 years); 14, BAS – non-verbal performance (age 12.2 years); 15, Wechsler intelligence scale for children (third edition, WISCIII, UK) [29] – non-verbal performance (age 13.1 years); 16, block design sub-test from the BAS [18] – ability score; 17, Raven's progressive matrices [30] – standardised score. An asterisk indicates a standardised residual score greater than 4.00.

were regular ('look–looked'), irregular ('swim–swam') or novel ('plam–plammed', 'crive–crived/crove') [21]. According to one theory, irregular past tense forms are thought to be learnt and stored in memory, while regular past tense forms are thought to be formed as the result of a grammatical rule: add an '-ed' to the verb stem [22]. Normal speakers use this grammatical rule to form the past tense for verbs they do not know [21,22]. Our children heard two sentences and had to insert the missing word in the second sentence; for example, 'Every day I look/plam at Susan. Yesterday I … at Susan.' [21]. For 30 out of 32 real verbs, AZ produced the unmarked form of the verb ('look', 'swim'). For the novel verbs he produced just one regular past tense form, which was homophonous with a real word ('sheel–sheeled', compare with 'shield'). However, AZ understood the task and an analysis of spontaneous speech revealed that he correctly produced 52 words ending in one of the required final consonant clusters; for example 'grou*nd*', 'fir*st*', 'le*ft*'. The 36 younger control children produced the past tense forms correctly for the majority of the real verbs. They used the grammatical '-ed' rule to form a past tense for the novel verbs approximately 50% or more of the time. AZ's performance is severely and significantly impaired for his age. AZ's failure to produce the past tense ('looked', 'plammed') would not be expected even in much younger children with similar general language scores (Figure 1b, tests 4–6).

The last grammatical test investigates the syntactic knowledge needed for the assignment of reference to pronouns ('him') and reflexives ('himself') in certain kinds of sentences [2]. By around five years of age, children know that in sentences such as 'Mowgli says Baloo is tickling him/himself', 'him' cannot refer to Baloo but may refer to Mowgli. In contrast, 'himself' must refer to Baloo and cannot refer to Mowgli. This grammatical knowledge tells us exactly which person 'himself' or 'him' can or cannot refer to in the sentence. Non-grammatical, pragmatic and semantic knowledge of pronouns and reflexives is less precise. Pragmatic knowledge merely tells us that 'him' or 'himself' may refer to someone already mentioned. The semantic knowledge may tell us the sex of the person. On occasions, non-grammatical knowledge is sufficient to determine who the pronoun or reflexive refers to. AZ had to say whether or not a picture matched a sentence spoken by the experimenter. For two sets of sentences, syntactic knowledge of the grammatical constraints was crucial for the judgements. For a set of control sentences (for example, 'Grandpa says Granny is pinching him' shown with a picture of Granny pinching herself) the non-grammatical knowledge was sufficient to reject a sentence–picture mismatch (for example, 'him' refers to a male, therefore not 'Granny').

When non-grammatical knowledge is sufficient for the judgements, AZ scored 96% correct (46/48). In contrast, when syntactic, grammatical knowledge is crucial for the judgements, AZ's performance did not differ significantly from chance. Figure 1b (tests 7,8) shows that his performance is generally significantly below the control children's performance when syntactic knowledge is required for the judgements. The score in Figure 1b (test 8), which falls just within the expected normal range in comparison to the younger children, is not due to AZ's success on this condition. It is because the very youngest children (aged 5 years 5 months) made some errors (albeit less than AZ) when rejecting a picture for a reflexive sentence ('Mowgli says Baloo is tickling himself') if the incorrect referent ('Mowgli') was carrying out the correct action. To summarise, although AZ understood the task and performed well on the test sentences that do not require knowledge of grammar, he did not have the grammatical knowledge associated with pronouns and reflexives which normally developing children have from the age of four to five years.

The second set of investigations, like the control sentences above, tested AZ's non-grammatical language abilities. We first tested AZ's pragmatic social knowledge of pronouns with a picture storybook. Pragmatic knowledge involves anticipating the knowledge and needs of your listener (intuitive psychology) rather than knowing the grammatical rules of English (grammar system) [3]. For example, it is inappropriate to initially introduce somebody with a pronoun, as in 'Once upon a time *he* had a frog'. From around seven to eight years of age, children know that a person should be initially introduced and reintroduced using a name or noun phrase ('John', 'The boy'), and that pronouns should only be used to maintain reference [23,24]. Our younger control children of less than 7 years 4 months of age incorrectly used a pronoun ('he') to reintroduce as well as maintain reference to the boy in the storybook. On the 12 occasions when AZ used pronouns ('he', 'they', 'it') he correctly restricted their use to maintaining reference. Therefore, when appropriate, he alternated the use of pronouns with noun phrases (for example, 'he' with 'the boy'). This kind of performance could be expected of any socially competent person who can take into account a listener's knowledge. Thus, although AZ lacks grammatical knowledge associated with pronouns, he shows a mature pragmatic social knowledge of pronouns.

