Modularity and Innateness: Insight from a Grammatical Specific Language Impairment

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Abstract

The issue of whether our genes have discrete effects on higher cognitive functioning is highly contentious. Do our genes determine domain specific and relatively autonomous (modular) cognitive systems? The grammatical aspects of language is a candidate for one of the specialised systems. Children with a specific language impairment (SLI) have become a test case in this debate. A highly domain-specific grammatical impairment would (if it were true) constitute strong evidence for a genetic effect restricted to Grammar and the modularity of cognitive systems. Here we provide such evidence from a boy (known as AZ) with SLI. AZ exhibits a genetic impairment restricted to domain specific, grammatical abilities.

1. Introduction

The effect of our genes in determining aspects of cognitive functioning that are innately specialized, domain specific, relatively autonomous systems (i.e., modular functions) with their own mechanisms (Chomsky, 1989; Fodor, 1983; Pinker, 1991, 1994) has been challenged by connectionists' views of the organization of the brain (Elman et al., 1996; Seidenburg, 1997). They put forward that cognitive mechanisms are not innately specialised for only <u>one</u> particular domain of human cognition. Moreover, cognitive functions become specialised as the result of processing the input (e.g., Elman et al., 1996; Seidenberg, 1997).

Along with the senses, such as vision, the Grammar is hypothesised to be a candidate for a specialised system (Chomsky, 1986; Fodor, 1983; Pinker, 1994). The grammar is a central part of language but language does not only consist of the grammar. Broadly speaking, the grammar, consisting of the syntax (rules of structuring sentences), inflectional morphology (grammatical rules affecting parts of words, e.g. *jump<u>s</u>,jump<u>ed</u>,jump<u>ing</u>*) and phonology (the rules determining and structuring speech sounds), may be viewed as the core of the specialised language-specific grammatical system (Chomsky, 1986; Pinker, 1994; Smith & Tsimpli, 1995). Pragmatic knowledge (understanding words in their contextual and social environment) and verbal logical reasoning are also part of the language domain. However, they involve interactions with other cognitive functions (e.g. general problem solving abilities) and rely on world knowledge. Thus, these aspects of language are not part of the specialized grammatical language system (Smith & Tsimpli, 1995). Some non-linguistic cognitive abilities and language abilities may appear to place similar processing demands on mechanisms; e.g. in complexity or speed of processing (Bishop, 1997; Tallal et al, 1996). The implication is that similar mechanisms may underlie non-linguistic cognitive abilities and language specific abilities (Elman, et al., 1996). Such cognitive mechanisms would not be part of a uniquely specialized grammatical language system. However, if evidence were found for a genetic impairment restricted to grammar as opposed to language generally or to non-linguistic abilities which share similar processing demands, then this would constitute strong evidence to support genetically determined, domain specific modular cognitive systems (Elman et al., 1996).

Specific language impairment (SLI) is a heterogeneous group of language disorders, impairing language acquisition in an otherwise normally developing child. A genetic cause to this disorder is now generally accepted (Hurst, et al.,1990; Bishop et al, 1995; Rice, 1996; van der Lely & Stollwerck, 1996). The existence of such a syndrome is widely considered by all sides to the debate to be an important test of the modularity hypothesis. However, there is considerable controversy as to whether the impairment effects only the specialised language system (Elman, et al, 1996; Gopnik, 1990; Vargha-Khadem et al., 1995). Therefore it is important to provide the evidence from well-documented cases.

It is apparent that SLI may co-occur with motor-speech disorders (dyspraxia) and other cognitive impairments (Tallal et al, 1996; Vargha-Khadem et al., 1996). However, are there other children with SLI, whose impairment is restricted to the language domain or even, within this domain, only to grammar? Clinicians and researchers have long suspected that there are children like this, but there are no well-validated examples; here we provide one. Our evidence is from detailed investigations of a boy with SLI, known as AZ. AZ is a member of a sub-group of 12 *Grammatical SLI* children (aged between 9:3 to 12:10) that I have studied over 6 years (see, e.g., van der Lely, 1994, 1996,1997). The sub-group has been carefully selected for their clean dissociation between language and other cognitive abilities. These Grammatical SLI children have a strong familial incidence of SLI which is consistent with an autosomal (non-sex linked) dominant genetic inheritance (van der Lely & Stollwerck, 1996). AZ's was selected for his pattern of language impairment, which typifies Grammatical SLI. This study tests whether AZ's language impairment is a language-specific grammatical deficit. We investigate his core language-specific (grammatical) abilities alongside his non-language-specific abilities and non-verbal cognitive abilities which could underlie, or share common mechanisms with his language deficit.

