DEVELOPMENTAL STUDIES IN TIMED PERFORMANCE

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SUMMARY

The development of central input processing speed was mapped in the experiments of this thesis within the context of a procedure for measuring Inspection Time (IT). In the first experiment, the central locus of target-mask interaction was verified in a sample composed of 8 and 11 year old children and adults, the results suggesting a developmental increase in processing speed. Experiment 2 replicated this trend, with cross-sectional data confirming a significant decrease in IT between the ages of 6 and 11 years. Developmental change beyond this point was considerably less marked, with some suggestion of an asymptote in rate of processing at the onset of adolescence. These developmental differences were found to be reliable in a test-retest situation, despite a beneficial performance effect associated with practice in all groups. Cross-sequential analyses indicated that IT changes arose independently of cohort (i.e. differences in "life-histories"), while longitudinal change could not be explained purely in terms of practice since improvement over 1 year was significantly greater than improvement over 2 weeks.

Experiments 3, 4 and 5 attempted to ascertain the probable explanation for the developmental trend evidenced in Experiment 2. Experiment 3 indicated that the difference was not attributable to methodological considerations, and that task requirements did not differentially disadvantage younger children. In addition, comparability of performance on random unmasked trials suggested that differences in attention did not appear to significantly influence the results.

Experiments 4 and 5 indicated that at least part of the developmental trend was explicable in terms of age differences in intra-individual variability and, to a lesser extent, registration efficiency. Rate of processing from registration to a central location did not appear to contribute significantly to IT differences. In addition, a third factor, not successfully identified, appeared to contribute to age differences in IT, over and above the factors of registration and intra-individual variability. It was hypothesized that this factor represented a general "noise" variable which prevailed over the entire processing mechanism, thereby limiting its efficiency.

The final experiment (Experiment 6) indicated that the development of processing speed in a nonretarded sample related to maturation (as measured by MA) and efficiency in response style. The relationship between IT and Impulsivity was shown to vary with age, only reaching significance in children with a CA less than 8 years where longer ITs were associated with faster mean latency and higher total errors in the MFF. Within MA groups, IT did not correlate significantly with IQ.

STATEMENT

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University and, to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

I consent to the thesis being made available for photocopying and loan if accepted for the award of the degree.

Carlene Wilson
November, 1984

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CHAPTER 1

INTRODUCTION

Developmental differences in the human information processing system

1. The Development of Information Processing Speed

The notion of man as an information processor, analogous in some sense to a computer, which inputs information, performs certain transformations on this material and outputs a response, has provided a framework in the past four decades for analyzing the nature of human behaviour. Attempts to ascertain the probable components of this system have focussed on two particular performance variables; speed and accuracy.

Concern with the former has directed research to those procedural manipulations which either add to, or subtract from, time taken in the performance of some task. The assumption implicit to this approach is that any "process" performed by the system will take some finite, quantifiable time, most commonly labelled "reaction time" (RT). Accuracy has generally been used in conjunction with measures of time to reflect aspects of processing other than speed. Among these other aspects can be included the degree of caution exercised by the subject or bias for a particular kind of response. In recent years, accuracy rather than simply speed has been increasingly used as the dependent variable. On the basis of these techniques, it has gradually become possible to formulate a fairly detailed model of the human information processing mechanism which identifies stages within the processing sequence and describes their respective functions.

As a consequence, information processing models previously formulated on a purely theoretical basis have been provided with a body of empirical work against which they could be adjudicated. A process directing sensory input has been distinguished from others concerned with encoding, short-term memory, long-term memory, decision, response selection, organization and motor output. Subsequently, attempts have followed to examine the influence of various subject variables upon the functioning of specific components in the processing mechanism. In particular, research has been directed at the possible influence of variables such as mental retardation, mental disorder, and age, upon not only the processing mechanism as a whole, but also upon specific stages within the general model.

(i) Timing Mental Events

The notion that mental events could be timed and that this timing would reflect something meaningful about the nature of cognition has become popular in the latter half of the twentieth century, although Donders had refined a method for calibrating the time characteristics of the mind in 1868. The premise on which his system was constructed can be stated as the belief that the duration of mental events could be computed from the difference between a simple reaction time which involved response speed to a single stimulus when choice was excluded, and the speed of reaction in situations requiring some extra process or processes. This "subtractive" technique provided a means of distinguishing the temporal characteristics of cognitive components within the information processing system.

Donders
1868

Over the years this technique attracted considerable criticism, primarily on the grounds that it oversimplified the mechanisms of the brain. Thus, it was argued that increasing the difficulty of a task may do more than simply add links to the chain of processing events, a belief implicit to the assumption of pure insertion (Pachella, 1974). In an attempt to avoid the problem associated with this model, Sternberg (1969) devised an alternative model of mental chronometry. He maintained that the information processing mechanism consisted of a set number of stages, with total reaction time (RT) equal to the sum of component stage durations. Experimental manipulation was not conceived of as simply adding or subtracting stages but, rather, shortening or lengthening the duration of one or more of the constituent stages of processing. Furthermore interaction, or lack of interaction, between experimental factors in a statistical sense indicated whether they affected a stage in common or not. Thus this approach offered not only the possibility of identifying the existence of stages, but also provided a means for describing their functioning.

(ii) Reaction Time

Interest in group differences in mean RT extends back to Galton (1883) and often since that time such differences have been used to comment upon the comparative efficiency of the information processing systems of various populations. As early as 1894, J. Gilbert in a task involving simple, choice and discrimination RT, showed a negatively accelerating decrease in RT between 6 and 17 years of age. Later studies firmly established that at least part of this difference was due to factors other than motor ability. In succeeding years this developmental result was reproduced numerous times (Bellis, 1933; Jones, 1937; Philip, 1934; Pierson & Montoye, 1958).

In an attempt to localize the source of these performance differences within a neural mechanism, Hazard (1948) undertook a study in which he claimed to show that speed of neural conduction increases gradually with increasing chronological age. The conduction rates at various ages were determined by dividing the length of reflex arc by an average of several records of reflex arc. He concluded that,

> "on the basis of these data we would expect that RT involving reflex and higher neural centres would gradually decrease with age..."
>
> (Hazard, cited in Thompson, 1962, p. 221).

Still other studies have shown that the age - RT function is not limited to any one modality. Goodenough (1935) found that simple auditory reaction time decreased between the ages of 1.5 and 11.5 years, and Mathur (1964) reproduced these results with visual stimuli. Jones and Benton (1963) looked at both the auditory and visual modalities with a sample of nonretarded and educable retarded children, obtaining results which were comparable to those of Goodenough and Mathur and which showed that RT correlated highly with not only chronological age, but also with mental age. It is the generality of RT results which permits one to conclude that decreasing RT occurs concomitantly with the growth of cognitive maturity. Furthermore, the studies of Elliot (1970, 1972) and others suppport the suggestion that developmental reaction time differences reflect cognitive maturation, by illustrating how factors such as attention, motivation and reinforcement all affect performance.

(iii) Localizing Developmental Differences in Specific Temporal Factors

Still other research has been directed at the task of localizing the source of the developmental differences within particular stages or levels of processing. The discovery of age differences in choice reaction time (CRT), the magnitude of which are typically more pronounced than those observed with simple RT, has been interpreted as reflecting the influence of cognitive, decisional components upon speed differences (Jensen, 1982; Surwillo, 1971). Surwillo (1977) correlated the chronological age of 108 boys aged between 5 and 17 years with the log "decision time" (DT), calculated by subtracting each boy's simple RT from his CRT, and produced a significant correlation of -.69.

Using a different procedure to measure speed of decision, Jensen (1982) has also concluded that differences in speed of information processing are located centrally. Jensen calculated decision time by subtracting the movement time (MT) required to register a choice response from overall RT. Subsequently, he found a developmental trend in both DT (which he labels RT) and MT between the ages of 9 and 14. Further, performance on more complex RT tasks (i.e. those involving a greater number of "bits" of information) reflected age differences more clearly than those involving simple RT tasks. Jensen interpreted the stronger relationship between age and RT, compared with age and MT, as reflecting the fact that, "RT is clearly related to a subject's information processing capacity, which increases much more dramatically than motor speed and accuracy between ages 9 and 14." (Jensen, 1982, p. 106).

There is an abundance of other developmental literature which suggests that ontogenetic differences in simple RT are at least partly a product of centrally dictated factors. Dustman and Beck (1966), for example, found that the longer RTs of younger children to visual stimuli could not be explained in terms of evoked potentials since the latency of the initial wave of the evoked potential was not significantly different in groups aged 6 and 16 years. The evidence appears to suggest that at least part of the explanation for the RT results can be explained by reference to the cognitive maturity of the subjects. Elliot (1970), in his extensive comments about preparatory set[1], suggests that RT differences reflect developmental change in readiness to respond to the appropriate stimulus.

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[1] Preparatory set refers to a readiness to respond to the appropriate signal which is measured experimentally as the variation in RT that results from variations in the time between warning signal and target stimulus onset.

Other cognitive psychologists have attempted to specify a stage at which developmental differences manifest themselves. Probably the most comprehensive single study involving this approach has been that of Keating and Bobbitt (1978). Three groups of children aged 9, 13 and 17 years were involved, each of these being divided into equal numbers of subjects with high and low intellectual ability on the basis of their scores on Raven's Standard Progressive Matrices test. Performance on three processing tasks [simple vs choice RT, Posner letter identification (Posner et al., 1969) and Sternberg Memory Scanning (Sternberg, 1969)], was compared across groups. By taking this approach Keating and Bobbitt (1978) hoped to extract interactions of age and/or ability with task performance.

Briefly, the tasks involved the following: A subject's ability to make a binary decision rapidly was tested by comparing RT to a two choice (Red vs Green) decision with simple RT. In the second task, the retrieval of information from long-term memory was examined using Posner's task in which sorting time for letter stimuli based on physical similarity is subtracted from sorting time based on name similarity, with the resulting interval assumed to measure the efficiency of the long-term memory retrieval process. The last measure, concerned with short-term memory scanning efficiency, was derived by use of Sternberg's technique, whereby the subject is presented with a memory set varying in number from 1 to 5 digits. Following the offset of this display a probe figure is presented which must be judged as being either a member or not a member of the original memory set.

The results of this study, although very informative, failed to localize the age-speed difference in one specific function. To the contrary, significant performance differences were observed in all three measures, with younger children requiring more time to make a binary decision, for long-term memory retrieval and exhibiting differences in short-term memory retrieval. [In the latter case the difference was evidenced only in intercept, not in slope, i.e. differences were evidenced in encoding for and the responding to the probe stimulus (Keating & Bobbitt, 1978).]

In retrospect, attempts to specify the exact locus of the frequently observed speed change with age have primarily served to emphasize the degree to which the age-speed interaction dominates all aspects of the processing sequence. Given this fact, the hypothesis can be postulated that developmental differences may also be reflected in the speed of input processing.

2. Perceptual Processing Speed

In general, attempts to examine perceptual processing speed have tended to make use of the experimenter controlled temporal technique. In this procedure the experimenter dictates the time for which stimulus material is available for processing with subject accuracy the dependent variable. The technique is particularly useful in that, unlike reaction time measures, it tends to minimize contamination from criterial factors which can confound processing speed differences.

(i) Display Dictated Demonstrations of Perceptual Persistence

The notion of perception as occupying a temporally dictated "moment" is not new in psychology, with empirical justification for this view taking a variety of forms. Since the late 1960's the concept of the perceptual moment has involved the belief that processing occurs from physical registration into a very short-duration peripheral memory (sometimes termed the "icon" in the visual modality), in which material is held in a literal form for a brief period of time before being encoded into short-term memory.

Among early experimental demonstrations of the existence of some such form of visual store, or positive after-image, was that by Haber and Nathanson (1968; Haber & Standing, 1969). In the task used by Haber, subjects observed a picture through a 1/8 inch vertical slit in a screen which, if held steady, allowed the viewer to see only a narrow band of the picture, thereby making identification impossible. If, however, the picture was held steady and the slit moved rapidly back and forth across the picture, the entire picture suddenly became visible. The explanation was that each glimpse gave rise to an iconic trace, and these traces combined to produce an accurate visual representation in memory because of the persisting nature of perception.

Stanley and Molloy (1975) used this task to investigate developmental differences in visual persistence. In their experiment, estimates of Mean Sweep Time for report of a whole figure, in the form of a camel, fish, horse or duck, were obtained from a sample composed of a group of adults and a group of children aged 10. The results indicated that the children had significantly shorter times than the adults for the perception of the figure (180 ms vs 120 ms).

Another display-based technique termed the "fragmented forms task" was developed by Eriksen and Collins in 1968 for demonstrating perceptual persistence (summarized by Coltheart, 1976). In this experimental format a picture, word or letter is subdivided into dots which form two subpatterns. The stimulus can only be perceived as an integrated form if both subpatterns are presented together in close temporal contiguity. The time interval between presentation of these two patterns is varied until the minimum time is derived at which perceptual integrity and concomitantly, identification, can be achieved. Arnett and Di Lollo (1979) have more recently used this technique to investigate developmental differences in visual persistence in a sample composed of children aged 7, 9, 11 and 13 years. In contrast to the findings of Stanley and Molloy they found no significant variation in the duration of visual persistence across age groups.

(ii) Critical Flicker Frequency and Dark Interval Threshold

Critical flicker frequency has been widely used since the early years of the twentieth century to investigate the nature of perceptual processing. The finding that a light that is physically flickering will appear fused is a further illustration of the notion that perception is dictated in part by an internal clocking mechanism, rather than by external events alone. The main variable determining whether a light is perceived as flickering or fused is the rate of on/off fluctuation. The cycle time at which the subject notes a transition from flickering to fused, or vice versa, is defined as the Critical Flicker Frequency (CFF). The method of measuring this threshold is variable but typically a method of limits is involved with a yes/no response, or a forced choice task at a variety of cycle times.

Results from developmental studies of CFF have proven ambiguous. Misiak (1947, 1951) found a decrease in CFF between the ages of 7 and 89 years, although the difference only became statistically significant after age 55. Cross (1963), who cited a number of studies in which children alone have been used, pointed out the conflicting nature of many of the results (e.g. Hartman, 1934; Miller, 1942; McCormick, 1946; Simonson, Enzer & Blankenstein, 1941; Waters, 1954). She attempted to resolve this conflict in her own study in which she compared 120 boys on the CFF task, 30 each at the ages of 6, 8, 10 and 12 years. Results showed a marked increase in CFF with age, which was interpreted as reflecting increasing retinal efficiency. The decrease in CFF which appears to occur in old age has been variously attributed to, ". . . . a decrease in the flexibility of the ciliary muscles controlling pupil size, increased opacity of the lens, yellowing of the lens, and decrease in responsiveness of the nervous system both with respect to regulation of pupil size, and in general." (Brown, 1965, p. 267).

In recent years, the CFF method has been extensively modified and, in the process, given rise to a new procedure; Dark Interval Threshold (DIT). Pollack (Pollack, Ptashne & Carter, 1969) is one of the principal investigators to use this method, referring to it as a simplified version of CFF in which interflash interval, rather than cycle time, is varied to determine the minimum ISI required for perception of a dark interval. He has argued that this method measures the physiological efficiency of the receptor system, and that individuals who perceive a dark interval at shorter ISIs are exhibiting a better resolution rate for individual flashes.

The DIT technique has been used to distinguish differences in ability arising from both age and intelligence. Pollack et al. (1969) measured the threshold for dark interval detection of 240 children aged between 6 and 17 years. Flash duration was set at 20 ms with interflash interval varied between 0 and 250 ms in 10 ms steps. Results showed that DIT decreased in a linear fashion with increasing age, a finding attributed to physiological aging of the visual receptor system, which was thought to produce diminished persistence of the initial stimulus.

Thor and Thor (1970) continued Pollack's work with the DIT using a sample of 120 subjects varying in age and intelligence. Two flashes were presented at durations of 10 and 30 ms. Results showed that the mildly retarded subjects required longer ISIs to perceive a dark interval than non-retarded children of equal chronological or mental age (CA = 16 years, MA = 10). This result was interpreted by Thor and Thor as indicating that DIT is significantly related to intelligence and that the decrease in threshold with increase in CA is a reflection of a gain in temporal resolution capability.

To summarize, DIT results from children aged between 6 and 17 years have been interpreted as supporting the notion of a developing visual system throughout childhood.

> "The decrease in DIT with increasing chronological age and mental age may be considered an indication of an increase in processing rate or the developmental refinement of a visual system gaining a higher degree of temporal resolution."
>
> (Gollin & Moody, 1973, p. 18).