The second non-grammatical language investigation tested whether AZ could make a logical inference that required first, an implicated assumption; second, an implicated conclusion; third, modus ponens (if P then Q, P therefore Q); or fourth, modus tollendo ponens (either P or Q, not P therefore Q). Fifty mini-dialogues were staged and recorded by three speakers. The third speaker provided a probe question that required a 'yes' or 'no' answer; for example, Sam: 'Have you ever flown in a helicopter?' Mary: 'I've never flown.' Probe: 'Do you think Mary has been in a helicopter?' AZ's performance (86% correct) was normal compared to the expected performance for his age or vocabulary language score (Figure 1a,b, test 9).

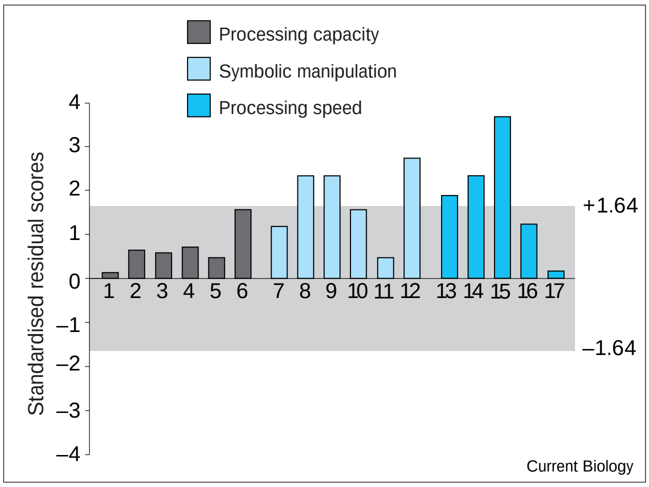
The final non-grammatical language investigation tested AZ's verbal logical reasoning. This task required AZ to apply his general problem-solving powers to language material using conscious reasoning, rather than the unconscious grammatical system. A sentence completion task was used, based on the classical analogy: A is to B, as C is to D; for example, 'kipper is to fish, as cheddar is to …' AZ produced 80% correct responses. Figure 1a,b (test 10) shows that AZ's performance was normal in relation to his age and his vocabulary score. Thus, we conclude that AZ's language impairment is not a primary deficit in non-grammatical language abilities.

The last set of investigations tested whether any non-verbal cognitive or auditory perceptual deficit, thought by some to cause SLI [1,4,7–11], could be found. First, we designed a test of complex structural mapping [25] with processing demands comparable to the grammatical tasks in which AZ fails. The grammatical rules that are problematic for AZ require complex structural mapping. For example, producing the inflection '-s' on a verb ('Mary likes Jill'; compare with 'I like Jill'), requires knowing something about the position of Mary in the sentence (that is, it is in a subject relationship to the verb) and knowing about syntactic properties of this subject noun phrase (that is, it is the third person singular). Visual transitive inference tasks also require a systematic relationship of one structure to another [26].

Our task required the child to judge the relative sizes of five differently coloured bars of increasing size (sequentially designated bars A to E). The BD combination of bars in the sequence, novel in the test phase, required a transitive inference to be made, as both bars were bigger and smaller in relation to other bars. AZ's accuracy overall (90% correct, 36/40), and for the crucial BD combination (100%), was above both his age peers (overall 87%; BD 89%) and language peers (overall 85%; BD 79%). Furthermore, his reaction times (overall 1563 milliseconds; BD 1309 milliseconds) revealed that he was faster than his age peers (overall 2585 milliseconds; BD 2806 milliseconds) and vocabulary language peers (overall 1783 milliseconds; BD 2202 milliseconds) as shown in Figure 1a,b (tests 11,12). Thus, on this test of processing complexity and speed of response, AZ performed normally.

