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REPORT

Modularity, mental retardation and speed of processing

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Abstract

This paper briefly outlines Anderson's (1992) theory of the minimal cognitive architecture underlying intelligence and development and briefly discusses its application to understanding mental retardation and specific cognitive deficits. An experiment on the relationship between face perception and mental retardation serves as an illustration of how the theory might be informative about the relationship between intelligence and cognitive architecture.

Introduction

It is fair to say that cognitive development and IQ have not gotten along well together. Researchers interested in each field have usually adopted different research methods, research philosophies and, crucially, participants. This is a shame. It is a shame because they started off pretty much in the same place. Binet used the increase in cognitive competence with age as the basis of the development of the first mental scale. This, in turn, led to the concept of mental age; a concept taken in one direction by Piaget (towards theories of cognitive development) and another by psychometricians (developing IQ tests).

There is one obvious exception to this standoffish-ness and that is the developmental study of cognitive deficits, where equating for mental age, and in some cases for IQ, has been seen as a necessary control condition. In this paper I want to outline the theory I developed while a member of the MRC Cognitive Development Unit that gives a central role to IQ in understanding cognitive architecture. In addition I will present some illustrative data using an experimental procedure that shows some promise for testing the relationship between IQ and information processing.

The theory of the Minimal Cognitive Architecture underlying intelligence and development (see Figure 1), argues that intelligence tests measure intelligence through assessing knowledge but that knowledge itself is acquired through two different routes and these two routes are differentially related to IQ differences and developmental change (Anderson, 1992).

The first route to knowledge acquisition is through thinking. The theory argues that thought is constrained by the speed of a basic processing mechanism (BPM) and it is this speed that is the fount of general intelligence, or IQ. Speed of processing is hypothesized to be unchanging with development and constitutes, therefore, the innate component of individual differences. The hypothesis that speed of information processing may be the basis of general intelligence is held by many (Eysenck, 1988; Jensen, 1982, 1987; Nettelbeck, 1987; Vernon, 1983). Support for this hypothesis comes from, principally, the correlation between measures of speed of processing such as reaction time and inspection time (IT) and intelligence test performance. In the case of IT (the stimulus exposure duration required by a subject to make a simple perceptual judgement, for example the relative length of two lines), two meta-analyses have estimated the population correlation between IT and intelligence for adults to be around -0.5 (Kranzler & Jensen, 1989; Nettelbeck 1987).

In the theory the second route to knowledge acquisition is through dedicated processing systems called modules, after Fodor (1983). These modules provide complex representations of the world that could not be provided by central processes of thought. The maturation and development of modules is the primary motor of cognitive development but because their operation is hypothesized to be independent of the speed of the basic

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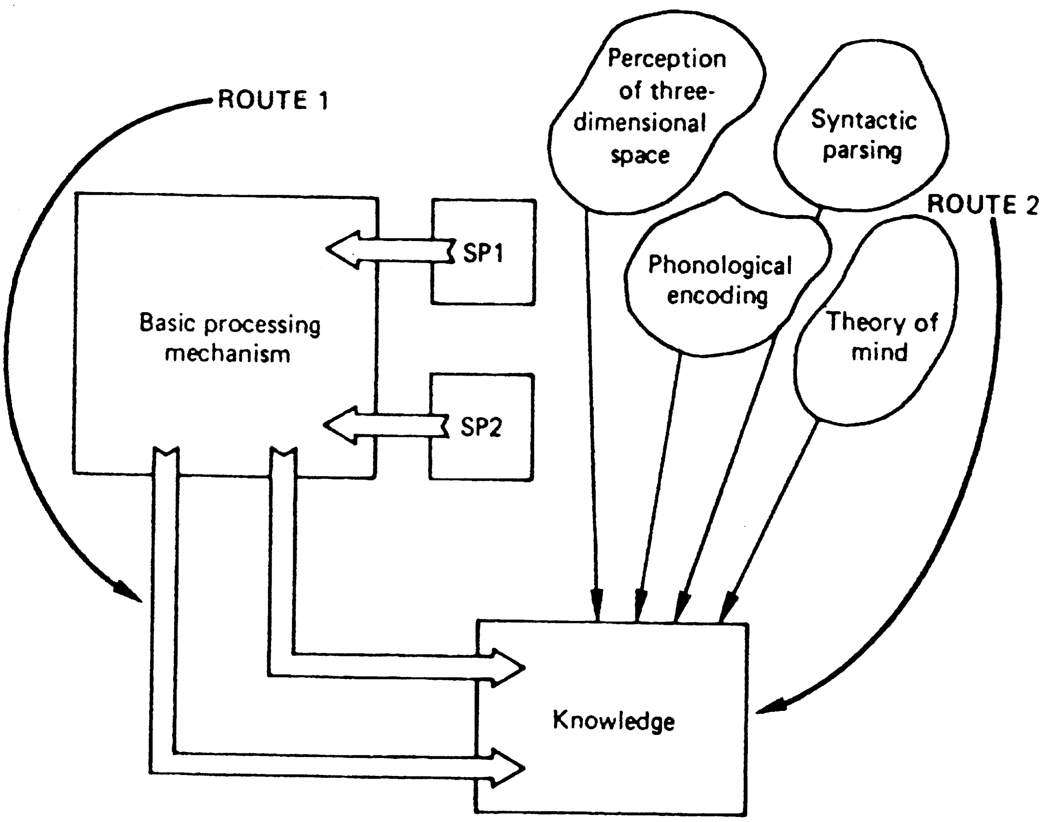