(iii) Backward Masking Technique

(a) Background

In more recent years, as the nature of the icon has been subjected to more rigorous and sustained speculation, increasingly attention has been focused on a central locus for the icon. Consequently, an approach has emerged which analyses input processing as a neural rather than peripheral phenomenon. Concomitantly the DIT technique has been reapplied within what could be labelled "backward masking" experiments. The methodology of these experiments has been simple. A target stimulus (TS) (usually an alphanumeric figure, a disk, or a geometric shape) is presented to the subject for a very brief duration (less than 100 ms), most commonly by means of a tachistoscope. The TS is followed at offset by a blank field, the duration of which is systematically varied and the luminance of which is, in general, equal to or less than that of the TS. This period, after the offset of the TS and before the onset of the next stimulus, is referred to as the interstimulus interval (ISI). Lastly, a masking stimulus (MS), which is matched to the TS for luminance and may be comparable to the TS in form, or composed of a pattern of random dots and lines, is presented for a fixed duration.

While the methodological foundations from which this technique developed can readily be ascribed to early DIT experiments, its theoretical underpinnings have a different source. The experimental work of Sperling (1960), in which performance on a partial report task was compared with whole report performance, pointed to the existence of a large capacity, short duration memory prior to short-term memory. This store was inferred from the finding that, under partial report conditions where a subject is given a relatively large set of briefly presented stimulus letters to process, but cued to report only a small part of the display, performance is significantly better than when a report of the whole display is required. Sperling argued that this finding suggests that a person may have a more substantial proportion of the initial set available in some form of memory than whole report data would suggest. From this it appeared logical to conclude that a brief visual representation of a display is still available for a short time after the display has been removed.

Experiments by Averbach and Coriell (1961) further defined the nature of this very short-term memory, providing empirical evidence to support the notion that a later arriving figure can "erase" an earlier stimulus. Neisser (1967) combined these two sets of data and coined the term "icon" to describe the phenomenon. From his work and that of later theorists the notion of the icon developed as a short duration, high capacity image distinct from both the visual after-image at the receptor level, and short-term memory. It was conceived of as uncoded and relatively instantaneous in nature. Although most early research involved vision, other studies identified comparable stores in other modalities, specifically "echoic" memory in the auditory modality. It was argued that the icon emerges at the onset of the stimulus and persists for a set time thereafter in either the presence or absence of the inducing figure, provided that no other figure is presented within a certain critical time interval. This time interval has been widely interpreted as being a measure of the speed of perceptual processing.

Wide acceptance of this basic theoretical formulation has resulted in the emergence of a vast body of research literature comparing the performance of various populations on backward masking tasks. Among these populations can be included those distinguished by retardation, schizophrenia, reading difficulties, and age. An implicit assumption underlying this work is that by measuring the time interval beyond which the presentation of a MS has no deleterious effect on the recognition accuracy of a TS, it is possible to measure processing speed. The dependent variable in such studies is usually operationally defined as the critical interval between target and mask onset, at which masking produces a specified decrease or increase in recognition accuracy. While this has occasionally been referred to as Mean Masking Interval, it is most commonly known as critical Stimulus Onset Asynchrony (SOA).

(b) The Nature of the Processing Controversy:

Although acceptance of the notion of an icon has been extensive, controversy surrounding the issue has been pronounced and varied. While a minority group have questioned the very existence of the image (Haber, 1983), others have disagreed on its nature and others, its locus. A large part of the debate has centred on the manner in which the masking figure interacts with the target to affect processing.

Holding (1970, 1972, 1973) who has used the partial report technique to investigate the icon, has concluded that iconic memory is a spurious construct and that all existing data can be explained without any necessity to refer to a very short-term memory. He argued this on the basis of three types of data: firstly, a failure to find partial report superiority; secondly, guessing strategies on the part of the subject which affect the amount of "decay"; and lastly, a failure to find decay with unfamiliar material.

Support for Holding's conclusions has been minimal although recently one of the prime instigators of iconic research has come to believe that an image-like, very short-term memory is not essential to the human information processing model. Thus, Haber (1983) has argued that the concept of an icon is useless in normal perception.

> "Since the visual world that provides stimuli for perceptions is continuous and not chopped up by tachistoscopes, and since our eyes and heads are rarely motionless, no realistic circumstances exist in which having a frozen iconic storage of information could be helpful."
>
> (Haber, 1983, p. 1)

The rejection of the notion of the icon has not gone unchallenged. Coltheart (1975) has analyzed Holding's paper in detail pointing to some logical inconsistencies in his argument and the procedural ambiguities which give rise to difficulty in data interpretation. Furthermore, Coltheart argues that absolute rejection of the notion of an icon would make it impossible to account for the phenomena observed in the following:
(a) Averbach and Coriell's results; (b) direct investigations of visual persistence; and (c) integration and interruption effects in backward masking (Coltheart, 1975). Coltheart (1980) has subsequently developed his own model of visual persistence based on an extensive reappraisal of existing empirical data. According to this model, three forms of visual persistence are identifiable: neural, visible and informational. Neural persistence exists as continuous activity at the photoreceptor level and at various stages in the visual pathway after stimulus offset.

Visible persistence takes the form of a visual image which persists for some period of time after target offset. It is dependent upon neural persistence at both the photoreceptor level and high levels in the visual pathways. Coltheart further argues that this form of persistence is not restricted to a peripheral locus, citing data from stereoscopic studies of perception to support the contention that visual persistence also occurs at the cortical level.[1] Thus visible persistence cannot be distinguished on the basis of locus, existing in a variety of forms from the retina to higher neural centres. The feature of visible persistence which does distinguish it from informational persistence (see below) is its two fundamental properties. These consist of: the "inverse duration effect" whereby "the longer a stimulus lasts, the shorter is its persistence after stimulus offset," and the "inverse intensity effect" according to which, "the more intense the stimulus, the briefer its persistence." (Coltheart, 1980, p. 183. cf. Turvey's (1973) multiplicative rule.)

In contrast to visible persistence, informational persistence does not depend upon the energy characteristics of the physical target. It is hypothesized to be most directly measurable by the partial report technique, being the only true iconic memory. Although dependent upon input from the visual system it is not intimately linked to processing going on in the visual system. Instead, it can be thought of as a cognitive process, rather than a visual image, storing information about the nature of the target figure after physical offset. The form of this information is visual in nature, involving such attributes as colour, and is also pre-categorical, containing no semantic or phonological data. However, the locus of this persistence is undoubtedly central in the Coltheart model.

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[1] Studies of perception have shown that the effect of stereopsis is dependent upon the existence of both monocular and binocular persistence. Monocular persistence explains why a second member of a stereo pair must be presented within 80 ms of the offset of the first, in order to generate a stereoscopic sensation. Once this stereoscopic picture has been presented, it will remain visible for up to 300 ms as a form of binocular persistence without having to re-present the component members. (Engel, 1970).

Attempts by Coltheart and others to specify the locus of the icon, and by implication masking effects, have resulted in fairly heated debate. While it is commonly assumed by many experimental psychologists that the masking produced in their own work has a central source, the theoretical discussions on this issue make this assumption questionable. For example, Barbara Sakitt (1976) has argued strongly that the icon

> ". . . is predominantly a rod phenomenon in normal subjects . . . [and that] . . . all or most of iconic storage is located in the photoreceptors in the retina." (p. 257).

Although Sakitt's interpretation would be a minority view it does illustrate the possibility of a fundamental inadequacy in studies that assume the icon to be a central phenomenon.

In a similar manner, the nature of the effect of the mask upon the target also requires clarification in the face of existing confusion. The notion that a "visual image" exists at two levels, both peripherally and centrally has implicit in it the notion that masking can also occur at two locations. The two-level interpretation as developed by Turvey (1973) has gained considerable acceptance.

The peripheral image is probably most sensibly viewed as a form of visual persistence which is energy dependent, resides in activity along the afferent visual pathway, and is retinoptically organized (Breitmeyer, Kropfl & Julesz, 1982). Integration may occur when two temporally contiguous stimulus figures summate to form an image which reduces the perceptual clarity of both because of the composite nature of the resultant picture.

The central, iconic image is generally believed to be a form of cognitive store - a very short-term memory which is unprocessed in nature. The image is hypothesized to be spatiotopically[1] organized and time, rather than energy, dependent. As a consequence of this dependence on temporal factors, masking at this locus appears to involve the process of "interruption". According to this mechanism, the arrival of a second stimulus within a critical time period following the onset of the first will serve to redirect attention and processing capacity to the later arriving figure, interrupting processing of the former and thereby affecting perceptual accuracy. The general conclusion, in the context of a two-level model of persistence, is that masking will elicit either interruptive or integrative effects depending upon the nature of the figure, target duration, and the interval between target and mask onset (Kahneman, 1968; Scheerer, 1973).

The distinction between the two masking locations, and more particularly the two mechanisms of masking, is not always as clear cut as the above account implies. Turvey (1973) has argued that while peripheral masking always involves an integrative mechanism, central masking takes a variety of different forms and can result from: integration through common synthesis, interchannel inhibition or stimulus replacement. These processes will be described in more detail in Chapter 2 but the important point coming out of Turvey's work to note here is that peripheral masking, by virtue of the fact that it is energy dependent, is best characterized by a multiplicative rule (refer to Chaper 2, Equation 2.1, p. 38) while central masking depends upon the time interval elapsing between target and mask onset and is consequently better described by an additive equation (Equation 2.2, p. 38).

Although the belief in two mechanisms of masking is well established in the literature, it has been questioned by Felsten and Wasserman (1980).

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[1] A 'spatiotopic' image is one that involves a mapped, stable representation of the world (Breitmeyer, Kropfl & Julesz, 1982).

They cite, firstly, a number of studies showing that neural integration can produce time dependent effects on masking and, secondly, other psychophysical studies which indicate that integration alone can account for all masking phenomena.

The issues outlined above are intended only as a brief survey of the controversies associated with the input processing area. The purpose of their inclusion here is to illustrate the complex nature of the issues and the confusion existing over the question of the structure and function of input processing mechanisms. Furthermore, they demonstrate the need for caution when interpreting results obtained with a backward masking procedure and, in particular, when drawing inferences about the locus and nature of masking effects.

(c) Developmental Results

Unfortunately a large number of Backward Masking studies have failed to authenticate the central nature of the input processing mechanism. However, in spite of interpretational difficulties which this fact gives rise to, the research does appear to support the existence of a developmental component to input processing speed, similar in character to that observed in the other paradigms described in the preceding sections.

Backward masking results have been summarized for groups distinguished on the basis of age and intelligence by Ross and Ward (1978). Other relevant material is discussed by Saccuzzo and Michael (1982) who have centred their interest on schizophrenia. In the chronologically ordered discussion to follow, it will become obvious that out of a wide body of procedurally varied experiments, the majority can be viewed as supporting the existence of a developmental component in speed which asymptotes during adolescence and which is amenable to explanation by reference to a variety of different theories.

Pollack (1965) is widely cited as being the first to use the backward masking technique within a developmental context. In a sample composed of children aged 7, 8, 9 and 10 years, he found that the Mean Masking Interval (defined empirically as the mean of the 16 midpoints between ISI's eliciting reports of detection and non-detection), decreased monotonically with increasing age. Spitz and Thor (1968) replicated this finding using letters as stimuli, with a sample of retarded subjects and nonretarded children. These two studies provide support for the interpretation offered by Ross and Ward (1978), that perceptual processing speed is slower among younger children since their perceptual accuracy is consistently more adversely affected by the imposition of a masking figure than are their older contemporaries. Furthermore, the Spitz and Thor results suggest that processing speed may relate to MA rather than to CA.

Liss and Haith (1970) attempted to control for such nonprocessing variables as task comprehension and motivation. They included a forward masking condition in their experiment, arguing that nonprocessing variables, if significant, should influence performance in both forward and backward masking conditions. Thus any age differences in the latter, over and above differences in the former, could be attributed to differences in the ability to encode from the icon. Although their results showed a significant difference in the accuracy of the perception of a 20 ms stimulus between groups aged 4 to 5 years, 9 to 10 and adults, they concluded that there was no relationship between processing speed and CA. Instead they argued that the results reflected a comparative advantage in the older subjects in the use of subtle and partial cues as well as the possession of a more efficient processing strategy.

Other researchers have shared Liss and Haith's reluctance to interpret development differences in performance as a reflection of differences in absolute input capacity. Instead, it has frequently been proposed that functional, strategic differences provide the most satisfactory explanation for performance differences between younger children and their older controls. Shiengold (1973), in an experiment which attempted to analyse developmental differences in intake capacity, concluded that while capacity does not change, performance differences arise at other points in the sequence of human information processing events, possibly at those points involving visual memory.

Blake (1974) has been another to share Liss and Haith's belief in the functional source of developmental differences. In what was a fairly complex experimental procedure, she presented children at a range of ages with an array varying in size. Her subjects were required to make either a partial or whole report at a number of different ISIs. For each group, the TS duration was set as the minimum value at which recognition accuracy was at a specified high level, in an attempt to control for the possibility that backward masking results were an artifact of inadequate recognition durations. Although no significant main effect for age was found in the single item array condition, developmental differences were observed under the multiple array condition. These results led Blake (1974) to conclude,

> "Under the full report conditions, all subjects showed a parallel-processing strategy as array size increased from one to two items, but four-year-olds did not apply this strategy, as efficiently as older subjects." (p. 133)

Welsandt, Zupinck and Meyer (1973) have suggested that ontogenetic differences might be explained in terms of environmental factors. They hypothesized that experience can account not only for their own experimental results, but possibly for those of other backward masking studies. Essentially, their argument was that the increasing experience with the environment which mirrors maturation provides the child with an ever-increasing repertoire of skills for dealing with the environment, and that this process may even affect performance on backward masking tasks.

Gummerman and Gray (1972) have disputed the environmental viewpoint, postulating that age-dictated differences in the speed at which perceptual stimuli can be processed can be localized in the nature of the icon. This conclusion was drawn not only from a re-interpretation of past work but also from their own experimental evidence. Their study incorporated two masking conditions. The first involved a pattern mask[1], while the second entailed the use of a "white mask" which was operationally equivalent to a no-mask condition. The TS figure was exposed tachistoscopically for durations of 70 and 10 ms under the respective conditions. Results showed that all children performed at least as well as the adults in the no-mask situation where all were allowed unrestricted processing time, suggesting that they were as accurate as the adults when perceiving briefly presented stimulus figures. In the pattern mask condition, however, developmental performance differences were observed, comparable to those of other backward masking studies. The disparity between the results obtained under the two conditions persuaded Gummerman and Gray to conclude that the iconic storage of younger children is processed more slowly and is probably longer lasting than that of adults.

The relationship between visual information processing speed and other seemingly extraneous factors such as economic status and cognitive style has also received some attention in the backward masking literature.

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1. A pattern mask is one which is matched to the contour of the TS, completely overlapping all components of this figure.

Bosco (1972) compared speed of perceptual processing in lower and middle class children aged approximately 7, 10 and 12 years. The findings indicated that,

> ". . . disadvantaged children required more time to process visual information than did middle-class children, but the processing speed for the two groups tended to become more similar as grade level was increased." (p. 1418).

A study, procedurally similar to the social class study of Bosco (1972), was carried out by Weiner (1975). It compared two groups of children, 8 and 10 years of age, distinguished within groups on the basis of impulsivity in response style. Age and style interacted significantly, with older, reflective children exhibiting smaller critical SOA than impulsive children of a comparable age who were, in turn, faster visual processors than younger impulsive or reflective subjects.

One of the most contentious backward masking studies comprised two experiments each involving subjects aged about 19, 12 and 6 years (Lawrence, Kee & Hellige, 1980). In this study, the target stimulus figures consisted of four arrowheads each pointing in a different direction. The masking figure completely overlapped the target. In the first experiment where recognition accuracy levels were set at 100% in a no-mask condition, the usual age ISI interaction effect was observed. Possible confounding of results with ceiling effects led to the completion of a second experiment in which no mask recognition was set at the 75% level for the grades sampled. In this experiment, no-mask recognition accuracy was manipulated by varying the size of the target figure. While a significant main effect for grade was observed in this experiment, the grade x ISI interaction was nonsignificant. On the basis of this latter result, Lawrence et al. concluded that, if ceiling effects are removed, visual information processing speed is equivalent across ages and any observed developmental differences may be attributed to functional immaturity.

The validity of the technique, differing as it does from the typical backward masking study, can be queried. Saccuzzo and Michaels (1982) have in fact done so, suggesting that the lack of comparability between the size of TS figures in the second experiment, not only across groups but also across individuals, raises doubts as to the resulting comparability of the task and results. This consideration is particularly important in light of the findings of Haith (1971) who has shown no significant age difference in visual sensitivity. The fact that the Lawrence et al. task also involved a 4-choice decision (up-down-left-right) led Saccuzzo and Michaels to question whether the complex nature of the discrimination may have resulted in confusion among some of the subjects. For all of these reasons these researchers have expressed some doubt as to whether the results of Lawrence et al. can really be interpreted as indicating that visual information processing speed does not relate to age.