One possible outcome of these investigations is that AZ's pattern of performance across the tasks is similar to younger children developing normally; that is, his development is generally delayed. Alternatively, his performance may fall within the normal range of variability, albeit at the lower level of the range on all language tasks. These outcomes would not provide support for a specialised language-specific system. To test for these possibilities, we compare his performance with 36 younger children, aged 5:4 to 8:9, matched on overall language abilities as measured by standardized tests (see below) (the language controls), and 12 children matched on chronological age, aged 9:4 to 12:10 (the chronological age controls). All the control children were developing language normally.

2. AZ: Background information

AZ is the first of two sons in a family with a reported history of language impairment (Father and paternal Uncle). AZ was late in speaking. At five years old he only used three words. Since this age, with intensive remedial help, AZ has made great progress. AZ was aged 10:3 at the beginning of this study, which was conducted over two years. He communicated in short sentences, which frequently contained grammatical errors such as 70% to 80% of the time omitting the inflection *s* (e.g. *My Mum make_ the breakfast. My Dad go_ to work)*, or omitting whole constituents of sentences (e.g. *The dog was poking* [his head] *in*[-to the jar]). These errors are not found in his local dialect. He did not use any complex phrases, such as *The small black dog.* Subordinate or embedded sentences (such as, *Can you ask Mum if I can have an ice cream?)* are used by children from 4 years of age. In a story-telling test (Renfrew, 1991), AZ did not use any subordinate clauses at age 10:3 (test score, less than 4:0 years) and used only two subordinate clauses at 12:2 (test score 4:8 years). AZ's speech, recorded on high quality digital tape, was analyzed by a phonetician. This confirmed that his speech is clear and does not contain any articulation errors.

An initial assessment of AZ's language abilities was conducted using standardized tests. These standardized tests are not designed to distinguish language-specific abilities from non-language specific abilities. This contrasts with the language tests central to this study reported in the following sections, which enable a differential assessment of language-specific and non-specific language abilities. The standardized tests, however, provide general, overall measures of language functioning and, therefore, appropriate measures for selecting the language control group. On a picture-selection, sentence comprehension test (Bishop, 1983) (e.g. *The boy is pushed by the elephant)* and a sentence completion expressive test of general morphology (Kirk et al., 1968) (e.g. *There is milk in this glass. It is a glass* _______), AZ shows a severe impairment, scoring at a level expected for a child of 5:10. AZ's comprehension and expression of single word vocabulary (Dunn et al., 1982; Elliott et al., 1978) is less severely impaired; he performed at a level equivalent to a 7:10 year old (Fig.1*a*).

If AZ's language were severely delayed, we could expect him to perform at a similar level to the younger language control children on language-specific and non-language-specific tests. Moreover, if non-specific cognitive abilities or mechanisms underlie his language impairment, we may also expect his performance to be similar to the younger children, but worse than his age peers on non-verbal cognitive tasks. This assumes that similar processing functions, such as rapid information processing, for all modalities (e.g. auditory, visual) reflect common cognitive mechanisms in the brain. In contrast, if AZ's language impairment were a deficit of only language-specific abilities, we could expect him to perform below the younger children on language-specific tasks but normally on non-language-specific and cognitive tasks.

3. AZ: Language-specific abilities

We report on two investigations which test AZ's language-specific abilities. The first, a test of inflectional morphology, assesses his ability to produce the past tense form of 60 verbs which were either regular *(look-looked)*, irregular *(swim-swam)* or novel *(plam-plammed, crive-crived/crove)* (Ullman, 1983). The children heard two sentences and had to fill in the missing word in the second sentence, e.g., *Every day I look at Susan. Yesterday I* ______ *at Susan.* AZ understood the task and analysis of spontaneous speech indicated he could