Figure 1 *Two routes to knowledge. Route 1 is through thought and IQ-related. Route 2 is through modules and is IQ-independent. From, Anderson, M. (1992). Intelligence and development: A cognitive theory. Oxford: Blackwell.*

processing mechanism, the knowledge they provide is available to all, independently of differences in IQ. There are, then, two influences on changing knowledge as measured by intelligence test performance (mental age). IQ will influence knowledge acquisition through the constraint on thought imposed by speed of processing. However, knowledge acquisition that depends on the development or maturation of modules will be independent of IQ.

A major goal of the theory is to integrate the construct of general intelligence with attempts to explain patterns of specific deficits and abilities using the distinction between processing that is constrained by the speed of the BPM, and hence related to IQ, and that which is modular, and hence unrelated to IQ. Currently the theory has been applied to autism, savant syndrome and general mental retardation.

If representations are missing because of damage to a module, there will be striking patterns of cognitive breakdown. One hypothesis is that individuals with autism, who mostly have low IQs, have impairments in one or more modular systems (principally, a 'theory of mind' module, Leslie & Thaiss, 1992) but are unimpaired in the speed of the BPM (Scheuffgen, Happé, Anderson and Frith, submitted). Autistics have low IQs because of the general consequences of a damaged crucial cognitive module and not because of slow speed of processing, as is argued to be the case for the generally mentally retarded (Anderson, 1986).

Savant skills present in the otherwise mentally handicapped, are taken as evidence for the independence of modular and IQ related central processes. Isolated skills in art, music, language, spatial processing or memory are taken to indicate the functioning of a preserved module, spared by the global brain damage that affects predominantly the functioning of the BPM (see Nettelbeck & Young, 1996, for a review). Anderson's theory has already been used to explain specific cases of savant syndrome, such as an individual with a low IQ who has learned many different languages (Smith & Tsimpli, 1995), and an individual with a low IQ who can recognise prime numbers (Anderson, O'Connor, & Hermelin, in press).

While general mental retardation is hypothesised to be caused by slow speed of processing (Anderson, 1986), Moore, Hobson and Anderson (1995) have shown that the mentally retarded may be as capable of executing the complex perceptual processes underlying person perception and some aspects of object perception as individuals of normal IQ. In contrast, performance on a simple (but thoughtful) perceptual discrimination that is required by an inspection time task, is impaired in this group relative to normal IQ participants. The following study expands on Moore *et al.*, illustrating how the modularity idea might be tested in a different domain using an improved experimental design that equalizes task difficult across conditions for a 'normal' IQ group.

In Moore *et al.* (1995) the modular and non-modular conditions used quite different stimuli and tasks. In this paper we aim to test whether if the *same* stimulus information is processed by central thought, on the one hand, and by a module, on the other, differences in the former will be related to IQ but in the latter they will be independent of IQ. To do this we use a version of an inspection time task that requires the same perceptual judgment but that evokes a different processing route, one route being through central thought and the other through a module.

As another example of a modular condition we have chosen face processing. There is a great deal of research that suggests that many aspects of face processing may be modular even according to Fodor's original strong criteria. There is evidence that aspects of face perception may be innate and subject to characteristic and specific patterns of breakdown (Moscovitch, Winocur & Behrmann, 1997); may use localized neural structures around the fusiform gyrus in the inferior temporal gyrus (Puce, Allison, Gore, & McCarthy, 1995); and, more problematically, may be informationally encapsulated, at least for early stages of structural descriptions (see Bruce & Young, 1986; Schweinberger, 1996; but see Rhodes & Tremewan, 1993).