In summary, the majority of backward masking results suggest that age relates in some systematic way to the speed at which perceptual information is input into the system. Although no two studies have used exactly the same procedure, this fact in itself has associated with it advantages and disadvantages when it comes to interpreting the available evidence. While the lack of methodological consistency does give rise to certain interpretational difficulties, it also illustrates the robustness of the developmental result. The problems encountered generally are a reflection of an apparent unwillingness among some researchers to control for, or even to acknowledge, methodological weaknesses inherent in the backward masking technique. Ross and Ward (1978) have listed these weaknesses as three main considerations: judging the locus of masking effects; the extent of involvement of memory and learning processes; and possible influence of attentional factors.

As has been pointed out in the previous section, the locus of masking effects has been a topic of controversy in recent masking studies. Although a majority of the studies have assumed a central locus, only a few have attempted to verify this fact empirically. In addition, given that a number of studies have involved tasks with fairly complex cognitive components which draw upon both learning and memory processes (e.g. partial report studies and those involving alphabetic TS figures), it is possible that, at least in these cases, processes other than input speed are responsible for developmental differences. Lastly, few studies have attempted to ensure that masking is equally effective across age groups or that each group is attending appropriately at TS onset.

Notwithstanding these procedural inadequacies, the discovery of age effects in input processing efficiency has given rise to two theories on the ontogeny of the human information processing mechanism. While Ryan and Jones (1975) suggest functional ontogeny provides a satisfactory explanation, with younger children processing the icon's information less rapidly than adults because of strategic considerations, Ross and Ward (1978) have argued that a structural source for the difference could be hypothesised with the icon of younger children being shorter and fading more quickly. At this point in time, either interpretation can adequately explain developmental backward masking findings while neither can proffer evidence which refutes the other.

(iv) The Inspection Time Technique

(a) Background

In the past ten years a new measure of input processing speed based on a cumulative model of discrimination has attracted a large amount of attention (Vickers, 1970, 1979; Vickers, Nettelbeck & Willson, 1972). This measure has been developed within the context of an "accumulator" model of decision processing, according to which evidence for a decision in a discrimination task is accumulated as a consequence of a number of brief "inspections" of sensory stimulations. These inspections, or brief observations each occupying a fraction of a second, are accumulated in memory banks representing the alternatives, with a decision occurring when one of the stores reaches criterion. Thus, the caution with which a response is finally made can be incorporated within this model by reference to the subject controlled criterion level and it is subsequently possible to distinguish subjects on the basis of speed and accuracy.

Theories concerned with the psychological moment indicate that perception requires a certain minimal time to develop and is not a direct function of physical reality (Stroud, 1954; Efron, 1967). stimulus detection It is this minimum temporal interval which can be labelled, "inspection time" (IT). Operationally it is defined as the stimulus duration at which performance on an extremely easy discrimination is virtually free from errors, this point being accepted as 97.5% accuracy.[1]

The techniques used for obtaining this measure have been described elsewhere (Nettelbeck, 1983), and will be dealt with in relation to specific experiments in subsequent chapters, so only a brief summary of the procedure need be included here. The IT procedure is basically a modified backward masking paradigm which restricts processing to the interval between stimulus and mask onset (SOA) but which varies TS duration rather than ISI. In other words, MS onset immediately follows TS offset and accuracy is measured over a number of TS durations.

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[1] 97.5% accuracy was arbitrarily selected as an adequate reflection of perfect accuracy given the existence of chance errors resulting from random attentional fluctuations and fatigue.

In general, this TS has taken the form illustrated in Figure 2. in Chapter 2, with the shorter of the two lines located either to the left or right. These lines subtend a difference considered large enough to be an easy discrimination, on the basis of preliminary studies with elderly subjects in which "noise" in the system was calculated as .3° of visual angle. It was considered appropriately conservative to select 1.6° of visual angle as sufficient to compensate for any systemic noise even among retarded populations (Vickers et al., 1972; Nettelbeck & Lally, 1976).

At offset the TS figure is followed by the onset of a MS which is matched to the target for contour and totally overlaps this figure. The target and masking figures are presented to the subject tachistoscopically after the initial presentation of a cue figure, usually a small dot or cross located in the area where the critical length difference will be observed. The subject is required to press one of two keys to indicate the relative location of the shorter line.

Although the technique as described above has been used in the majority of IT studies, there is a second method which has also been used in a number of experiments. This task involves a panel of eight lights in a horizontal row divided into two groups of four by a midline. The TS, the light to either the immediate left or right of the midline, is lit up for a brief period followed at offset by the lighting up of the entire panel (Smith, 1978; Wilson, 1980; Nettelbeck, 1982; Nettelbeck, Hirons & Wilson, 1984).

In a small number of studies attempts have been made to measure processing rate in modalities other than vision. Brand and Deary (1982) have developed a "tachistophone" that measures auditory processing rate in basically the same way as visual displays have been used to measure the visual rate, while Nettelbeck and Kirby (1982) have used a tactile discrimination task to measure processing in that modality.

The IT procedure involves a pre-testing sequence of practice trials intended to familiarize the subject with the task and then the subsequent presentation of discrimination trials at a number of durations. Accuracy of performance is measured and from this actual IT can be derived (from the normal cumulative ogive mapping the relationship between exposure duration and discrimination accuracy), as that duration at which 97.5% accuracy is achieved.

Most studies undertaken with the IT paradigm have been primarily concerned with the issue of mental retardation. (A good summary of this work with particular reference to studies at the University of Adelaide is to be found in Nettelbeck, 1982, in press). In brief, these studies have tended to show a consistent and substantial difference between ITs of retarded and non-retarded adults, generally with the former at least twice the duration of the latter. For nonretarded adult controls mean IT approximates 100 ms while for retarded subjects 250-300 ms is found (e.g. Nettelbeck & Lally, 1976; Lally & Nettelbeck, 1977; Nettelbeck & Lally, 1979; Nettelbeck et al., 1980; Lally & Nettelbeck, 1980; Nettelbeck et al., 1981; Nettelbeck & Kirby, 1983a; Nettelbeck & Kirby, 1983b). A variety of control studies have been undertaken which establish the fact that these results are not an artifact of such factors as heterogeneity of variance (Nettelbeck, 1984), non-equivalence of masking across populations (Lally & Nettelbeck, 1977), non-equivalence of initial registration (Nettelbeck & MacLean, 1984), or response organization (Nettelbeck, Evans & Kirby, 1982). Instead, this body of evidence is amenable to an explanation based on a dysfunctioning central executive attentional mechanism,

> "...which is responsible for directing attention to
> different stages of processing and therefore governing
> all functional levels, including pre-registration processing."
> (Nettelbeck, in press)

(b) Developmental Results

In contrast to the other perceptual processing paradigms previously described, very few developmental studies have been undertaken within the framework of the IT paradigm. The first study to compare IT performance of subjects at different ages failed to find a significant developmental difference (Nettelbeck & Lally, 1979). In this experiment, 10 retarded adults with IQ's ranging from 51 to 71 were compared on the task with 10 nonretarded CA controls and 28 nonretarded children. The children consisted of groups at the age of 7 years (number of children; 5), 8 (10), 9 (8) and 10 years (5). The experimental trials were presented at TS durations of 10, 70, 130 and 700 ms and on the basis of performance at each of these points the psychometric function for each subject was derived and inspection time estimated directly from this function. Although the results showed a small, consistent decrease in IT with increasing chronological age, (7 years = 147, 8 = 142, 9 = 137, 10 = 139, Adults = 130) the main effect for age was not statistically significant. Despite this finding, in a later reappraisal of findings then available, Nettelbeck and Brewer (1983) hypothesized that IT might decrease with increasing age, at least up until 10 years.

Results obtained in Edinburgh at about this time provided supportive evidence for this hypothesis. Although no large cross-sectional or longitudinal study was undertaken, the limited data available did appear to suggest the existence of an age factor in input speed. For example, Hosie (1979; cited by Brand, 1981) used a modified tachistoscopic technique with a sample of 4-year-old children, obtaining IT measures that were approximately four times the size of mean adult IT.

One IT study which has directly compared children's performance with that of adults and obtained a significant difference used the lights task described on page 26 in the previous section rather than the line discrimination task. Wilson (1980) measured IT in groups of children aged 8 and 11 years and in two groups of adults, one mildly retarded, one nonretarded. The results, although producing relatively low ITs in all groups, did show a significant main effect for age. Planned comparisons showed a significant difference between the performance of the 7 and 11-year-olds, while the older children's mean IT failed to differ significantly from that of the adult, nonretarded controls. Furthermore, the adult retarded subjects exhibited a mean inspection time which was significantly greater than the estimates from all nonretarded groups.

In summarizing this research it becomes immediately apparent that there is a dearth of IT evidence on the developmental nature of input processing efficiency, in contrast to the wealth of studies based on alternate procedures. Given the results obtained with these other techniques, it would appear logical to hypothesize some sort of change with age which might, in turn, reflect something about the manner in which the human information processing mechanism develops.

3. The Measurement of Input Processing Speed: Selection of a Procedure

The preceding literature survey, while suggesting that perceptual processing speed is subject to ontogenetic change, is of only limited usefulness, given the methodological flaws which proliferate in the literature. To examine adequately the developmental nature of the information processing system, and more particularly the input processing mechanism, requires the selection of a paradigm and procedure which is both procedurally rigorous and methodologically sound. A cross-sectional developmental inspection time study incorporating a large age range, especially in those ages at which change has been evidenced (6 to 11 years), would appear to provide the opportunity for establishing the ontogeny of input processing.

There exists a variety of arguments which can be enlisted to support the selection of the IT method as the most adequate processing speed measure. Firstly, it is possible using this technique to satisfy most of the methodological considerations raised by Ross and Ward (1978). While this method, like the others, assumes that the processing tapped is central in origin, and that the arrival of a MS interrupts the processing of the TS, there is some evidence to support this interpretation (Nettelbeck, Hirons & Wilson, 1983). Furthermore, the characteristics of the target and mask and the manner of their presentation is such as to induce central rather than peripheral processing. These issues are discussed in greater detail in Chapter 2. Suffice to say at this stage that the conditions of centrality described by Turvey (1973) appear to be met.

Secondly, the relatively simple nature of the task, defined to be as such on a population of elderly subjects and mildly retarded young adults, makes the task suitable for use with a young age group. Avoidance of the memory and learning processes necessary for a partial report technique is obtained by the use of a single, non-alphanumeric figure. Furthermore, the cognitive load of the task is further reduced by avoidance of the concepts left and right and their replacement by a judgement involving "sides".

Although the IT research to date has not satisfactorily determined whether developmental differences in speed are the result of attentional variables, a consideration which must be raised given the brief duration of the TS, this issue has been looked at with mentally retarded subjects. Nettelbeck, Hirons and Wilson (1984) used a pendulum tracking task to examine voluntary and involuntary attentional fluctuations. Velocity arrests during the eye tracking task were found to correlate significantly with IT estimates obtained from retarded subjects. These results therefore supported Nettelbeck and Brewer's (1981) notion of a central attentional impairment in mentally retarded persons, although they failed to explain its nature or extent. Thus any developmental IT differences observed may reflect attentional variables and consideration will given to this factor in the subsequent chapters.

Other advantages are specific to the method. These include the fact that IT is only a small part of a larger model of information processing (Vickers, 1979), and as such provides the option for generalizing beyond input processing efficiency. For example, Vickers' accumulator model of decision processing makes it possible to investigate the relative caution of various groups or individuals in decision making.

The IT procedure also tends to avoid at least some of the conceptual complexities of the backward masking studies, in particular, those evoked by the notion of an icon. The IT method concedes the existence of some such store by using a backward masking stimulus but makes no assumption about its nature. It does this by making TS duration equal to SOA and avoiding any confounding involved by the introduction of an ISI. This approach is therefore not only conceptually more simple but also a more realistic technique in an environmental sense. As Dick (1974) has saliently pointed out,

> "...the icon might be viewed as an artifact of the tachistoscopic procedure, since in the natural environment, the duration of the stimulus is seldom restricted. From this point of view the persisting icon would be redundant, since the physical energies are available long enough for complete processing." (p.533).

Even if the physical presence of the stimulus is redundant to processing and all processing occurs from an iconic image, the IT paradigm is not disadvantaged by such a fact. Rather, the technique can be seen as conservative since it makes few assumptions about the actual manner in which processing occurs.

Lastly, a main advantage of this technique lies in the large number of studies available based strictly on this one procedure and the possibilities for comparison they offer. Furthermore, these studies also substantiate the validity and reliability of the method. (A detailed description of these two issues is included in Nettelbeck, 1983). It is sufficient to say here that test-retest correlations range from .25 to .92 averaging .65 in nonretarded adults, and data on validity, while more problematic, do exist (see Nettelbeck, 1984; Nettelbeck & Kirby, 1983; Nettelbeck & Lally, 1976; Nettelbeck, Cheshire & Lally, 1979).

In summary, the IT procedure used in a cross-sectional study which incorporates a wide range of ages provides the possibility for detailing the nature of input processing speed changes with age, and for clarifying some of the ambiguity raised by other studies based on other procedures.

CHAPTER 2

EXPERIMENT 1

An investigation of the locus of target-mask interaction

1. The Functional Locus of the Inspection Time Measure

The survey in Chapter 1 of the developmental iconic processing literature describes a body of research characterized by diversity in methodology. As a consequence, complications arise when attempting to generalize beyond the specific boundaries of the experimental situation from which particular findings have been derived. The theoretical ambiguity attached to the topic of input processing further increases the difficulty of interpretation Thus, even though researchers are virtually unanimous in their support of the notion of a developmental component to processing speed, attempting to equate results across experiments results in interpretational confusion.

Input processing is generally conceived of as occurring at two levels of brain organization; a peripheral, retinal level and a more central, neural level. While a small number of the early researchers studying input processing implied a peripheral locus for their measure, the majority ignored the issue of locus completely. Confusion associated with reading this literature is therefore partly a result of that fact that many researchers have not established the qualitative nature of the masking evoked by their own particular procedural manipulations. In recent years, studies formulated using backward masking methods have been particularly remiss in this area despite, or perhaps because of, the general assertion that the theoretical rationale behind such methods has been that the arrival of a masking stimulus interrupts iconic processing of a target figure centrally.

Given the extent to which central and peripheral processing can be confused, to fail to identify locus of processing is a serious omission. Furthermore, when different groups distinguished on the basis of age or intelligence are compared within an experimental design, the possibility of a group x masking locus interaction arises, which adds further to the confusion. In other words, establishing the qualitative nature of the masking effect is essential to the interpretation of results, particularly where group comparisons have been made on the basis of age or intelligence.

(i) The Concurrent-Contingent Model of Visual Processing

In the face of this widespread confusion in the 1970's, Turvey (1973; Michaels & Turvey, 1979) succeeded in producing a coherent theoretical framework which clarified some of the issues. Based on an extensive foundation of empirical evidence, this work provided a model of the processing mechanism and a relatively simple technology for experimentally distinguishing peripheral from central masking effects. Turvey, while acknowledging the early contributions of Kinsbourne and Warrington (1962a, 1962b), provided an original framework for viewing perceptual processing, and more particularly, the relationship between perception at a peripheral and central locus, by proposing that the latter related to the former in a "concurrent-contingent" manner.

The basic premise of this model, to be discussed below, was described as follows:

> "The central process is directly contingent on the
> output of the peripheral nets and operates
> concurrently with the activity of these nets."
> (Michaels & Turvey, 1979, p.4).

Even though central processing is dependent upon peripheral functioning, the nature of the relationship is such that it is possible to distinguish the two by experimental manipulation.

While formulated on one simple premise, Turvey's model involves considerable complexity in detail. The brief description to follow provides a general appreciation of the nature of the model but cannot do justice to the breadth of detail, an understanding of which requires reference to the source articles (Turvey, 1973; Michaels & Turvey, 1979). Figure 2.1, taken from the 1973 paper, provides a pictorial representation of input processing, illustrating the nature of the hypothesized link between processing peripherally and centrally. Input from the environment is analyzed by a set of operationally parallel and independent peripheral nets, each of which is differentially sensitive to some particular aspect or function of the visual input (e.g. hue), and which has its own "firing rate". The rate at which these visual nets transmit information is a product of the strength of the environmental information ("stimulus energy") to which any particular net is attuned. The output from each of these nets is registered at a set of central addresses each of which is selectively responsive. Given variance in peripheral resolution rates, central registration from these nets occurs asynchronously. The central processor operates upon these stored elements in the order in which they arrive at central locations, with the information from the fastest nets processed first.

Turvey distinguishes two independent central processes. The first, the "constructor function", actively constructs the iconic representation on the basis of incoming information about light and other features originally emanating from the peripheral network. The second, the "algorist function", attempts to identify the image by subjecting it to identification algorithms.