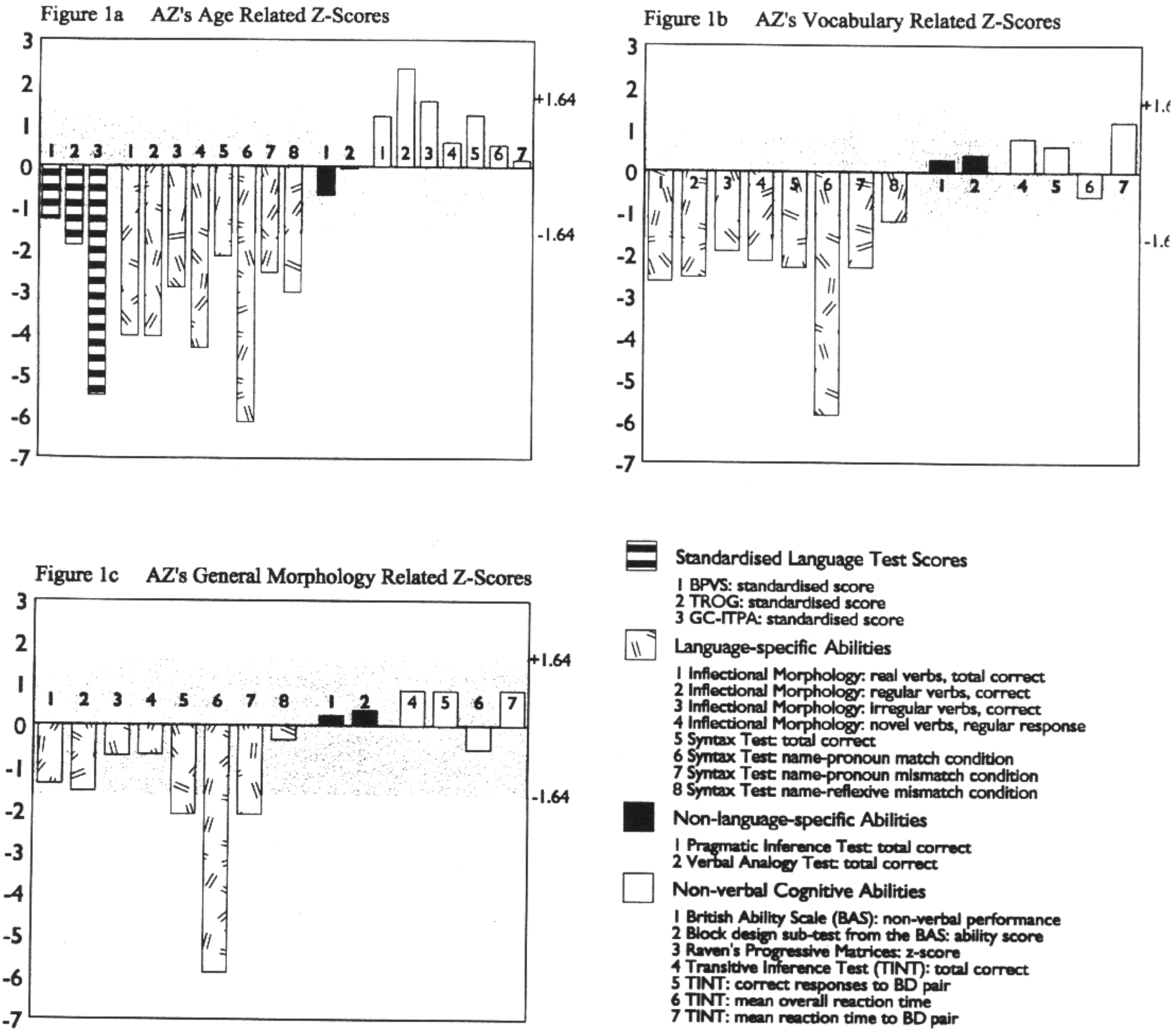

Figure 1: AZ's Z-Scores for the Language-specific, Non-language-specific and Non-verbal Cognitive Tests.