In the experiment reported here, participants must make a line-length judgement, as in a standard IT task, under two conditions. In the modular (by hypothesis) condition the lines represent noses embedded in a schematic face. In the other non-modular (by hypothesis) condition the lines are embedded in the same location but within a scrambled face configuration. The difficulty of each process was adjusted prior to testing so that each is of equal difficulty for a group of individuals with normal IQ. If one condition (face) evokes modular processing and the other (scrambled-face) central processing and these are of equal difficulty for a normal IQ group, it is predicted that, relative to a mental age control group, a low-IQ group will show a deficit in the scrambled-face condition only.

Method

Participants

Adolescents of low-IQ, aged between 15 and 17, in special education centres in the metropolitan area of Perth, Western Australia were approached to participate in the study. Participants were individually tested on Raven's Standard Progressive Matrices, a non-verbal test of general intelligence (Raven, 1989). Mental ages (MA) were calculated by adapting the classical formula for IQ ($MA = (IQ^{*}CA)/100$), by first converting raw scores from the Raven's test to age standardized equivalents (or estimated IQs) from the appropriate standardization table. The 12 individuals so selected (mean age = 16 years, 2 months) had a mean estimated IQ of 72 and a mean mental age of 11.65 years. A year six class at a local metropolitan school was then tested on the Raven's test and 12 children with average IQs were selected as the mental age matched group (mean MA = 11 years, 1 month, mean CA = 11 years, 1 month).

Apparatus

The inspection time tasks were run on an IBM-compatible personal computer. A custom built response box measuring 21.5 cm by 11 cm was used by the participants to make their responses. Participants responded 'same' (line-length) by pressing a blue button and 'different' by pressing a red button on the box. Both buttons were 2 × 2 cm. Participants began each trial by pressing one of four grey, same-size, buttons located in a row immediately below the red and blue buttons.

Stimuli and materials

Raven's Standard Progressive Matrices

This is a non-verbal test of general intelligence that requires participants to complete the pattern of a two dimensional matrix of shapes by selecting from a range of alternatives. The maximum score on the test is 60.

Inspection time stimuli

The stimuli for the face and scrambled-face conditions are shown in Figure 2. The backward mask stimulus consisted of the combination of the scrambled and unscrambled faces with the long 'noses', with visual noise added randomly around a randomly chosen subset

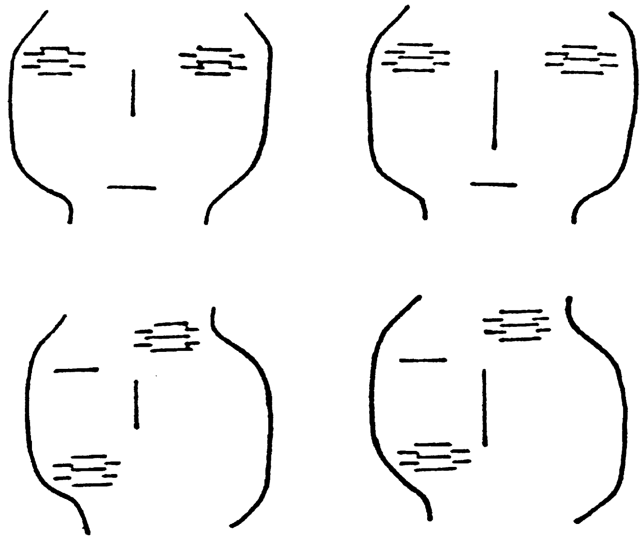

Figure 2 *'Different' Stimuli used in the face (top) and scrambled-face conditions (bottom).*

of pixels that made up the composite image ('bristles' created out of pixel sequences of varying lengths). Because the stimuli differ on more dimensions than 'face-ness' alone (for example the face stimuli could be considered less 'cluttered' and more symmetrical) the logic of the experimental design required that the difficulty level for each of the stimuli be the same for participants of normal IQ. Consequently a number of alternative backward masks with different levels of visual noise (how long each 'bristle' was and how many pixels had 'bristles' attached) were tested in a pilot study using 12 undergraduates as participants. The masks selected for each condition were those that resulted in the most similar inspection times (see below for inspection time procedure) for the face and scrambled-face conditions (mean IT = 78.45ms, and 77.67 ms, respectively).

Design

The experiment used a mixed design with one between groups factor, GROUP (low IQ, mental age matched children) and two repeated measures factors STIMULUS (face, scrambled-face) and PRACTICE (run1, run2).