KEY:	I	Input
	p	Peripheral nets ("logical units") which are specialized to different aspects of the same Input and give rise to different outputs.
	o	Output of the peripheral nets.
	d	Operating time for the peripheral nets.
	S	Central storage units which store the outputs of peripheral nets for use by the central decision process. Base state of the unit is null (Λ).
	C	Central nets operating serially - a "decision tree".
	O_k	Final output of central nets.
	D	Operating time for central nets.
	↺	Looping at the input by C_i which is waiting for some output O_{ij}.

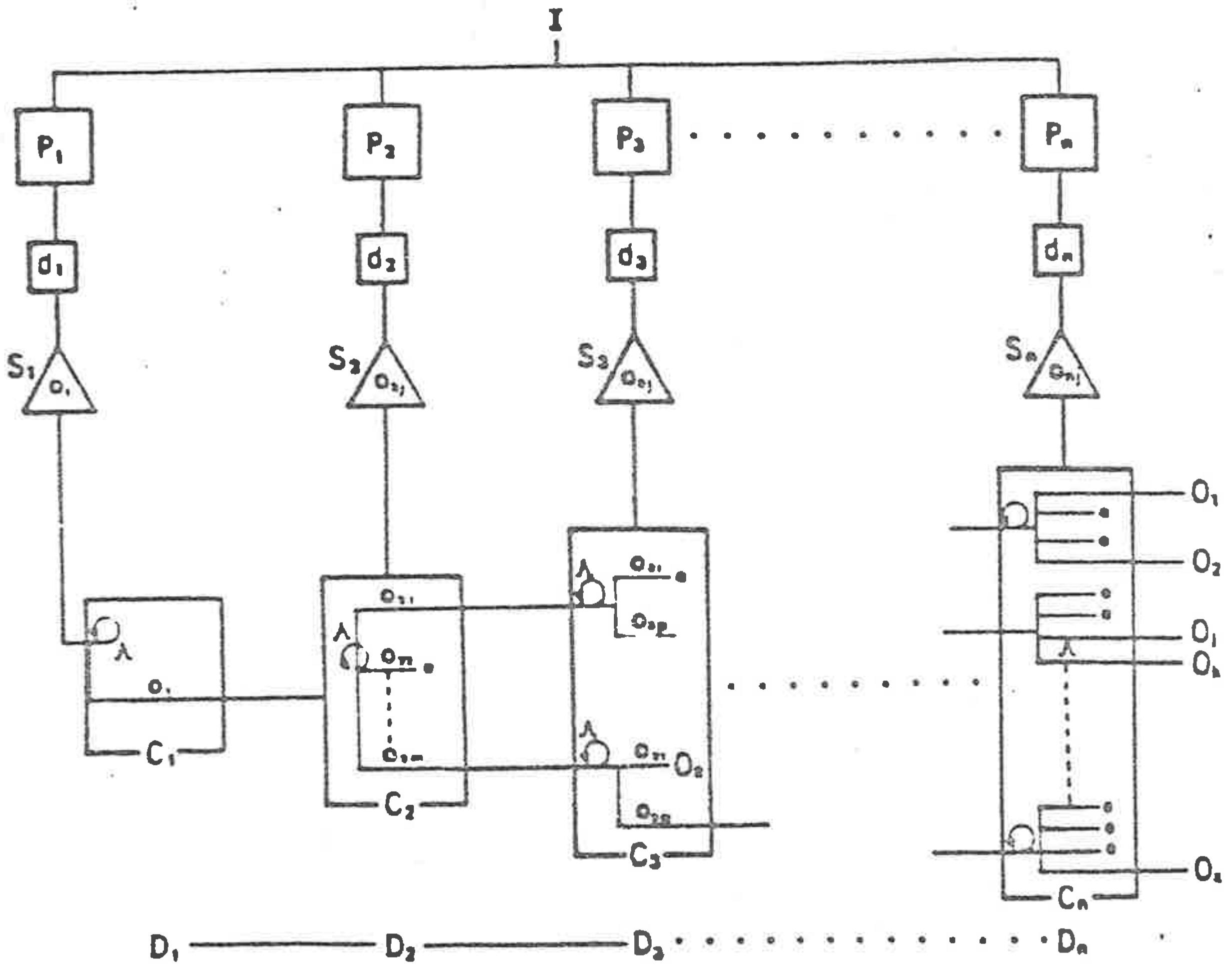

FIGURE 2.1. Schematic Representation of the Concurrent-Contingent Model of Perceptual Processing.
(Reproduced with permission from Turvey, 1973, Fig. 14, page 28)

The arrival of a second, masking stimulus (MS) within a critical time period after the onset of the target stimulus (TS) may give rise to a decrease in perceptual accuracy as a consequence of masking at either a peripheral or central locus. Turvey has been able to analyze this effect in detail, describing four separate mechanisms of masking, only the first of which has an effect in the peripheral location. This occurs when two stimulus figures "integrate" because of within-net time sharing. The operating time of any net depends on stimulus energy. Under these conditions it is the stimulus figure with the greatest energy which will dominate the net and, consequently storage. Peripheral processing speed is best characterized by the "multiplicative" rule.

TS energy (i.e. duration X luminance) X ISI = k (a constant). . . .

Equation 2.1

All other forms of masking arise centrally. The first, "integration through common synthesis", arises when both the TS and MS have been synthesized centrally, thereby constructing a composite image which makes identification for the algorist function more difficult. The second, "interchannel inhibition", involves the inhibition of slower sustained peripheral nets by the transient channels that respond to MS onset and may prevent perception of the finer details which give rise to identification. Lastly, "replacement" of the target occurs when insufficient time is available to the algorist function for identification. The arrival of the MS directs the attention of the algorist function away from the first arriving stimulus figure and to the latter. As a consequence, central masking arising from this process is temporally dictated and can be described by the "additive" function:

TS duration + ISI = k (a constant) . . . . Equation 2.2

(ii) Establishing the Nature of the Perceptual Processing Paradigm

The concurrent-contingent model provides both a theory of input processing and techniques for distinguishing masking locus. Appropriate procedural manipulations can increase the probability and, in some cases, ensure a central locus, while the additive and multiplicative functions provide an inferential test of target and mask interaction.

Procedurally, central masking is always evidenced under dichoptic presentation of TS and MS; that is, where the TS is presented to one eye, and the MS to the other. Under these conditions, any interaction has to occur neurally since a dichoptic procedure involves stimulation of peripheral retinal nets in different eyes. Interaction may also be produced binocularly and monoptically; in the former case where the TS and MS are presented to both eyes, and in the latter case, where the TS and MS are both presented to one eye. In these circumstances, however, interaction of the two stimuli may occur either at the brain or the eyes. It is not possible with binocular or monoptic presentation, therefore, to distinguish central from peripheral masking effects except by inference via experimental manipulations aimed at testing the extent to which performance conforms to the additive or multiplicative rules described by Equations 2.1 and 2.2, above.

As described by Turvey (1973), there are certain procedural manipulations, over and above actual presentation technique, which can increase the probability of evoking a specific form of masking. Briefly, these include:

(1) Masking type: Use of a random "noise" mask produces masking only peripherally. However, a "pattern" mask matched closely to the contour of the TS will result in either peripheral or central masking. The critical variable distinguishing pattern from noise mask appears to be the figural similarity of mask to target, with difficulties arising

where the MS falls somewhere in between a totally random configuration and one which completely overlaps the TS.

(2) Target to mask energy ratio: use of a TS of greater energy than the MS should increase the probability of obtaining central masking as peripheral masking is unlikely to be successful under these conditions. This is because peripheral masking invariably arises out of the process of integration of target and mask, and integration will not produce adequate diminution of the quality of the TS and hence, adequate masking, if TS energy is greater than that of the MS.

(3) Target duration: Use of an extremely brief TS duration will increase the probability of a peripheral locus for masking. When target duration, and concomitantly energy, is low enough, peripheral operating time is slower than central operating time and, given that the latter is linked to the former in a concurrent-contingent manner, the central operations are delayed. Thus, masking under these conditions is dictated peripherally. However, when TS duration (and energy) is such that the output of the peripheral nets runs ahead of the central decision, masking is central in origin.

The inspection time procedure like other backward masking methods, assumes a central locus for target and mask interaction. It conforms to two of the above stipulations, using a pattern mask that totally overlaps the target figure which, in turn, is exposed for a duration equal to SOA. These characteristics therefore increase the probability that central interruption of target processing does occur. Evidence concerning the target to mask energy ratio is more problematic, however. In the majority of IT studies MS luminance has been set at a level to equal that of TS. However, since MS duration is generally considerably longer than TS duration, the target to mask energy (duration x luminance) ratio favours the latter. This procedure evolved because initial development work (Vickers, Nettelbeck & Willson, 1972) involved presenting target and mask on a visual display screen for which luminance of task components could not be varied independently.[1]

The higher mask energy and the use of a binocular presentation technique introduce uncertainty as to masking locus, especially in those studies in which group comparisons are involved and a masking locus by group interaction may raise. This issue was addressed directly in the first experiment, as described in the section that follows.

(iii) Developmental Results

Turvey's multiplicative and additive functions provide not only a ready basis on which to define central and peripheral masking operationally, but also a standard against which performance of different groups can be judged. Novik (1973) tackled this task within a developmental context in an attempt to discover the qualitative similarity, or otherwise, of masking effects across age. A series of experiments in which he varied presentation procedure along the lines described by Turvey (1973) established three important findings. Using a sample of children aged 6 years 9 months and 11 years 1 month from the first and fifth grades respectively, a group of adults, and

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1. The arrangement was retained for studies using a tachistoscope because the intention was to compare results from this thesis with results from other IT experiments. Furthermore, plans to develop a version of the IT task to be used on a small portable computer also dictated that the luminance of target and mask be equated for consistency across experiments since, in the computer display version, luminance of TS and MS would be necessarily the same. A more efficient method of manipulating mask energy so as to favour the target would have been possible by manipulation of mask duration, given that energy is a function of duration x luminance, but such a manipulation would have made cross-study comparisons problematic. However, in future research in which visual displays are used with fixed luminance, central masking would be more effectively evoked if target and mask durations were covaried so as to ensure that the target-to-mask energy ratio always favoured the target.

a binocular presentation technique involving a random noise mask (i.e. the basic peripheral masking procedure) Novik showed performance at each age to be best characterized by the rule: TS energy x ISI = k (i.e. Equation 2.1). On the other hand, dichoptic presentation of a pattern mask produced performance in all age groups which was most appropriately described by the rule of central masking, Equation 2.2, i.e. TS duration + ISI = k. Lastly, an ambiguous masking procedure involving the binocular presentation of a pattern mask produced a shift in all groups from the multiplicative to additive rule when TS duration equalled 8 ms. Novik concluded that the shift occurring at this duration in all groups suggested that peripheral processing speed does not change as a function of age.

Thus, in this series of experiments the nature of target and mask interaction did not appear to change with chronological age (CA). However, analysis of the critical Stimulus Onset Asynchrony (SOA) required to evade masking in a central context showed a relationship to age which might be interpreted as reflecting a developmental increase in speed of information processing, not attributable to functional masking differences.

These findings while interesting in themselves, also illustrate the necessity of closely examining the nature of masking in a developmental setting. Since binocular presentation involving a pattern mask is conducive of both peripheral and central masking in Novik's study, the need in any one instance to establish the qualitative nature of masking under the particular conditions used becomes obvious. This is especially so when dealing with children of different ages, where it is possible for age differences to be confounded by the issue of masking locus. As previously stated, although the IT procedure attempts to control for the peripheral masking effects by the use of a binocular presentation technique involving a pattern mask and a TS of relatively lengthy duration (equal to SOA), set at a luminance level equal to that of the MS, the central nature of the paradigm still requires substantiation, particularly in a developmental context.[1]

Therefore, before analysing the developmental nature of IT, as measured by the typical tachistoscopic pattern mask technique, it would appear wise to establish the exact nature of the task. The assumption of centrality in masking effects, implicit in the literature, requires clarification when comparing groups of subjects of different ages. Equally important is the issue of the functional equivalence of IT (the minimum TS duration at which 97.5% accuracy is achieved) and critical SOA (the minimum interval between stimuli onset at which 97.5% accuracy is achieved). According to Turvey (1973), these measures are theoretically equivalent, support for this assertion coming from data that have shown the two to be indistinguishable in an adult population. However, in children the results are much more equivocal. Ferreira (1978) in one experiment showed TS duration to significantly affect critical SOA in the groups of children measured, while in another instance she found no effect. It is the ambiguity of these results and their ramifications for IT that makes the equivalence of critical SOA and IT an issue worthy of examination.

Comparison of results obtained from the same subjects under a binocular presentation procedure with those obtained under a dichoptic procedure would establish the equivalence or otherwise of these techniques of measuring IT. Moreover, if children were to be included in the sample, comparison would test the effectiveness of the typical binocular pattern-mask procedure for measuring information processing of a central nature over a wide age range. Measuring critical SOA by fixing TS duration should also indicate if SOA is the primary determinant of central information processing speed in all groups.

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[1] Nettelbeck, Hirons and Wilson (1984) have established the central nature of the masking effect in the IT paradigm when dealing with mildly retarded and nonretarded adults.

In terms of the concurrent-contingent model of processing, it is hypothesized that binocular IT should not differ significantly from dichoptic IT in adult subjects. Novik's (1973) results would also suggest the existence of a qualitative similarity in masking locus across age, and a difference in speed of processing which should be evidenced in critical SOAs. Selection of children aged approximately 7 and 11 years would provide groups comparable to those of Novik and other backward masking studies (eg. Pollack, 1965; Gummerman & Gray, 1972; Welsandt, Zupnick & Meyer, 1973), thus permitting the comparison of results. It is also worth noting that children at these ages fall neatly between the Piagetian stages of Pre-Operational and Concrete Operations (age 7) and Concrete and Formal Operations (age 11). If cognitive maturation is an important variable in speed of processing, this distinction might prove crucial.

2. Method

(i) Subjects

Subjects consisted of 20 children, 10 each at the mean ages of 8 years 3 months (range 7 years 8 months to 8 years 9 months) and 11 years 11 months (range 11 years 5 months to 12 years 0 months). 10 adult university students with a mean age of 20 years 0 months (range 17 years 3 months to 24 years 5 months) also participated, as part of a first-year psychology course requirement. All subjects had normal, or corrected to normal visual acuity.

(ii) Apparatus

The SOA at which each subject achieved 85% accuracy was ascertained under four separate conditions:

(1) Binocular critical SOA (ISI = 0; effectively equivalent to IT) was measured by a tachistoscopic procedure, both TS and MS being presented to both eyes. The target figure consisted of two vertical lines 10mm apart and 24 and 34mm in length, terminated at the top end by a third line. This figure was presented for a short duration on each trial by means of a four field tachistoscope.[1] The shorter line of the TS was located either to the right or left of a cue figure (a dot of 1000 ms duration) which was presented prior to target onset, and situated so as to facilitate easy discrimination between the lines of different length. The apparatus displayed the various figures at a viewing distance of 80cms, so that the stimulus difference corresponded to a visual angle of 1.6 degrees. Luminance of the fixation field was set at approximately 3.43 cd/m^2 and the target and mask fields, 6 cd/m^2. After presentation of the TS a pattern mask designed so as to completely overlap the target appeared for 500 ms. These figures are reproduced in Figure 2.2.

(2) Dichoptic critical SOA (ISI = 0) was measured using the same procedure but with the insertion of polarizing filters into the eye-piece and body of the tachistoscope, thereby ensuring that the target stimuli were presented to the left eye and the MS to the right. The cue figure was viewed binocularly, with luminance reduced to .43 cd/m^2. Luminance of the target and mask also decreased (.86 cd/m^2) after polarizing filters were inserted.

(3) Critical SOA (ISI > 0) was measured binocularly with a set TS duration held constant at 25 ms, while ISI was varied by computer program. The nature of the figures and basic task requirements remained unchanged,

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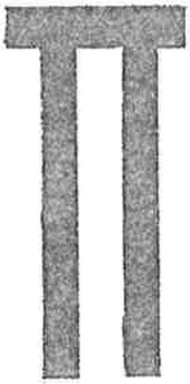
[1] A Gerbrands Model G-1130 tachistoscope was modified by the addition of a fourth field.

except that following presentation of the TS to both eyes a blank, dark field was presented for some variable interval (ISI), followed by the MS.

(4) Critical SOA (ISI > 0) was also measured dichoptically by inserting polarizing filters and using the same methodology.

a. Targets



b. Mask

FIGURE 2.2. Targets and Masking stimuli.

Responses made to the location of the shorter line involved pressing one of two keys. These keys interfaced with a portable INTERTEC computer programmed to initiate the next trial 2 sec after response completion.