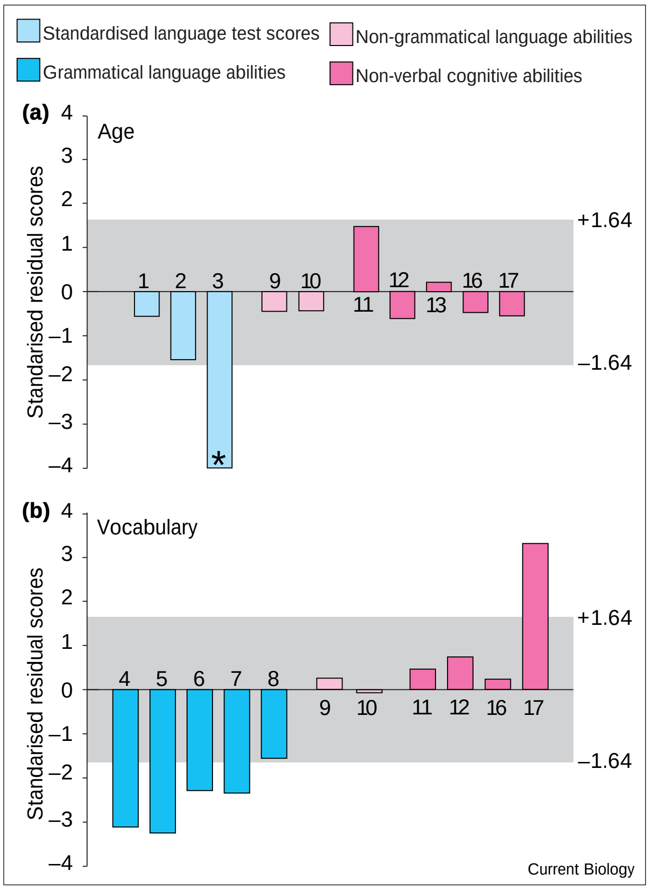
Certain investigators have claimed that SLI is caused by a general slow-down in information processing, including auditory perception, not by a deficit in core grammatical abilities [1,4,8–11]. To test this proposal, we first administered an inspection time task, developed by Anderson and Karmiloff-Smith, which had been adapted to assess information-processing speed in children using visually presented material [27]. AZ's average score on two runs (99, standard deviation (SD) 20.14) put him in the average range in relation to Anderson and Karmiloff-Smith's preliminary analyses of adult subjects (range 27–181, with the majority of subjects scoring between 39 and 113). We also tested AZ's auditory processing on two tasks which have been claimed to distinguish normal children from those with impaired language development [9–11]; firstly, Tallal and Piercy's same/different task with varying interstimulus intervals (ISIs; 8–428 milliseconds) [28] and, secondly, backward masking [10]. AZ (aged 15 years 6 months) showed no errors on the same/different task at any ISI, and his backward masking thresholds — mean 50.4 decibels (dB) sound pressure level (SPL) — were well within the normal range for teenagers (mean 48.6 dB SPL, SD 5.7 dB). AZ's performance thus rules out the possibility of an auditory training programme alleviating any of his grammatical difficulties [9,11].

Figure 2



AZ's standardised residual scores for his age for non-verbal cognitive IQ sub-tests and experimental tests, administered at ages 6, 12 and 13 years. The standardised residual scores are summarised according to three broad areas of non-verbal abilities, hypothesised by some to cause SLI. Tests of processing capacity: 1, BAS – immediate visual recall (age 6 years); 2, BAS – delayed visual recall (age 6 years); 3, BAS – recall design (age 12.2 years); 4, BAS – matrices (age 12.2 years); 5, WISCIII (UK) – coding (age 13.1 years); 6, picture arrangement (age 13.1 years). Tests of symbolic manipulation: 7, BAS – block design, accuracy (age 6 years); 8, BAS – block design, accuracy (age 12.2 years); 9, BAS – visualisation of cubes (age 12.2 years); 10, Raven's progressive matrices (age 12.2 years); 11, WISCIII (UK) – picture completion (age 13.1 years); 12, WISCIII (UK) – object assembly (age 13.1 years). Tests of processing speed: 13, BAS – block design, speed (age 6 years); 14, BAS – block design, speed (age 12.2 years); 15, BAS – block design, speed (age 13.1 years); 16, TINT – mean reaction time (age 12.2 years); 17, TINT – mean reaction time to BD pair (age 12.2 years).