Procedure

The low-IQ and mental age-matched groups were tested on Raven's Standard Progressive Matrices individually at their respective schools, before attending the IT testing sessions.

The IT tasks were administered in two half hour sessions on consecutive days. Each IT task was administered twice. The order of IT task (face or scrambled-face) was counterbalanced across participants. Before each task participants were taken through a practice session using the same procedure described below but where the minimum exposure duration of the stimuli was relatively long (280 ms).

In the IT task two stimuli (each 3.5 cm square) were presented side-by side in the centre of the screen and the participants had to decide whether the centre lines ('noses' in the face condition) were the same or different lengths. They were told that if they were the same length they should press the blue button on the response box and press the red button if they were different lengths. The computer emitted a 'beep' as feedback for a correct response. To start the next trial they were told to press one of the grey buttons immediately below the red and blue response buttons. A trial sequence consisted a central fixation cross (500 ms) followed by a blank interval (500 ms) followed by the two stimuli for a variable duration followed immediately by the backward mask. Stimulus exposure duration was controlled by varying the stimulus-onset-asynchrony (SOA) of the stimulus and the backward mask using a PEST procedure (Taylor & Creelman, 1967) designed to estimate 70% accuracy of responding. The initial exposure duration used by the PEST procedure was 568 ms (40 screen-frames), the initial step-size was 114 ms (8 frames) and the final step-size was 14.2 msec (1 frame), which is the shortest SOA possible. Participants completed two runs of 100 trials for each task.

Results

Table 1 shows the mean and standard deviations of mental age, IQ, Raven's score and chronological age for the Low IQ and mental age matched groups. Inspection times were calculated for each IT condition by taking the mean of the last four turns in the exposure duration/

Table 1 *Chronological age, mental age, IQ and raw Raven's score for the loow IQ and mental age matched groups*

Group		CA	Mental Age	IQ	Ravens
Low IQ	Mean	16.16	11.64	72	31
	SD	0.38	1.08	7	8
Mental Age Matched	Mean	11.12	11.06	100	42
	SD	0.32	0.58	5	2

trials performance staircase. One subject from the Low-IQ group was designated a clear outlier in all conditions (mean IT = 691 ms; 540 and 842 ms in the face and the scrambled-face conditions, respectively) and was removed from all subsequent analyses.

A three-way ANOVA with STIMULUS (face, scrambled face) and PRACTICE (run1, run2) as within subject factors, and GROUP (Low IQ, mental age-matched normal) as a between subject factor, revealed main effects of GROUP ($F(1,20) = 17.59$, $p < 0.001$), STIMULUS ($F(1,21) = 5.63$, $p < 0.05$), and PRACTICE ($F(1,20) = 68.27$, $p < 0.001$). The predicted 2-way interaction between STIMULUS and GROUP just failed to reach statistical significance ($F(1,20) = 3.48$, $p = 0.08$), there was a large effect of PRACTICE ($F(1,20) = 68.27$, $p < 0.001$). Given that PRACTICE was involved in a significant three-way interaction with GROUP and STIMULUS ($F(1,20) = 5.7$, $p < 0.05$, two-tailed) a further two-way ANOVA was carried out on the second (practiced) IT only. The predicted two-way interaction between GROUP and STIMULUS again just failed to reach statistical significance ($F(1,21) = 3.62$, $p = 0.07$).

Figure 3 reveals that although the expected rise in IT was found for the Low-IQ group in the scrambled face condition it was also found for the face condition. A calculation of the effect sizes showed that using a population standard deviation estimate of 30 ms for normal participants of similar ages on similar IT tasks, the effect size of the scrambled versus the unscrambled face was 2.26 (standard deviation units), which is a very large effect. Even using the more conservative sample standard deviation for the second run (88 ms) the effect size was 0.78, still considered a large effect. The effect sizes for Low IQ versus mental age matched groups in the face condition was 1.86 and 0.64, using each standard deviation respectively, again a large effect.

For the normal IQ mental-age matched group the correlation between Raven's score (reflecting within group differences in intelligence) and IT was −0.39 and −0.44 for the face and scrambled-face conditions respectively. For the low IQ group the correlations were 0.3 and −0.43. Neither of these correlations was statistically significant.