(iii) Design

Initially each subject undertook a period of intensive practice, completing a minimum of 60 trials presented in blocks of 10. For the youngest group practice consisted of 10 trials at 1000 ms duration, 10 at 500 and 10 at 300 (all to a criterion of 100% accuracy), as well as 10 trials each at the durations 100, 50 and 25 ms without any accuracy criterion attached. In the two older groups, practice consisted of 10 trials at 500 ms and 10 at 300 (requiring 100% accuracy), followed by 10 trials at each of 150, 100, 50 and 25 ms. In each subsequent session these practice trials were readministered.

Following practice, the computer-controlled PEST program (Parameter Estimation by Sequential Testing) presented trials throughout the experimental session. The session terminated when a preprogrammed accuracy level of 85% correct trials for some stimulus exposure duration had been achieved by the subject. Because of individual differences in performance, testing time ranged from 10 to 25 minutes and the number of trials for program completion from 80 to 300.

The PEST program measures both critical SOA, ISI = 0 (i.e. IT), and critical SOA, ISI > 0, by responding to the accuracy achieved by a subject and comparing this to the preprogrammed level of accuracy required. In this experiment, the target exposure duration or SOA at which the subject achieved 85% accuracy was selected on the basis of evidence from a pilot study which had shown this level to be comparatively quickly and easily achieved.[1] If

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[1] In the pilot study, 15 adult subjects were measured on the binocular IT task using the PEST procedure to determine the target exposure duration at which the subject achieved accurate discrimination on 75, 85 and 90% of trials. No significant order or practice effects were evidenced. The 85% level was eventually selected because it fell between the means of the 90% and 75% levels and could be derived in relatively few trials. (Refer to Appendix 2.1).

accuracy at one duration went above 85%, the duration on subsequent trials was lowered; if accuracy fell below 85% then duration was raised. In effect, therefore, the program produced a sawtooth procedure that gradually arrived at the minimum SOA at which the specific level of accuracy was achieved. For the youngest group, initial TS duration was set at 500 ms, while for the older two groups, the program commenced with a TS of 300 ms.

(iv) Procedure

The adult and Grade 7 children completed the four measures in two sessions. In the first, having been familiarized with the task by extensive practice, measures of binocular and dichoptic critical SOA, ISI = 0, were obtained, the order of completion of these measures being balanced within groups. In the second session (a few days later) they completed the remaining two tasks in which ISI was varied, again balanced for order in terms of the binocular and dichoptic procedures, having been familiarized with the slightly different task by means of practice. The youngest children participated on four separate occasions and these were also balanced for order of presentation technique.

A fully balanced within-subject design including both ISI conditions could not be achieved with the number of subjects available, since this would have required 24 different orders. The implications of the design adopted for practice effects in ISI > 0 conditions were recognized and these are discussed in Section 3, to follow.

On each occasion, before the program was begun, care was taken to ensure that each subject fully understood the requirements of the tasks. Card reproductions of the cue, target and mask figures were used to demonstrate the sequence of events as they would occur when viewed in the tachistoscope. Subjects were informed of the non-informational nature of the MS and the need to attend to the TS. An attempt was also made with the younger children to avoid the added confusion of the terms left and right by simplifying their instructions to the command:

"Press the key on the same side as the short line."

Two further points were also stressed; that to complete the task successfully, the child would have to concentrate as hard as possible, and that accuracy of responding rather than speed was required. Subjects were instructed to guess on which side the short line was located as the task became more difficult at shorter durations, and to persevere in these circumstances since the task would gradually become easier again.

3. Results and Discussion

The dependent variable, defined as the SOA at which 85% accuracy was achieved, was examined in a 3 x 2 x 2 x 2 analysis of variance looking at the effects of two between-subject variables; Group (8-year-olds vs 11-year-olds vs adults) and Order of task completion (Binocular/Dichoptic vs Dichoptic/Binocular); and two within-subject variables, Presentation technique (Binocular vs Dichoptic) and ISI (ISI = 0 vs ISI > 0). Planned comparisons were also included which compared performance of the youngest group with that of the 11-year-olds and adults, and the two older groups with each other (refer to Appendix 2.2). Session was not included in the analysis because the four measures had been obtained in four sittings in the younger group and only two in the older, with the intention of alleviating fatigue and keeping motivation at a high level in the young group.

The analysis of variance summary table is included in Appendix 2.1. The Order in which the tasks were completed did not produce a significant effect (F(1, 24) = .02). Similarly, method of task presentation also failed to exhibit a significant effect (F(1,24) = .24). Table 2.1 illustrates this finding, showing the comparable nature of the measures obtained within each group, across presentation techniques. This result therefore supports the notion of central interaction of target and mask under binocular conditions since performance under these conditions does not differ from the dichoptic condition where target and mask interaction must always occur centrally.

TABLE 2.1. Critical Stimulus Onset Asynchrony (SOA) (ms) at which 85% accuracy is exhibited by different age groups under binocular and dichoptic procedures and with ISI equal to or greater than zero.

GRADE	PROCEDURE Binocular		Dichoptic		TOTAL
	SOA ISI=0	SOA ISI>0	SOA ISI=0	SOA ISI>0	
3	110	123	107	148	122
7	72	75	62	74	71
Adults	68	66	64	70	67
TOTAL	83	88	78	97	87

The period between target offset and mask onset (ISI = 0 or ISI > 0) did produce a significant effect (F(1,24) = 7.84, p < .01), with performance accuracy adversely affected by the introduction of a blank interval between target and mask. This finding could raise doubts as to the additivity of performance in the respective age groups. However, although the younger group appeared more adversely affected than the two older groups by the introduction of an ISI with a duration greater than 0, the Group x ISI interaction was not significant (F(2,24) = 3.02, p > .05). Furthermore, the dichoptic, ISI > 0 condition in which masking must be central, produced the longest critical SOA, as reflected by a significant Presentation technique x ISI interaction effect (F(1,26) = 7.09, p < .05).

The similarity of these results to those of Ferreira (1978) reinforces her comments about the difficulty of measuring critical SOA for young children using a backward masking task. Ferreira, in a binocular masking task, set TS duration at 10 and 20 ms and measured critical SOA in two sessions across age groups. Results showed that while 10 vs 20 ms threshold differences appeared on the first session's data of the 5-year-old children, similar differences appeared only in the second session's data of the adult group, resulting in an age x session x target duration interaction. She concluded from this that group differences were really the consequence of practice within sessions for different target durations, rather than a reflection of qualitatively different functioning at different ages.

Thus, despite the existence of a significant ISI effect, the central nature of the masking function has been satisfactorily established. The exact manner in which the performance of the adults and 11-year-olds conformed to the additive rule confirms the central locus of masking. Moreover, even the performance of the youngest group much more closely approximated the additive than multiplicative rule, with binocular critical SOA not differing significantly from dichoptic critical SOA, the latter of which automatically evokes central masking.

From this it is concluded that masking performance of young children does not differ qualitatively from that of adults, at least within the conditions specified by this experiment. The fact that binocular critical SOA, ISI = 0 did not differ significantly from dichoptic critical SOA, ISI = 0, even in young children, is strong evidence on which to conclude that the traditional binocular IT task is tapping a central masking process.

Correlational data provided further support for the contention that all four measures (Binocular ISI = 0; Binocular ISI > 0; Dichoptic ISI = 0; Dichoptic ISI > 0) tapped the same function within each age group. The performance variability of the children, especially the Grade 3 children, was reflected in lower correlations between conditions (refer to Table 2.2). However, even in this group the correlations were of an order which suggested that like processes were being measured.

TABLE 2.2. Pearson correlations between critical SOA measured under binocular conditions with ISI > 0, binocular conditions with ISI = 0, dichoptic conditions with ISI > 0, and dichoptic conditions with ISI = 0.

GRADE	Dichoptic; ISI = 0	Binocular, ISI > 0	Dichoptic; ISI > 0
Grade 3 (n = 10)			
Binocular ISI=0	.60**	.88***	.60*
Dichoptic ISI=0		.55*	.75**
Binocular ISI>0			.61*
Grade 7 (n = 10)			
Binocular ISI=0	.81**	.56*	.53
Dichoptic ISI=0		.48	.43
Binocular ISI>0			.91***
Adults (n = 10)			
Binocular ISI=0	.75**	.70*	.66*
Dichoptic ISI=0		.83***	.91***
Binocular ISI>0			.94***
TOTAL			
Binocular ISI=0	.76***	.82***	.71***
Dichoptic ISI=0		.72***	.82***
Binocular ISI>0			.82***

* $p < .05$ (one-tailed)
** $p < .01$ (one-tailed)
*** $p < .001$ (one-tailed)

The finding of a significant main effect for Group (F(2,24) = 9.94, p < .01), the source of which was located by planned comparisons as a difference between the performance of the youngest group (i.e. those aged 8) and the two older groups (i.e. those aged 11 and adults) (F(1,24) = 19.81, p < .01) indicated that critical SOA varies with age. Young children appear to require a significantly longer interval between target and mask onset to achieve equivalent level of accuracy. This may be due to differences in the speed at which information can be processed or it may reflect developmental differences in a variety of other variables including, but not limited to, attention, motivation and masking. The planned comparison also found no significant differences between 11-year-olds and adults (F(1,24) = .08), suggesting that adult levels of discrimination accuracy are reached by early adolescence.

4. Conclusions

The results of this experiment suggest that perceptual processing speed measured by a binocular inspection time procedure involves a central locus not only in adults, but also in children as young as 7 to 8 years of age. However, young children differ significantly from older children and adults in the SOA at which 85% accuracy is obtained. This finding suggests the existence of a developmental component to central input processing speed and thereby provided the impetus for the cross-sectional and longitudinal studies described in Chapter 3.

CHAPTER 3

EXPERIMENTS 2.1 AND 2.2

A cross-sequential investigation of the developmental IT function; its validity and reliability

Results obtained from the few developmental IT studies discussed previously have been ambiguous. At best, they provide an equivocal argument for the existence of a relationship between speed of processing and age, with the former increasing concurrently with the latter. Primarily this argument is based on evidence from Wilson (1980), together with the results of experiment 1, both of which seem to show decreasing critical SOA (and therefore IT) with age at least until the commencement of the teen years. Furthermore, the vast body of perceptual processing studies using procedures comparable to that for IT have tended to support developmental performance differences. In contrast, however, are the several studies which have not found age differences, including the results of Nettelbeck and Lally (1979). It is these studies which provide the impetus for a more rigorous exploration of the area.

1. Experiment 2.1. A Cross-sectional Study of IT

(i) Methods in Developmental Psychology

The primary aim of most developmental studies in psychology is to examine the influence of the general factor of maturation on a specific dependent variable. Generally the term "maturation" is qualified so as to refer to a particular aspect of behaviour change such as decreasing egocentrism, increasing cognitive maturity, or increasing skills repertoire. Certain developmental studies have also examined environmental and hereditary effects and often these factors can confound what is intended to be a purely maturational study. This results in great difficulties for the psychologist who wishes to conclude that a variable is "developmental" (i.e. "related to age in an orderly or meaningful way", Kessen, 1960, page 36). Such a conclusion is not always possible, especially in those studies in which samples are distinguished by chronological age (CA) but confounded by date of birth (i.e. cohort).

In recent years, the developmental literature has come to be dominated by two methodologies, each subject to serious limitations:

(a) The Longitudinal Approach: This method calls for the measurement of a specific dependent variable within one sample on a number of different occasions. The approach attempts to provide a means for monitoring changing performance over age.

(b) The Cross-sectional Approach: This procedure calls for the measurement of subjects from a cross-section of ages on a specific variable at approximately the same point in time.

The primary distinction between the two approaches is in the nature of the sample used. While the first involves a repeated measures design on the factor age, the latter is based on independent observations.

(ii) Selection of a Design

The selection of a suitable procedure for an initial investigation of the relationship between age and IT requires consideration of the aim of such a study and the comparative appropriateness of, and problems associated with, each technique. An examination of the developmental psychological literature would suggest that only a longitudinal study could accurately reflect development since a cross-sectional study is always severely limited by the heterogeneity of the sample. Thus, any performance difference that arises across age cannot be distinguished from differences associated with the diverse "life-histories" of the various comparison groups. On the other hand, the repeated measurements required by the longitudinal study can confound developmental results with those which arise as a consequence of practice. The factor of practice can produce a highly significant performance improvement, especially in certain types of tasks. Where the measure is primarily cognitive in nature and requires the internalization of simple rules, extended exposure to the task can lead ultimately to the discovery of various strategic short cuts. Even where attempts are made to decrease the cognitive component, increased familiarity produces facilitatory performance effects, purely as a result of increasing task-specific knowledge.

In addition to the limitations arising from repeated measurement in the longitudinal task are those which are due to "selective survival" and "selective sampling", both of which serve to reduce the heterogeneity of the sample in a longitudinal study (Baltes, 1967). Selective survival refers to the fact that, "a given population at birth changes in its composition in conjunction with the aging process as a result of death or incapacitation. The effect of selective survival tends to be in the direction of positive selection." (Baltes, 1967, p. 150). Selective sampling, on the other hand, refers to the fact that the necessity for repeated participation, inextricably linked with the very nature of longitudinal studies, makes the requirement of representative sampling difficult to maintain. Furthermore, the logistic difficulties of a study which involves a time span of several years are mammoth. This problem is particularly noticeable in light of the comparative ease with which cross-sectional results can be obtained.

Cross-sectional studies are, however, beset by one major problem. They do not only compare subjects of different ages but by necessity compare different cohorts - i.e. subjects who were born in different years. Thus any observed group difference does not necessarily represent an unconfounded mapping of maturation but may also result from varying environmental influences associated with different birth dates. Ultimately, it is the goal of the study which must guide the selection of the procedure, and if this goal is primarily descriptive, as is often the case in preliminary developmental investigations, the selection is made more simple:

> "For most of the studies that are designed to provide good general guidelines for later intensive studies; the cross-sectional study is ideally suited. For a relatively small expenditure of time and effort the general character of a developmental pattern can be discerned." (Kessen, 1960, p. 51)

Results obtained using this procedure, by providing a rough outline of a phenomenon, can serve as a source of more specific hypotheses and provide a base from which a general developmental function can be postulated. Subsequently, ". . . a researcher may proceed to a longitudinal analysis with more confidence and with a markedly increased chance of finding a significant relationship." (Kessen, 1960, p. 52). Therefore, in face of the primarily exploratory nature of the proposed experiment, a cross-sectional study would appear to be the most appropriate technique.

(iii) Validity of the IT Measure

Recently, attempts have been made to validate IT as a measure of information processing rate. Face validity, that is the degree to which the measure "looks like" it is measuring what it claims to, is high in the IT task. The simple nature of the task - the straightforward measurement of accuracy to changing TS duration - would appear to evoke similar "processing mechanisms" in all subjects, irrespective of age and IQ. The reality of this assumption is yet to be challenged substantially.

Particular difficulty is involved when developing a scale which is equally applicable as a uniform measure, for all groups, at all ages. Wohlwill (1970) succinctly argued that,

> "The applicability of a scale has to be understood to be a joint function of the attributes of the task utilized - eg. its suitability for eliciting meaningful responses across the age spectrum - and of the measuring instrument employed - particularly its power to discriminate among individuals over all portions of the age spectrum." (Wohlwill, 1970, p. 153)

The inspection time measure, with its minimal cognitive load, and wide range of difficulty levels, hopefully provides the opportunity in the light of the comments of Wohlwill, to discriminate not only group differences, but individual differences as well.

It is the data on concurrent and predictive validity which gives rise to some doubts about the appropriateness of the IT measure. Although no extensive validational studies have been carried out, Nettelbeck (in press) summarized existing evidence providing some tentative suggestions that, at least with adults, IT measures information processing rate. Correlations between IT and other measures of processing speed constitute the main form of cited evidence and given that generally these alternate scales are confounded by factors other than pure input processing speed, correlations are always far less than unity. Lally and Nettelbeck (1977), for example, correlated IT with "rate of information processing", operationally defined as the slope of the function obtained from the regression of choice RT on "bits" of information, obtaining a Spearman rho = .65 with a subject pool composed of low, average and high IQs. However, when correlations were re-calculated within IQ groups, the correlation decreased to nonsignificance.

Correlations calculated between IT and RT have also proven to be low. Nettelbeck and Kirby (1983a), obtained significant correlations of .21 and .40 between these two measures in two samples of average/above-average subjects and low IQ subjects, respectively. Given the manner in which RT is confounded by other than pure input variables (eg. response selection, decision making, etc.), the size of the correlation does not seem counter-intuitive.

Probably the most useful validational studies are those which have attempted to obtain convergent measures of IT. Nettelbeck, Hirons and Willson (1984) derived 2 independently estimated ITs from each subject; one by the traditional IT procedure, and the second by following a proposal of Vickers (1970) according to which "IT could be estimated as the difference in speed between the fastest and modal correct responses obtained from the distribution of a large number of reactions to an easy visual discrimination." (Nettelbeck, in press). Once again, the correlation was calculated with subject pools of both nonretarded and retarded adults producing resultant correlations of .65 and .29 respectively. This latter correlation was increased to .77 by the subsequent deletion of 2 atypical outlying subjects.