produce the required final consonant clusters (e.g. -*kt*,-*md*). However, for 30/32 real verbs he 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, cf. shield).* In contrast, the 36 language control children correctly produced the past tense forms for the majority of the real verbs. In addition, they were able to use the grammatical -ed rule to form a past tense for the novel verbs approximately 50% or more of the time. Three separate regression analyses were carried out to evaluate AZ's past-tense production in relation to the normally developing children. First, his performance is compared with children of the same chronological age (Fig. 1*a*) and then compared to children with the same vocabulary score (Dunn et al., 1982) (Fig 1*b*) or general morphology score (Kirk et al., 1978) (Fig. 1*c*. It is clear, when AZ's performance is evaluated in relation to his chronological age (Fig. 1*a*), he shows a severe and significant impairment, with z-scores of up to -4.36. Surprisingly, even when AZ's performance is compared to the younger language control children, he still shows a substantial impairment, with Z scores of between -0.7 to -2.6 (Fig. 1*b* & 1*c*). Thus, AZ's failure to produce past tense inflectional morphemes would not be expected even by much younger children with similar overall language performance.

The second investigation of language-specific grammatical abilities tests AZ's syntactic knowledge, which is needed to assign reference to pronouns (*him/her*) and reflexives (*himself/herself*) in certain kinds of sentences. By around 5 years of age, children know that in sentences such as *Mowgli says Baloo is tickling him/himself, him* can not refer to Baloo but may refer to Mowgli. In contrast, *himself* must refer to Baloo and cannot refer to Mowgli. The reason for this is because of two grammatical constraints, one on pronouns, and one on reflexives (Chomsky, 1986; Chien & Wexler, 1990). These grammatical constraints relate to the syntactic structure of the sentence; they have nothing to do with the social or pragmatic context in which pronoun or reflexive is used. Our test used a sentence-picture judgement paradigm. AZ had to say whether or not the picture matched the sentence spoken by the experimenter. For a set of control sentences, the semantic properties of the pronoun or reflexive (e.g., *him/himself* refers to a male referent) were sufficient to reject a sentence-picture mismatch. (Note, this semantic knowledge associated with pronouns is not part of our grammatical, language-specific abilities.) For two sets of sentences, syntactic knowledge of the grammatical constraints was crucial for the judgements.

AZ's overall total number of correct responses is significantly below the expected score, with z-scores around -2.2 based on his age and his general language abilities (see Fig. 1). Interestingly, when semantic knowledge is sufficient for the judgements, AZ scored close to ceiling at 96% correct (46/48). In contrast, when syntactic knowledge is crucial for the judgements, AZ's performance, like the other Grammatical SLI children in this sub-group (van der Lely & Stollwerck, 1997) did not differ significantly from chance. Figure 1 shows that, when language-specific knowledge is required, his performance is generally significantly below his age and language peers' performance. The z-score which falls within the normal range of variability, shown in Fig. 1c, is not due to AZ success on this condition. It is because the very youngest children (aged 5:5) made some errors (albeit fewer than AZ) with rejecting the wrong referent for a reflexive (*himself*) if the referent was carrying out a reflexive action. In addition to accepting wrong referents for pronouns and reflexives, AZ also rejected correct referents for pronouns. AZ's extreme z-scores for this pronoun-match condition (-5.9 or more: Fig. 1) reveal that normally developing children rarely reject correct referents.

Thus, this investigation has revealed that AZ does not have the syntactic knowledge associated with pronouns and reflexives which normally developing children have from age 4 to 5 years. But he understands and performs the task, and gets the answers right as long as they don't require knowledge of grammar.

4. AZ: Non-language-specific abilities

The next set of investigations, like the pronoun control sentences above, tests AZ's non-language-specific abilities. These language abilities have nothing to do with grammar *per se*. For example, pragmatic knowledge involves anticipating the knowledge and needs of your listener (intuitive psychology) rather than knowing the grammatical rules of English (language module).

The first investigation of non-language-specific abilities tests if AZ can make a logical inference which requires either: i) an implicated assumption, ii) an implicated conclusion, iii) Modus ponens (if P then Q, P therefore Q), iv) 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 which required a yes/no answer; e.g., Sam: *Have you ever flown in a helicopter?* Mary: *I've never flown.* Probe: *Do you think Mary has been in a helicopter?* AZ achieved 86% correct responses, indicating that he could generally make the required inference to complete the task. AZ's performance is normal compared to language matched and chronological age matched children (see Fig.1).