Discussion

The pattern of data is intriguing. First, the hypothesis that the low IQ group would find the face condition just as easy as the mental age matched group can be rejected. However, the hypothesis that the low IQ group would be differentially slowed in the scrambled-face condition received tentative support. The predicted two-way interaction between stimulus condition and group approached significance and the effect size of the face

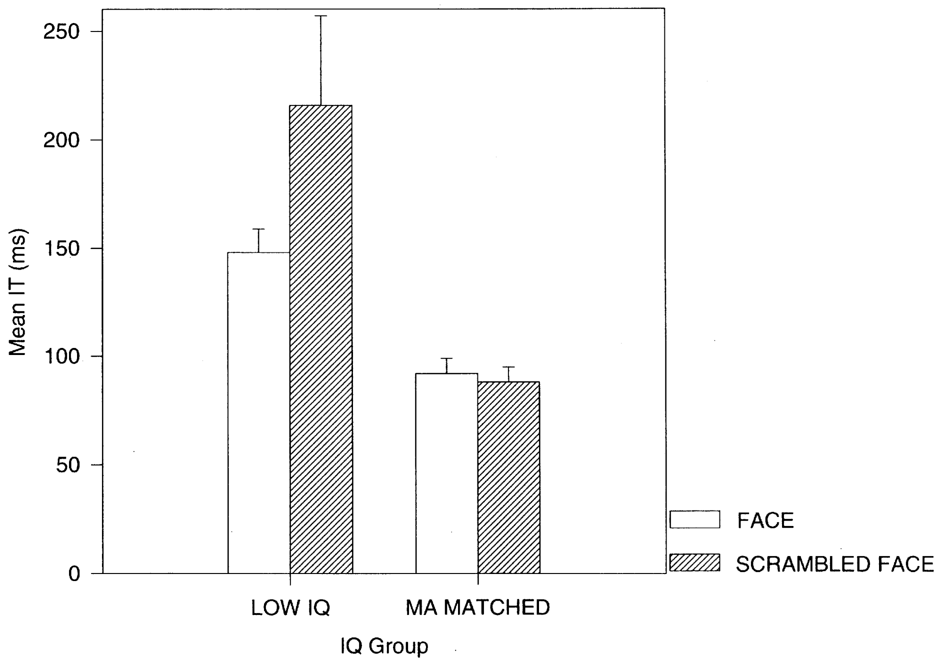

Figure 3 *Mean inspection times (ms) and standard errors for the Low-IQ and the mental age matched groups in the face and scrambled-face conditions.*

versus scrambled-face condition for the low-IQ group (there was no effect for the normal IQ group) suggests that the scrambled-face condition was, as predicted, differentially difficult. Note that because these conditions were equally difficult for the normal IQ group, it is hard to explain this discrepancy without postulating that some processing differences interact with IQ.

There are a number of possible explanations for the particular pattern of data found. First, it might be that the central hypothesis is wrong and that both modular, and non-modular processes are influenced by IQ. But because there appears to be a differential effect of IQ on the face and scrambled-face conditions we would have to suppose that some modular processes are more influenced by IQ than others.

Second, it might also be that the specific requirements of any comparative judgement task may involve central processes that influence performance after modular processing is completed. If this were the case then the face condition would still show an effect of IQ, albeit reduced, because of the modular component to pre-judgement processing.

At least one other possibility suggests itself. Perhaps the face condition for normal subjects did not evoke the face processing module. This would presumably happen if the task was 'easier' to do with central processes. Certainly a feature based search strategy carried out in central processing might be faster than using the output from a face module as the basis of a comparative judgement. But what then of the mandatory nature of a face module? How can subjects choose to ignore that processing route? Remember that the inspection time task uses a mask to prevent further processing of the stimulus. If stimulus exposure duration dropped below that required by a module then the module would not be evoked. Such an effect depends on central processes being fast enough to make the necessary perceptual discrimination. In the case of normal subjects they can make the same feature discrimination in the scrambled face condition at an exposure duration of about 90 ms. The low IQ subjects on the other hand take about 216 ms to make the same judgement. In their case it could be that 'the module' is faster. Indeed if this hypothesis is correct then the face module takes about 150 ms to process the face stimulus. Certainly fast enough to support any ecological function and consistent with data on exposure times that normal subjects (undergraduates) find necessary for face recognition using real faces (Rhodes & Tremewan, 1993). Tentative support for this hypothesis is provided by the correlational data. While none of the correlations were statistically significant, in three conditions the size of the Raven's correlation with the obtained IT (-0.4) was of the order predicted by the standard IT/IQ correlation. Those three correlations were found in both face conditions for normal IQ subjects but only in the scrambled-face condition for the low-IQ subject. In the face condition the correlation (although still not significant) was in the *opposite* direction (0.3) a result never reported for IT/IQ correlations.

Whatever the real reason for these data they suggest that the effect of IQ on face processing may be a promising domain for testing ideas about modularity, intelligence and development.

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