Other attempts to validate the notion that IT measures a general processing rate reflecting inputting efficiency rather than more peripheral resolution rates, have examined the issue by cross-modality research. Brand and Deary (1982) obtained a visual and auditory IT measure from 13 subjects ranging in IQ from 59 to 135. The resultant high correlation of .99 must be considered in light of the wide IQ variability, but it does at least suggest that IT reflects some aspect of general efficiency within the processing system. Attempts by Nettelbeck and Kirby (1983b) to correlate visual with tactile IT resulted in significant correlations of .75, .37 and .32 in samples composed respectively of below-average, average and above-average IQ subjects. Technical difficulties involved in obtaining the tactile measure may account, at least in part, for the relatively small size of the correlations from other than the below-average IQ group.

The issue of the validity of the IT task as a measure of information processing speed still remains to be documented conclusively, particularly across ages, where no relevant results are available. A technique for validating the measure is far from obvious. The uniqueness and specifity of the task ensures that attempts at predictive validation will be subject to great difficulty. The possibility of correlating IT with convergent measures of processing speed requires selection of a scale which can be applied to a sample covering a wide age range, and which has at least theoretical comparability to the IT measure. One scale is available which holds some promise of fulfilling these requirements.

The "Speed of Information Processing" subscale of the recently published British Ability Scale[1] was primarily developed to measure "mental speed". The test is essentially a number checking procedure, consisting of 2 booklets, A and B, which can be combined or used individually. Each book, and each item within each book, increases sequentially in difficulty. A booklet contains 12 pages, 2 sample items and 10 test items, these consisting of a page of numbers. In turn, on each page five rows of numbers are set out and it is the task of the subject to put a line through the highest number in each of these rows. Accuracy is stressed with errors corrected at the end

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1. The British Ability Scale, which is still in the process of being developed, consists of subtests to measure the following abilities: Reasoning, Spatial Imagery, Perceptual Matching, Short-Term Memory retrieval, Applications of Knowledge, and Speed of Information Processing. The latter is included on the strength of the belief that speed is a primary factor in intelligence.

of each page. A time limit for each item is specified, which if exceeded results in no marks being recorded. The scale is designed so as to be appropriate for a fairly large age range (from 8 to 13 years) by the selection of an appropriate booklet. Inclusion of this particular test provides the means for examining concurrent validity of IT across age groups, while simultaneously providing some possible insight into the relationship between speed and intelligence.

(iv) The Relationship Between Speed and Intelligence

The notion that speed of performance is a variable inextricably linked with intelligence has a long history in psychology stretching from Galton (1893) through Peak and Boring (1926) to Jensen in the 1980's. Although interest in it as a major cognitive factor in intelligence has been less than enthusiastic in recent years, virtually all group tests of ability make some allowances for the influence of speed, with faster subjects obtaining higher scores.

There are a few intelligence scales which have given the speed factor pre-eminence. For example, in the Nufferno test, Furneaux (1960) distinguishes between speed and difficulty level by the utilization of a "time-difficulty" scale. He developed this so as to analyse both power and speed when deriving overall intelligence level. A more detailed description of the Furneaux model will be elaborated in a subsequent chapter. Suffice to say at this point that Furneaux's primarily mathematical model defined the basic attributes of speed, accuracy and persistence, and mapped their interaction in different kinds of conventional tests and from these defined his own intelligence measure, incorporating these factors.

Despite its breadth of detail, the Nufferno test has achieved little general popularity. However, the British Ability Scale (BAS), which incorporates a similar construct, has attracted widespread interest. As described above, this scale incorporates a speed of processing factor into its model of intelligence, over and above time limits on subtest performances as included in the more widely used Wechsler intelligence scales. Elliott and Murray (1977), who developed the BAS, determined a "time-difficulty" level for each problem within the Speed of Information Processing subscale, expressed as mean time in seconds to respond, against which individual performance could be adjudicated and norms derived. Scores are obtained from two sources: speed of response (if it exceeds the standard, zero is scored for the item), and accuracy (more than 2 errors per item, a score of zero is obtained). As items become increasingly difficult these speed and accuracy factors are thought to increasingly differentiate children, on the basis of ability in the following manner:

> "Each problem in cognitive tests has a number of facets which require comparison, processing and decision making activity, each part of which has an associated latency. The sum of these latencies will be the solution time to the problem, more difficult problems requiring a larger number of comparisons or decisions. Hence for more difficult problems, individuals with slower decision making latencies would show a greater rate of increase in time to solve them than individuals with relatively fast decision making latencies."
>
> (Elliott & Murray, 1977, p. 59)

Therefore, it would seem that a test which involved increasing difficulty, and which takes both speed and accuracy into consideration, could be thought to reflect g more efficiently than measures that are concerned primarily, or only, with difficulty level.

In recent years Brand (1981) and Jensen (1980), in particular, have supported the notion that speed is inextricably linked with general intelligence. Jensen has long been a proponent of the speed-intelligence relationship, concentrating on studies of RT and, lately, separate decision and motor aspects of RT (Jensen & Munro, 1979). In a series of experiments in which he has examined the relationship of IQ, as measured by conventional intelligence tests, to timed performance, he has asserted that there is an important although statistically small relationship between these factors. The apparatus used in these studies consists of a console of 8 keys located immediately below and slightly to the left of 8 lights which serve as the stimulus figures, and a home key which is located equidistant from all 8 response keys. Movement time is measured as the time between lifting the finger off the "home key" and pressing the "response key", while the initial decision (which Jensen terms RT) is the time between stimulus onset and release of the home key. In all experiments the decision has involved a single light or a choice between 2, 4 or 8 lights.

Results have indicated that while movement time shows no significant relationship to bits of information processed, RT increases monotonically, with the responses of individual subjects each showing a close fit to Hicks' Law.[1] The association of performance on this task (as measured by the intercept and slope of the Hick regression function and by variability of RT), with general intelligence has usually been found by multiple regression to be of the order of R = .3 to .4. It is the consistency, rather than the absolute size, of this correlation across a wide range of experiments investigations, involving a large number of subjects, which leads Jensen to conclude that speed of performance is inextricably linked to intelligence, and furthermore, reflects some underlying neurophysiological limitation. According to Jensen's theory, individual differences are ultimately based on two factors; firstly, the number of neural "elements" activated by a stimulus and, secondly, the rate of oscillation of the excitatory-refractory phases of these activated elements (Jensen, 1982).

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1. According to Hick's Law, RT in a multiple-choice task increases as a linear function with an increase in the amount of information in the stimulus array, when the information is measured in 'bits' (Hick, 1952).

The notion that individual differences in processing speed results from inherent processing differences in "capacity" which are physiologically based has provided a biological basis to Hendrickson and Hendrickson's (1980) theory of intelligence. They have specified the actual "mechanics" of intelligence, in terms of a neural "pulse train". Receptors respond to environmental stimulation by firing, and it is the frequency of firing within a given unit of time which reflects the strength of stimulation. Information is represented by the temporal spacing of nerve impulses ("pulses") and, according to the pulse train hypothesis, "certain neurons require constant or minimum number of pulses to be sent to them in a single train before they will logically respond" (p. 5). Intelligence differences can be characterized in the following manner:

> "High IQ subjects have low pulse transmission errors. Each pulse train is therefore more likely to convey the needed information than pulse trains with high error components in the intervals. Because the number of required pulse trains is fewer, the stimulus exposure time that is required is shorter. The lowest IQ subjects would require far more pulse trains to occur before they could 'count on' the required information being reliably acquired. Thus the stimulus exposure time needs to be longer." (Hendrickson & Hendrickson, 1980, p. 32)

If a biological basis for intelligence can be ascertained the possibility would exist of developing a culture-fair measure able to predict performance on the basis of this underlying "capacity" for intelligence. In recent years, Brand (Brand, 1981; Brand & Deary, 1982) has argued that the inspection time measure might provide such a test of intellectual capability. Envisaging inspection time as a measure of fluid rather than crystallised intelligence (in Cattell's terms), Brand has produced correlations between

IT and IQ ranging from -.26 to -.98. The higher correlations have generally been obtained when retarded subjects have been included in the sample, with the correlation decreasing considerably when only average or above average IQ subjects have been used. Brand interprets this finding as support for the notion that IQ measures crystallized intelligence, arguing that IT reflects the fluid capability for intelligence at a young MA. As MA increases with CA the influence of environmental factors on measured intelligence becomes increasingly important. Brand further states that "once a certain 'information processing speed' is attained, there are other influences that increase and sustain measured intelligence, [and this accounts for the fact] that the IQ-IT correlation [is] stronger over the lower ranges of intelligence." (Brand, 1981, p. 591). Thus the IT-IQ correlation would be highest in those samples restricted to low IQ subjects in adults or low MA.

The response to Brand's suggestion has been mixed. Mackintosh (1981) and Nettelbeck (1982) have both argued that hypothesizing a causal IT-Intelligence relationship is premature. Certainly, it would seem a large extrapolatory leap from acceptance of the notion of IT as a measure of input processing speed, to one of a culture fair test of a biologically based fluid capacity for intelligence, especially in light of the sparsity of relevant data.

In the section which follows a cross-sectional study of IT is described which compares the performance of children between the ages of 6 and 12 years and which also examines the hypothesized IQ-IT relationship. Subsequently, a second study is presented examining the influence of age on the IT-IQ relationship. This study is a longitudinal follow-up to the first involving the same participants. It attempts to distinguish the effects of maturation on IT performance from those due to practice and cohort.

2. Cross-Sectional Study : Method

(i) Subjects

Eighty subjects participated in the cross-sectional study. Ten adult university students completed the task as part of a first-year psychology course requirement, while 70 children were obtained on a voluntary basis from 2 schools in the suburbs of Adelaide. Sixty of these children were attending one Primary School; 10 being randomly selected from each of the Grades 2, 3, 4, 5, 6 and 7, with the constraints that a maximum of 5 could be obtained from any one class within a particular grade, and excluding those children who were planning to relocate within the succeeding 12 months. The remaining 10 subjects were obtained from a first year Secondary School class (Grade 8). All children were tested prior to participation with a Snellen eye chart, to check visual acuity. Table 3.1 provides a breakdown of the subjects by age and sex.

TABLE 3.1. Breakdown of subjects by Grade, Sex and Age.

Grade	Sex (m/f)	Mean Age (Years,Months)	Range
2	6m 4f	7y 4m	6y7m - 8y6m
3	5m 5f	7y 10m	7y2m - 8y4m
4	5m 5f	8y 8m	8y5m - 8y11m
5	4m 6f	9y 10m	9y3m - 10y7m
6	6m 4f	10y 11m	10y4m - 11y4m
7	6m 4f	11y 11m	11y6m - 12y4m
8	6m 4f	13y 2m	12y10m - 13y9m
Adult	7m 3f	21y 10m	18y1m - 27y3m

(ii) Apparatus and Design

A modified Gerbrands four field tachistoscope was used to measure binocular inspection time (IT). The stimulus and masking figures described in experiment 1 were also used in this study. Subjects were tested individually, the PEST procedure being used to establish the stimulus exposure duration at which 85% accuracy was achieved. Each trial involved the following sequence of events: A cue dot was presented initially for a duration of 1000 ms. This figure would appear at a location designed to facilitate discrimination, approximately half-way between the two legs of the TS figure, at the point at which the difference in length would be evident. The cue was followed at offset by a TS of variable duration. A masking stimulus (MS), matched in form to the TS and completely overlapping it, immediately followed offset of the TS. Young children were instructed to press the key on the "same side" as the short line and were assisted in their response selection by reproductions of the two stimulus figures placed above the respective keys. Any child exhibiting difficulty in practice trials was further asked to point physically to the correct responses, before pressing the response key.

Practice consisted of a minimum of 60 trials, and was discontinued beyond this when a satisfactory level of accuracy had been achieved. In the older groups (Grades 4 and above), subjects completed 10 trials at a duration of 500 ms, 10 at 300, 10 at 200, 10 at 100, 10 at 50 and 10 at 25 msec. The younger children, those from Grades 2 and 3 were also given 10 trials at 1000 ms and 10 at 750, all of which required completion to the 100% accuracy level. Performance accuracy was stressed and speedy responding discouraged. The 85% accuracy exposure duration was subsequently obtained, and, by reference to the normal cumulative ogive, IT derived.[1]

(iii) Procedure

The SOA (i.e. target exposure duration) at which 85% accuracy was achieved was measured, together with two other tests for most subjects, in one session of approximately an hour's duration. Each subject was allowed a brief rest period between completion of each test, in an attempt to alleviate fatigue and maximize attention to each new task. The Peabody Picture Vocabulary Test (PPVT) was used to provide an estimate of MA and IQ., after which the Speed of Information Processing Subscale of the BAS was administered to each child with the appropriate subtest selected according to the child's age. This test was not administered to the two youngest groups or the adult group since norms were not available for these. Nor did the adult group complete the PPVT it being assumed that the IQ of these subjects was at least average.

3. Results and Discussion

(i) The Relationship between IT and Age

The mean 85% accuracy exposure duration of each group are listed in Table 3.2. These were converted to IT to enable comparison with past research. As is obvious from the table the means decreased substantially with increasing age. The resulting overall correlation between IT and age was -.37.

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[1] Previous studies which have examined IT by the use of the MCSD procedure have shown that the function relating accuracy to target exposure duration conforms to the top half of the normal cumulative ogive, passing through zero at 50% accuracy (Nettelbeck, 1982). Given this fact, it is possible to extrapolate an estimate of IT (i.e. 97.5% accuracy) from other points on the curve (eg. 85%) by the simple multiplication of a constant which is equal to the ratio of the Z scores associated with 97.5% and 85% of area under the normal curve (i.e. 1.96/1.04 = 1.88). In other words, IT is simply an arbitrary value useful in cross-study comparisons as a uniform estimate of processing speed. The SOA at which 85% accuracy is achieved provides a satisfactory index for within-study comparisons, with no extrapolation needed.

TABLE 3.2. Mean 85% Accuracy Exposure Duration (ms), Standard Deviations (in parentheses) and Range. Estimates of IT have been extrapolated from the normal cumulative ogive.

Grade	N	Mean		IT	Range
2	10	231	(171)	434	29-450
3	10	133	(45)	250	64-213
4	10	125	(48)	235	34-193
5	10	115	(46)	216	64-215
6	10	101	(40)	190	34-171
7	10	70	(43)	132	18-156
8	10	86	(24)	162	26-107
Adult	10	61	(44)	115	13-130

The large difference between the standard deviation of the measure among Grade 2 children and that for all other groups raised serious doubts as to the validity of the data from this grade. Furthermore, difficulty in obtaining measures from certain of these children due to their unwillingness to attend and/or persist for the required length of time, suggested that recalculation of the IT-age correlation after the deletion of this group would be appropriate. The correlation calculated on this basis increased to $r = -.41$ ($n = 70$, $p < .001$).

A oneway analysis of variance of IT performance across groups indicated that performance varied significantly with age ($F(7,72) = 5.86$, $p < .001$; refer to Appendix 3.1 for the complete summary table for this analysis). Neuman-Keuls post hoc comparisons of these groups produced two subsets, one of which consisted of Grades 3, 4, 5, 6, 7, 8 and adults and the second of which consisted of Grade 2 children alone.

As previously stated, doubts about the validity of data obtained from the youngest group led to recalculation of the IT-age analysis after the deletion of these subjects. The resultant $F(6,69) = 4.18$ remained significant ($p < .01$), with Neuman-Keuls post hoc comparisons distinguishing 3 subsets;

one composed of the four oldest groups (Adults, Grade 8, 7 and 6 children); the second, the four oldest groups of children (Grades 8, 7, 6 and 5); and the third composed of the four youngest groups (Grades 3, 4, 5 and 6) plus the Grade 3 children.

If the Grade 8 results are accepted as anomalous, the other data can be interpreted as illustrating a function which relates age to IT in an asymptotic nature, with performance improvement decreasing significantly with increasing CA. This is seen in Figure 3.1.