The second investigation of AZ's non-language-specific abilities tests his verbal logical reasoning. This task requires AZ to apply his general problem solving powers to language material --it is *metalinguistic*-- using conscious reasoning, rather than the unconscious, natural language system. A sentence completion task was used, based on the classical analogy; A is to B as C is to D. For example, the experimenter said: *Cry is to cried, as look is to* _____. AZ produced 80% correct responses. It is interesting that AZ is able to complete analogies, such as the one illustrated above which involves adding an *-ed* to the verb, even though he omits such inflections in his spontaneous speech and is virtually unable to mark verbs using the same inflection, when the cue for doing so requires grammatical knowledge. Figure 1 shows that AZ's performance is at the expected level in relation to his age, and is above average in relation to his general language scores. Thus, we conclude that AZ's language impairment does not affect non-language-specific abilities.

5. AZ: Non-verbal cognitive abilities

The final set of investigations tests whether any non-verbal cognitive impairment can be found which concurs with, or underlies AZ's language impairment. Standardized non-verbal cognitive tests were administered (Elliott et al., 1978; Raven et al., 1978) These non-verbal IQ tests tap a range of intellectual abilities. For example in one sub-test, the *Block Design* task (Elliott, et al., 1978), the child has to copy pictures of increasing geometric complexity, as quickly as possible, using coloured blocks. Thus, fast visual analytic skills and problem solving abilities among other abilities are required. AZ achieves IQs from 119 to 132 - the top 10% to 1% of ability for his age (Fig 1*a*). Two further tests were administered which were designed to have comparable processing demands to the language tasks in which he was failing. The first task assesses complex structural mapping (Halford, 1987). The language functions, which cause AZ problems, require complex structural mapping; for example, producing the inflection *-s* on a verb (*Mary likes Jill*), requires knowing something about the position of *Mary* in the sentence (i.e. it is in a subject relationship to the verb) and knowing about syntactic properties of this subject noun phrase, (i.e., it is the third person singular). Visual transitive inference tasks also require a systematic relationship of one structure to another (Bryant & Trabasso, 1971); for example, if rod A is bigger than rod B, and B is bigger than rod C, we can infer that A is bigger than C. Thus, knowing about the relative position of the rods and something about their properties is required. In this experiment we use such a task.

Our task required the child to judge the relative sizes of five differently coloured bars of increasing size (bars A to E)[1]. The crucial combination was the BD combination as it was a novel combination in the test phase and both bars were bigger and smaller in relation to other bars. Figure 1 shows that AZ's accuracy overall (92% correct, 36/40), and for the crucial BD combination (100%) is above both his age and language peers. Furthermore, his reaction times overall and for the BD combination reveal that he is as fast, if not faster, than his age and language peers. Thus, on this test of processing complexity and speed of response, AZ performs normally.

Some investigators have claimed that SLI is caused by a slow-down in information processing in general, not by a deficit in core language abilities (Elman, et al., 1996; Tallal, et al., 1996, Leonard et al., 1992). To test this we administered an Inspection Time task, developed by Karmiloff-Smith and Anderson, which had been adapted to children to assess information processing speed (Anderson, 1992)[2]. AZ's average score on two runs (99 SD: 20.14) puts him in the average range in relation to adult subjects. Based on Karmiloff-Smith and Anderson's preliminary analyses of data for normal children at two age groups (8 and 10 year olds), AZ's score falls within the normal range of both groups, approximating most closely the normal range for the 8 year olds.

Together, the tests of non-verbal cognitive abilities have revealed that AZ is functioning in the average to high range of abilities. Thus, there is no evidence for any deficit in general processing mechanisms which could underlie his language impairment.

6. Conclusion

Based on extensive investigations of core language-specific grammatical abilities alongside otherwise comparable non-language-specific and non-verbal cognitive functioning, this study has revealed a discrete, domain-specific, grammatical language deficit. Thus, AZ provides the first clear evidence of a genetic impairment affecting only grammatical abilities. This illustrates the discrete effect that genes may have on specialized higher cognitive systems.

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[1] The Visual Transitive Inference task was presented on a computer screen. During the teaching phase only adjacent pairs of bars were presented. In the experimental phase all possible parings occurred. A randomized prompt, *bigger* or *smaller*, appeared on the screen and was read by the experimenter. Two bars with their tops hidden 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 randomized. 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, as quickly as possible.

[2] The Inspection Time task, developed by Karmiloff-Smith and Anderson, 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, until a reliable inspection time is established for 71% of the time.

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