Figure 3



The mean standardised residual scores for six children with SLI (mean age 13 years 1 month) for the grammatical and non-grammatical language tests and non-verbal tests computed from the expected score for each child for his/her **(a)** age and **(b)** vocabulary score [17]. A bar below the shaded area (–1.64, $p < 0.05$) indicates a significant impairment for the children's mean standardised residual score. The key is as described for Figure 1.

Finally, we report the results of full-standardised non-verbal cognitive tests [18,29,30] administered at ages 6, 12 and 13 years. AZ achieved overall non-verbal IQs from 119 to 131, the top 10% of ability for his age (Figure 1a, scores 13–17). Figure 2 summarises the sub-test scores from the standardised IQ tests and our experimental test scores according to the three main areas of non-verbal abilities hypothesised by some to cause SLI [1,4,7–11]. AZ does not show any deficit at any age in these areas, as assessed by this varied test battery (Figure 2).

Current investigations of another six children with SLI are revealing similar profiles [14,24,31]. Consequently, we do not think that AZ is atypical of a subgroup of the SLI population. The group data (Figure 3) show the same dissociation, found for AZ, between grammatical and other cognitive abilities when compared with the expected performance for children of similar ages or vocabulary abilities.

Conclusions

We have provided evidence for a discrete developmental grammatical language deficit. AZ shows no evidence of the auditory or cognitive deficits hypothesised to be responsible for SLI. The results have important implications in two areas. First, they raise the possibility that auditory and cognitive deficits which co-occur with language impairment in some SLI children may not be the cause of the impairment. This has implications for the diagnosis and treatment of SLI. Second, the results argue for the existence of a genetically determined specialisation of a sub-system in the brain required for grammar [2,3] and, it appears, for nothing else.

Materials and methods

Subjects

Each child with SLI (including AZ) was individually matched to one or more control children developing language normally [31] on the basis of chronological age, or vocabulary raw score [17]. There were 12 age-matched control children whose ages (11 years 6 months to 14 years 9 months) and non-verbal abilities as assessed by the block design [18] did not differ statistically from the SLI group. Thirty-six control children (age 5 years 5 months to 8 years 9 months) were statistically matched on vocabulary scores [17]. The 36 younger language-matched control children participated in all the experimental tasks. The age control children participated in the tests of non-grammatical language abilities, and the non-verbal test of visual transitive inference, but were not tested on the grammatical tasks because the eight-year olds were already at ceiling on these tasks.

Data analysis

Using the data for the control children, first-order (linear) or second-order (quadratic) polynomial regressions were carried out as appropriate to predict the expected performance on the experimental tasks based on the children's age or vocabulary score. Prior to each regression, the data were screened for outlying values by computing the Mahalanobis distance for each case. A case was rejected if $p < 0.02$. No more than two outliers were identified and removed in a number of the analyses. Then, for each child with SLI, we computed the standardised residual (SR) score for the experimental tasks according to their age, or vocabulary score [17]. SRs are rescaled raw scores, with a mean of 0 and a SD of 1. The SR tells us how far a subject's score differs from the expected score in SD units for normally developing children. A score of 0 is the expected SR (the population mean) for AZ's age (Figure 1a) or vocabulary score (Figure 1b); 95% of the population falls above –1.64 SD in a normal distribution. The greater the magnitude of the SR score, the lower the likelihood that he would have obtained that score if he had come from a normal population. In normally developing children, most grammatical and non-grammatical language abilities have been acquired by eight years or before. Therefore, we would expect little change between age and vocabulary SR scores on these measures. The use of these tests to assess children with other disorders (for example, autism) has revealed that the tests are sensitive to deficits in the target areas.

The visual transitive inference task was presented on a computer screen. During the teaching phase, adjacent pairs of bars were presented. In the experimental phase, all possible pairings occurred. A randomised prompt, 'bigger' or 'smaller', appeared on the screen and was read by the experimenter. Two bars with their tops hidden by a box then appeared, and the child had to press a key below the bigger or smaller bar. The left/right position on the screen where each bar appeared was also randomised. In the teaching phase, but not in the experimental phase, the box disappeared revealing the true height of the bars. The child was told to respond accurately and as quickly as possible.

The inspection time task [27] measures how long a subject requires to look at two bars presented on a computer screen, and subsequently masked, in order to make a judgement about which bar was the longer. If the subject makes two correct responses in a row, the time the bars are displayed is automatically decreased, and after one error it is increased, in a stepwise function, thus converging on the inspection time which leads to a correct response 71% of the time.

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