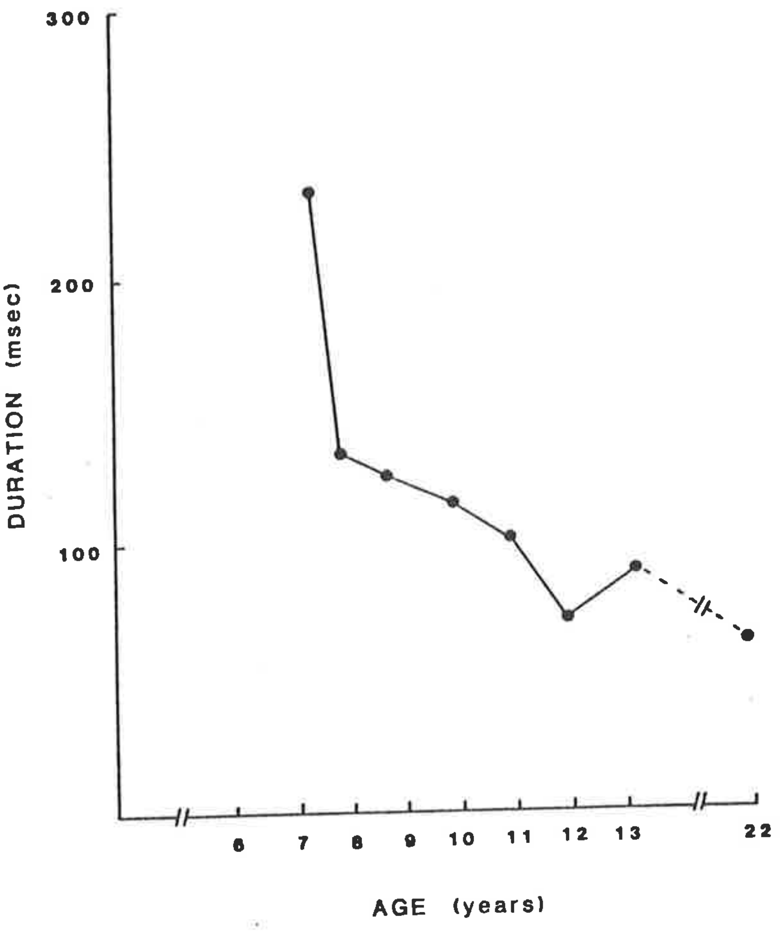


FIGURE 3.1. Mean 85% Accuracy Duration (ms) of subjects between the ages of 6 and 22 years.

The developmental asymptotic nature of this function was also reflected in a trend analysis which indicated that the data exhibited both a significant linear ($F(1,72) = 29.12$, $p < .001$) and quadratic trend ($F(1,72) = 5.43$, $p < .05$). However, reanalysis excluding the youngest found only a significant linear trend ($F(1,63) = 22.61$, $p < .001$).

(ii) The Relationship between IT, PPVT and the BAS Speed subscale

Means were calculated for each group on the Peabody Picture Vocabulary Test and the Speed of Information Processing subscale of the British Ability Scale. These are set out in Table 3.3. As can be seen from this Table, all Grades barring 2 and 8 showed a mean Mental Age (MA) considerably above the CA. However, the youngest group fell below, and this may account, in part, for the difficulty evidenced amongst some of the children in this group in grasping the intricacies of the IT task.

TABLE 3.3. Mean Chronological Age (CA), Peabody Picture Vocabulary Test score (PPVT), Mental Age (MA) as derived from the PPVT and British Ability Scale, Speed of Information Processing subscale score (Speed-BAS), for each grade.

Grade	CA	PPVT	MA	Speed-BAS
2	7.4	63	6.11	-
3	7.10	73	9.6	-
4	8.8	81	11.0	63
5	9.10	86	12.2	75
6	10.11	93	13.9	125
7	11.11	89	13.0	120
8	13.2	109	13.2	137

Closer examination of the relationship between MA as measured by the PPVT and IT revealed a significant correlation of -.43. The small numbers in each group resulted in a severely restricted IQ range, and, concomitantly severe confounding of MA with CA. When the latter factor was partialled out of the overall correlation it reduced to -.19 (p = .06). Correlations between MA, CA and IT are set out in Table 3.4.

TABLE 3.4. Correlations between Inspection Time, Mental Age and Chronological Age. (Full correlations are listed to the right of the diagonal; that to the left has partialled out CA.)

FACTORS	Mental Age	Inspection Time	Chronological Age
Mental Age		-.43*** (n=70)	.74*** (n=70)
Inspection Time	-.19 (n=67)		-.43*** (n=70)

*** p < .001 (one-tailed)

Correlations of the Speed subscale with IT produced an overall r = -.53 (n = 50, p = .001) which remained significant when CA was partialled out (r = -.38, n = 47, p < .01). Examination of this result within groups showed the correlation to be strongest among the youngest groups, decreasing to non-significance by Grades 7 and 8 (refer to Table 3.5).

TABLE 3.5. Correlation of Speed (BAS) and IT within grades.

Grade	Correlation
4	-.48
5	-.83***
6	-.53
7	+.15
8	-.28

*** p < .001 (one-tailed)

4. Conclusions

The results provide a general picture of an input processing system, the speed of which appears to relate to age in some systematic manner. From the data it is possible to discern the probable existence of a developmental function which may asymptote at a point somewhere around adolescence. Thus, these results reassert the conclusions of many other studies based on the backward masking procedure, and similar paradigms - that the speed at which information inputs into the processing system increases with increasing age. However, they also contradict the results of one of the only two previously existing developmental IT studies.

As discussed in Chapter 1, pp. 28-29, the Nettelbeck and Lally (1979) study comparing the IT performance of children aged 7, 8, 9 and 10 years with that of adult retarded and nonretarded subjects found no statistically significant difference between any of the nonretarded groups. This finding is contrary not only to the results described above, but also the results of experiment 1 and those of Wilson (1980). All three of these studies have appeared to show that the very young children, aged between 7 and 8 years, exhibit an input processing speed which differs significantly from older children, aged

10 to 11 years, as well as from adults, while these older groups fail to show any significant difference. The Nettelbeck and Lally study, while finding no significant IT differences between ages, did conclude on the basis of reaction times measured concomitantly with IT, that children reached a decision about the location of the shorter line in a different way to adults. It seems likely, therefore, that Nettelbeck and Lally's results are anomalous in some respect, although inevitably this ambiguity mitigates against the total endorsement of the cross-sectional data reported here. This is especially so in light of the inherent difficulties of the cross-sectional methodology, and there is a need for a more conclusive examination of the issue.

The results described above also provide further evidence on the issue of validity and the IT measure. The significant correlation between the BAS, Speed of Information Procssing subtest and IT, although not large, does suggest that the latter is measuring the speed at which information is processed. The comparatively small size of the correlation with age partialled out ($r = -.35$) is not unexpected, given that the BAS subscale is concerned with all aspects of the processing chain (decision making, response selection, etc.) while IT is assumed to be predominantly an index of input speed. The larger IT - age correlations among younger age groups is open to two possible interpretations. It may be that processes other than inputing speed (eg. scanning eye movements), become increasingly influential in determining the response to the BAS Speed of Information Processing items with increasing age, or alternatively, it might reflect the nature of the IT-IQ relationship. If, as is claimed by the designers Elliott and Murray (1977), the BAS Speed of Information subscale is a good measure of g, theorists such as Brand (1981) would predict that the correlation is logically higher at lower MA where it is more likely to reflect fluid intelligence, as opposed to later ages where intelligence as measured by IQ test is increasingly a function of external, environmental factors.

The notion of an IT-IQ association is further examinable in the PPVT data, although in light of the limited numbers in each group, the wide age distribution used, and small IQ range, one would not expect the resultant IT-IQ correlation to be high. There is a suggestion in the data that IT may relate in some way to IQ; however, the nature of the evidence is such that it is impossible to draw any substantial conclusion.

In summary, the primary usefulness of the cross-sectional study described above is as a guide to those areas which require more detailed examination. The suggestion of a developmental function provides a preliminary picture of the possible nature of the age-IT relationship, although the details are far from clear. Completion of a longitudinal study would provide a means of verifying the developmental trend suggested in the cross-sectional data, as well as providing a means for assessing test-retest reliability over a period of one year. Similarly, the possibility that IT may relate to intelligence, particularly at younger MA levels, is an issue that requires further clarification. The results described above provide limited support for this hypothesis. However, a study which encompasses a wider range of IQs at each MA is required to satisfactorily test this hypothesis.

5. Experiment 2.2. A Longitudinal Follow up of the Cross-Sectional IT Study.

(i) The Longitudinal Method in Psychology

With the increasing sophistication of developmental psychology satisfaction with the existing methodologies has waned, with only the longitudinal method retaining some semblance of popularity. Although it involves far greater expenditure of time and effort than alternative techniques, it provides a means for alleviating the confusion which arises when cohort effects (i.e. systematic differences in the shape of the developmental function resulting from extraneous factors like experience and environmental influences) confound maturation effects.

Primarily it is the property of a longitudinal study to provide the data from which a developmental function can be derived that accounts for its widespread popularity. "Developmental function", in this context, is intended to refer to "the form or mode of the relationship between an individual's age and the changes occurring in his responses on some specified dimension of behaviour over the course of his life." (Wohlwill, 1970, p. 151). Age, therefore, is part of the dependent variable, and it is the behaviour changes which are the substance of analysis. In other words, absolute amounts and types of behaviour that are evoked at any point in time, are not as important as the nature of the changes that occur over time.

Two basic longitudinal approaches are possible. The first involves independent random samples of the same cohort, drawn at successive times of measurement, representing different ages (Schaie, 1965). The second, more widely used approach, involves the repeated measurement of the same sample from the same cohort group.

The advantages associated with the longitudinal repeated measures approach are profound, especially at that point in a research project where the objective of the study is actually to map the developmental function. A repeated measures study, by virtue of its ability to take into account intra-individual variability, is more sensitive to age effects and also permits analysis of individual trends (Baltes, 1968). It provides the possibility of mapping individual development sequentially, and while corresponding functions for different individuals may exhibit some overall communality, it is possible that they would not be identical and that information would be lost by arbitrary grouping or averaging of results.

The IT task appears to be ideally suited to the longitudinal design. Its relatively low cognitive load increases the probability of eliciting meaningful and comparable responses across a wide age spectrum while retaining individual stability and reliable individual differences. As Wohlwill (1970) has pointed out, there are three types of information preserved by the longitudinal design, all of which contribute uniquely to the developmental function. These consist of:

1. The maintenance of individual identity. Repeated measurement of the same individuals ensures a more comprehensive examination of the exact nature of development by mapping the variability of the developmental function.
2. Re-measurement over a specified time period provides a picture of the temporal patterning of the developmental changes which occur in a given individual on a particular variable.
3. Lastly, repeated measurement illustrates the changing value of the developmental function by patterning the changing relationship between the variables.

In view of the advantages attached to the longitudinal methodology, an analysis of IT using this technique would appear desirable for mapping the development of input processing speed. Admittedly, there are a number of difficulties associated with repeated measures studies, especially those which take place over a period of a number of years. However, combining evidence from both cross-sectional and longitudinal sources should provide a more accurate description of the changing nature of performance with increasing age.

(ii) Practice Effects

A serious limitation of the longitudinal method is the confounding of genuine age-based performance changes with those arising from practice. Thus, in a repeated measures study any change in individuals over the period of re-measurement may be indicative of changing competence, which in turn may be due to either increasing cognitive maturity, or increasing familiarity with the task, or perhaps most probably, a combination of these factors.

Data from backward masking studies indicate that practice in such tasks does produce facilitatory effects (Braff, Sacuzzo, Ingram, McNeil & Longford, 1980; Schiller, 1965; Smith & Schiller, 1966). Ward and Ross (1977) examined the influence of practice among adult subjects on a central backward masking task completed over a period of 3 days. Results showed large improvements in performance over the period of testing, with a particularly large decrease in critical SOA between days 1 and 2. Ward and Ross (1977) hypothesized that this result could reflect the development, with experience, of more efficient strategies whereby critical TS features are enhanced and interference from irrelevant MS features attenuated. However, comparisons between groups distinguished on the basis of intelligence suggest that while practice does affect performance, group differences are not eliminated, with both retarded and nonretarded subjects improving over sessions (Friedrich, Libukman, Craig & Winn, 1977).

Nettelbeck, Evans and Kirby (1982) reproduced this latter result in an IT study of practice effects. In this study, a group consisting of 10 workshop clients (mean IQ = 60) was compared on the tachistoscopic IT task with a group of 10 undergraduate university students, each subject completing approximately 800 trials over 3 sessions. As well as examining practice effects, Nettelbeck et al. (1982) were concerned with the possible influence of response complexity on performance. They found the response factor to have no significant effect but did find that practice significantly decreased estimates of IT obtained from each group, while overall group differences were maintained. Although an asymptote was not reached data suggested that there was no difference in rate of improvement between retarded and nonretarded adults.

The possibility that groups distinguished on the basis of age might show differential practice effects was examined in a study by Hertzog, Williams and Walsh (1976). In their experiment a central masking paradigm was used to examine the effects of practice among subjects aged approximately 66 and 19 years. Results indicated that critical SOA for all groups was reduced by practice over a period of 5 consecutive days. The magnitude of change, however, did not vary with age, leading the authors to conclude that "there was no age-related decrement in the adaptability of central perceptual processes." (Hertzog et al., 1976, p. 428).

Developmental backward masking studies involving children, which have examined change in critical SOA over a period of 2 sessions, have shown that practice produces a significant effect (Ferreira, 1978; Gummerman & Gray, 1972; Liss & Haith, 1970). These studies suggest that caution is required when interpreting developmental differences in backward masking studies, because of the possibility that age differences in learning and memory processes may confound genuine processing speed differences. Longitudinal studies in which repeated measures are taken are particularly prone to confounding from this factor and it is only by including a practice control group that performance differences arising from maturation can be distinguished from those due to task-specific learning.

(iii) Reliability

The additional value of a test-retest design in psychology is the opportunity it provides for assessing the reliability of a measure. Moreover, a study which follows the same subject through a period of a number of years provides a means for observing individual differences. The assessment of reliability is essential to the comprehension of any results obtained with a developmental measure. It is only by acknowledging the amount of "measurement error" within a single score, that is, fluctuations which are random or irrelevant, that any real change in performance can be appreciated.

The issue of reliability of a measure becomes complicated when a heterogenous subject pool is involved - especially one differing greatly in age. Young children are notoriously less 'reliable' than their older counterparts, possibly as a result of their increased susceptibility to distraction from both internal and external sources. Therefore, when measuring subjects of different ages on IT, any performance difference must be interpreted in the light of the possibility that the data from the young children may be comparatively less reliable than that of the older children and adults. Despite this problem, it is hypothesized that the IT measure should elicit reliable measures from all groups since the task involves low cognitive load and conditions are such as to reduce distraction from external sources.

Perceptual processing speed test - retest reliability has been assessed in other backward masking studies. In a study by Dember and Neiberg (1966) 17 college students were tested twice over a period of a couple of days to obtain a 'maskability' index. The resultant Spearman's rho correlation was .92, indicating that, at least with adults, processing speed indexes appear relatively reliable.

Nettelbeck (in press) has summarized data on the reliability of the IT measure with the statement that, "measures of IT remain fairly stable from one occasion to another when repeated measures are made from the subjects, although occasional large individual changes have been found." Even the existence of practice effects with the subsequent decreasing IT across sessions does not mitigate against the obtaining of high correlations as relative performance within groups appears to remain consistent.

Correlation co-efficients obtained in IT studies at Edinburgh University have averaged .8, primarily in studies which have involved both retarded and nonretarded subjects (Brand & Deary, 1982). The range of the test - retest correlations obtained in Adelaide has been wide, stretching from .20 to .97 and averaging out at .71 from 31 instances in samples involving adult retarded subjects, and from .25 to .92, the average being .65 from 36 instances with nonretarded adults. Test-retest correlations involving elderly subjects have approximated the average of the nonretarded adults (Nettelbeck, in press).

As a whole, correlational studies involving adults suggest that although reliability varies between experiments it is generally of a magnitude as to ensure that the task is succeeding in measuring a viable and stable ability which can consistently distinguish individuals over a period of time. A longitudinal study of IT, as well as elucidating the nature of the developmental function would concomitantly establish the test-retest reliability or otherwise of the measure over the period of a year and longer.

6. Method

(i) Subjects

(a) Longitudinal Study.

A year after the original measures were obtained in the cross-sectional study a second measure of IT was taken. In light of the apparent asymptotic nature of development and the difficulty in following children from primary to high school, only primary schools groups were re-measured; i.e. the previous Grade 2 groups, now in Grade 3, and similarly the 3/4, 4/5, 5/6 and 6/7 groups. The adult group was also re-measured. A total of 5 children were lost in this period from the sample: 2 from Grade 5/6, and one each from Grades 3/4, 4/5 and 6/7.

In the following year (i.e. 24 months after the initial measure), a third estimate of IT was obtained. At this time the subjects were in the following grades: 4 (formerly 2, 3), 5, 6 and 7. A further 5 subjects were lost on this occasion reducing the original sample sizes from 10 to 9 in the first group; to 8 in the second, 9 in the third, and 5 in the fourth; (refer to Table 3.6 for a breakdown of the sample).

(b) Practice Control Study.

An independent sample of 30 subjects completed the IT task on two occasions serving as a control for practice effects in the longitudinal study. This sample consisted of 10 adult first-year university students with a mean

TABLE 3.6. Subject Breakdown of the Longitudinal Study over the Period 1981 - 1983.

COHORT*	GRADE 2	3	4	5	6	7
1975						1981 (n=10)
1976					1981 (n=10)	1982 (n=9)
1977				1981 (n=10)	1982 (n=8)	1983 (n=5)
1978			1981 (n=10)	1982 (n=9)	1983 (n=9)	
1979		1981 (n=10)	1982 (n=9)	1983 (n=8)		
1980	1981 (n=10)	1982 (n=10)	1983 (n=9)			

* Cohort is defined by the year of commencing school.

age of 20 years 2 months (range 17 years 1 month to 38 years 6 months) and 20 children, 10 each selected from Grades 2 and 7. The mean age of the Grade 2 children was 6 years 9 months (range 6 years 3 months to 7 years 6 months) and of the Grade 7 children, 11 years 9 months (range 11 years 5 months to 12 years 4 months). As may be seen by comparison with equivalent groups in Table 3.1, ages within these samples were comparable to those of subjects in the cross-sectional study, i.e. at the beginning of the longitudinal study. It should also be noted that the practice control sample was obtained from a different school than those children involved in the longitudinal study.

All subjects' eyesight was checked with a Snellen eye-chart prior to participation.

(ii) Apparatus and Design

(a) Longitudinal Design.

The same tachistocsopic IT task was used for all three measures obtained between 1981 and 1983. In successive sessions, the child was asked what, if anything, he remembered of the task which was then re-explained to each child before commencement of the experimental trials. Practice remained unchanged across sessions consisting of: 10 trials at 500, 300, 200, 100, 50 and 25 ms for the older groups with an extra 10 trials at 1000 and 750 ms for the youngest group.

(b) Practice Control Study.

Exactly the same apparatus and design was involved in the practice control experiment as in the major study, with special care taken to ensure that the Grade 2 children understood the nature of the task.

(iii) Procedure

(a) Longitudinal Study.

Measures were taken approximately one year apart. At the end of the third year each child was "debriefed" and discussed the task with the experimenter. Both of the follow-up longitudinal sessions took approximately 20 minutes to complete, with most children professing to remember the task from the previous occasion(s).

(b) Practice Control Study.

To distinguish performance effects due to practice in the longitudinal task from those due to development, the practice control involved the measurement of children and adults twice over a period of approximately 2 weeks. At the beginning of both the first and the second sessions each child completed the practice trials described above, these being followed after a brief pause by the experimental trials. As with all groups in the study, accuracy and not speed of responding was stressed. The TS duration at which 85% accuracy was achieved was derived by the PEST procedure.

7. Results

(a) Practice Control Study.

Mean 85% accuracy duration for each age was computed for both sessions. (Raw data is listed in Appendix 7). Table 3.7 lists these results. As can be seen from an examination of this data, all groups exhibited a small performance improvement, the absolute size of which decreased slightly with age (17% in Grade 2; 12% in Grade 7; 12% Adults).

TABLE 3.7. Mean 85% Accuracy Duration Exposure (ms), Standard Deviation (in parentheses) and Range for Practice Control Subjects.

Grade	First Measure		Second Measure	
	Mean	Range	Mean	Range
2	155 (84)	38-307	129 (79)	23-271
7	89 (45)	20-160	78 (34)	25-122
Adults	58 (37)	9-116	51 (27)	16-99

An analysis of variance comparing performance across sessions and grades showed this improvement to be significant, with all groups exhibiting a facilitatory practice effect ($F(1,27) = 6.44$, $p < .05$). A significant main effect for grade ($F(2,27) = 6.31$, $p < .01$) reinforced the results obtained in the cross-sectional study of an age difference in IT performance. (Refer to Table 3.2, p. 69). The nonsignificance of the Grade x Session interaction ($F(2,27) = 1.11$) indicated that no group improved significantly more than any other with practice. (Refer to Appendix 3.3 for details of this analysis).

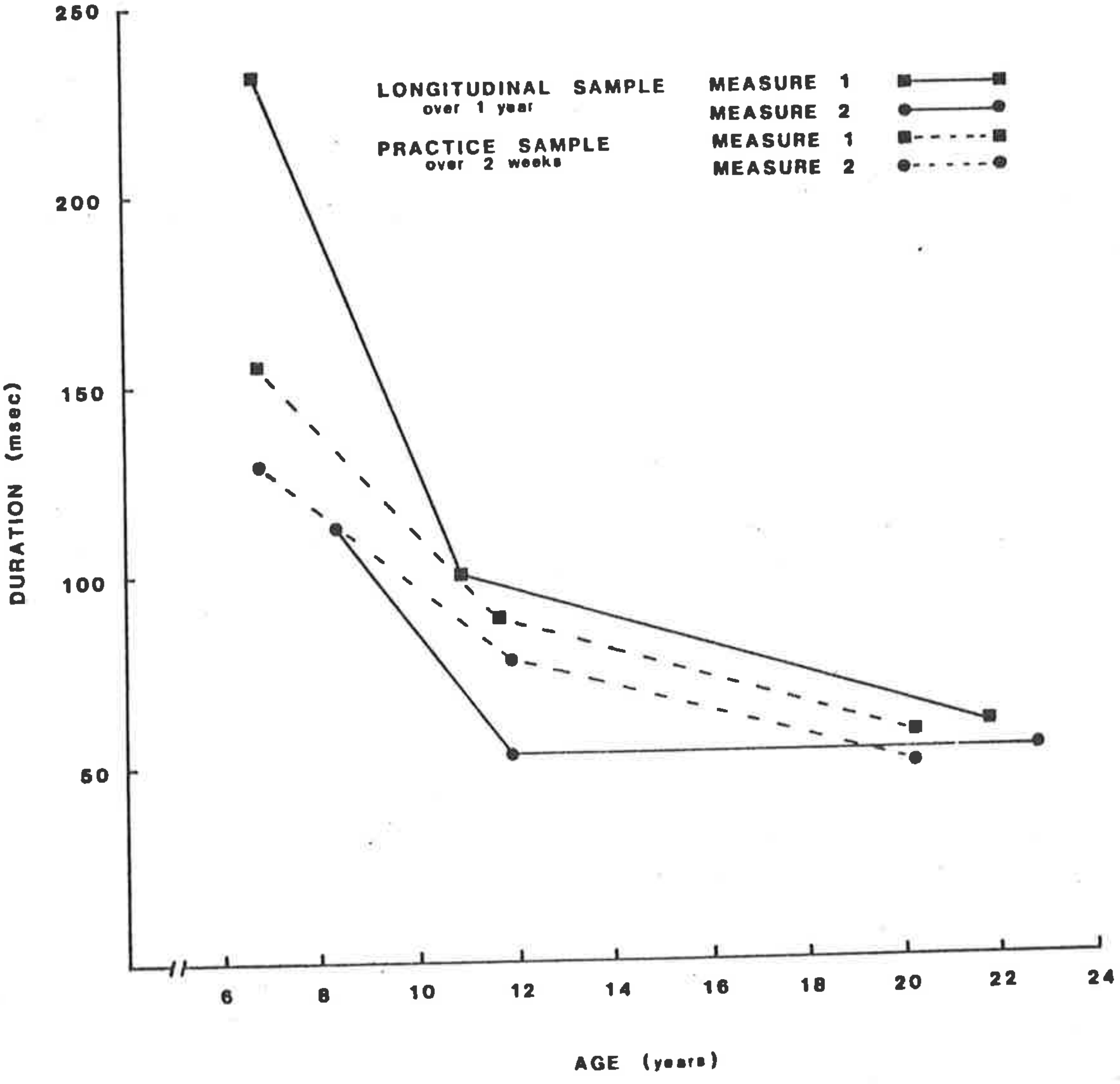


FIGURE 3.2. Two estimates of Mean 85% Accuracy Exposure Duration (SOA) over 1 year or 2 weeks for children and adults.

Planned comparisons showed IT to be significantly greater among Grade 2 children than in the 2 older groups (F(1,27) = 11.30, p < .01) with these two groups not differing significantly from one another (F(1,27) = 1.31). Thus, the same developmental pattern found in the cross-sectional study was evidenced - decreasing IT up until 11 years of age with no significant change in subsequent years. (Refer to Figure 3.1, p. 70)

Test-retest correlations indicate that IT is a reliable measure over a period of 2 weeks, despite the existence of practice effects. Each of the Pearson's r of .87 found in each of the 3 age groups were significant at the .001 level.

(b) Longitudinal Study.

Two sets of analyses of the longitudinal results were performed; the first after the second year, the second after the third. (Refer to Appendix 3.2.1.) Examination of Table 3.8 enables a comparison of means across both age and session. The means obtained in the cross-sectional study of the first year have been recalculated on the reduced sample measured in the follow-up.

TABLE 3.8. Mean 85% Accuracy Exposure Duration (ms) and Standard Deviations (in parentheses) calculated over the period of 2 years.

Group	Measure 1 Mean	Measure 2 Mean	N	% Improvement
Grade 2/3	231 (171)	113 (80)	10	52%
Grade 3/4	128 (45)	89 (70)	9	30%
Grade 4/5	117 (44)	87 (32)	9	26%
Grade 5/6	123 (48)	69 (41)	8	44%
Grade 6/7	98 (42)	53 (26)	9	46%
Adults	61 (44)	54 (55)	10	11%

The longitudinal study replicated the improved performance in all groups which was observed in the control study. A repeated measures analysis of variance examining change in IT performance over a period of 1 year produced a significant effect for both Group (i.e. Age cohort) and Session (1981 vs 1982) with F(5,54) = 4.16 and F(1,.49) = 31.91 respectively ($p < .01$). Furthermore, a significant Group x Session interaction was observed (F(5,59) = 3.13, $p < .01$), reflecting the asymptotic nature of development once again, with the youngest children showing greatest performance change over the period of 1 year. (Refer to Appendix 3.4 for a summary of this analysis).

Comparison of the amount of performance improvement which occurred over 1 year (i.e. in the longitudinal study) with improvement which occurred over a period of two weeks (i.e. in the practice control study) in groups aged 7 years, 11 years and adults indicated that longitudinal change could not be explained purely in terms of practice or task-specific knowledge. A repeated measure analysis of variance looking at the influence of Session, Cohort and Period between Sessions, with planned comparisons contrasting the performance of the youngest group with that of the two older groups, produced the following significant results: A significant effect for Age Cohort (F(2,54) = 12.92, $p < .01$) indicated that the youngest children in both the practice and longitudinal study had a significantly higher 85% accuracy duration than the 11 year old or adults (F(1,54) = 24.40, $p < .01$: Refer to Appendix 3.5). A significant effect for Session (F(1,53) = 18.77, $p < .01$) reflected the performance improvement exhibited in both the longitudinal and practice control studies, while a significant Session x Period between remeasurement interaction (F(1,53) = 6.73, $p < .05$) indicated that performance improvement over a year was significantly greater than performance improvement over a period of two weeks. This difference is illustrated in Figure 3.2. Further, a significant Age Cohort x Session interaction ($F(2,53) = 5.49$, $p < .01$) provided support for the notion of an asymptote in performance, with the youngest group improving to a greater extent than older children or adults. Post hoc comparisons also showed that the youngest children improved most across sessions which were separated by a period of 1 year ($p < .05$). Thus, the results of this analysis indicate that change in performance observed over a period of 1 year could not be explained solely by reference to practice, since change occurring over a year was significantly greater than that observed over 2 weeks, where the opportunity to develop task-specific knowledge was as great, if not greater. It would therefore appear that some factor, over and above the opportunity to develop more efficient strategies, must account for performance differences. One such possibility is changes in the efficiency of the input processing function occurring with maturation.

The measurement of different groups of same-age children from different schools on the same task has provided a means for testing the stability and generality of obtained age performance differences. In other words, by obtaining measures from different locations, it has been possible to assess whether the results were an artifact of an abnormal sample. This is especially important in light of the data obtained from the youngest children in the cross-sectional study with its associated high standard deviation. (Refer to Table 3.2, p. 69).

Within age comparisons using an unrelated samples t-test on measures obtained from the cross-sectional and control studies, showed no significant difference between any of the comparable age groups, providing support for the notion that it is possible to obtain a "meaningful" measure of IT from a wide age range and concomitantly discern any existing developmental influence; (refer to Table 3.9).

TABLE 3.9. Unrelated samples t-tests between IT measures obtained from same age comparison groups at different locations. (All are nonsignificant).

SCHOOL (Date of testing)	School 2: Grade 2 (1982) Control Study	
	Measure 1	Measure 2
School 1: Grade 2 (1981) Longitudinal Study	t = 1.25	t = 1.70
	School 2: Grade 7 (1982) Control Study	
	Measure 1	Measure 2
School 1: Grade 7 (1981) Longitudinal Study	t = 0.90	t = 0.43
School 1: Grade 7 (1982)	t = -1.98	t = -1.72

Test-retest reliability measured over the period of 1 year was also analyzed on completion of the second measure. As can be seen from the results listed in Table 3.10, reliability increased with increasing age peaking at .90 in adulthood.

In the following year, 12 months after the second measure was obtained, the task was administered a third time. Although the original sample was considerably reduced, mean IT data showed improvement to occur in all groups. Table 3.11 lists the means calculated on the basis of the reduced sample for each cohort group.

TABLE 3.10. Test-retest reliability obtained over the period of one year.

Group	Correlation Coefficient
Grade 2/3	.58*
Grade 3/4	.85**
Grade 4/5	.53
Grade 5/6	.74*
Grade 6/7	.80**
Adults	.90***

* p < .05 (one-tailed)
** p < .01 (one-tailed)
*** p < .001(one-tailed)

TABLE 3.11. Mean 85% Accuracy Exposure Duration (ms) and Standard Deviations (in parentheses) calculated over the period of 3 years, on the reduced sample of the third year.

Group	Measure 1 Mean		Measure 2 Mean		Measure 3 Mean		N
Grade 2/3/4	252	(167)	123	(78)	80	(36)	9
Grade 3/4/5	136	(41)	94	(74)	63	(50)	8
Grade 4/5/6	117	(44)	87	(32)	57	(27)	9
Grade 5/6/7	123	(55)	65	(47)	55	(31)	5

As can be seen from an examination of Table 3.11, each group exhibited decreasing IT with increasing age over the entire 3 years. A multivariate repeated measures analysis of data in the third year examining the within-subject factor, Session (1981, 1982, 1983) and the between-subject factor Age Cohort group (Group 1 = Grade 2/3/4, Group 2 = Grade 3/4/5, Group 3 = Grade 4/5/6, Group 4 = Grade 5/6/7) indicated a significant decrease in 85% accuracy duration across sessions (F(2,59) = 24.53, p < .01) and a nonsignificant effect for Age Cohort group. A significant interaction of Age Cohort x Session was also observed (F(6,59) = 2.36, p < .05), with post hoc comparisons indicating that the youngest cohort group improved more than any other (p < .01). In other words, while all cohort groups showed significant improvement over the three years of remeasurement, the amount of improvement depended upon how close to the oldest age represented a cohort group was, with the convergence of cohort groups upon asymptote mitigating against a significant Group effect in the final year of measurement. (Refer to Appendix 3.6 for the summary of this analysis).

Finally, test-retest correlations were examined once again. The resulting r's tended to decrease with increasing attentuation of range as the period between measurement increased. However, in the Grade 4/5/6 groups, the correlation increased; (refer to Table 3.12). The lowest correlation (.20) occurred between the measures of the Grade 2 children in 1981 and 1983. Given the large SD of the original measure (refer to Table 3.2, p. 69), this finding is not surprising, with the correlation for this group increasing to its most reliable in subsequent sessions (1982/1983).

The longitudinal results of the third year reinforce those of the second and those of the initial cross-sectional study. They show IT to be a reliable measure of input processing speed over a wide age range, reflecting stable individual differences. Furthermore, they indicate that IT relates to age over and above practice effects up until the early adolescent years.

TABLE 3.12. Test-Retest Correlations over period 1981, 1982, 1983.

Group	Year	
	1982	1981
Grade 2/3/4 (n=9)	Grade 3	Grade 2
1983 (in Grade 4)	.59*	.20
1982 (in Grade 3)		.50*
Grade 3/4/5 (n=8)	Grade 4	Grade 3
1983 (in Grade 5)	.97**	.94***
1982 (in Grade 4)		.90***
Grade 4/5/6 (n=9)	Grade 5	Grade 4
1983 (in Grade 6)	.52	.67*
1982 (in Grade 5)		.55
Grade 5/6/7 (n=5)	Grade 6	Grade 5
1983 (in Grade 7)	.80	.71
1982 (in Grade 6)		.80

* $p < .05$ (one-tailed)
** $p < .01$ (one-tailed)
*** $p < .001$ (one-tailed)

8. Discussion

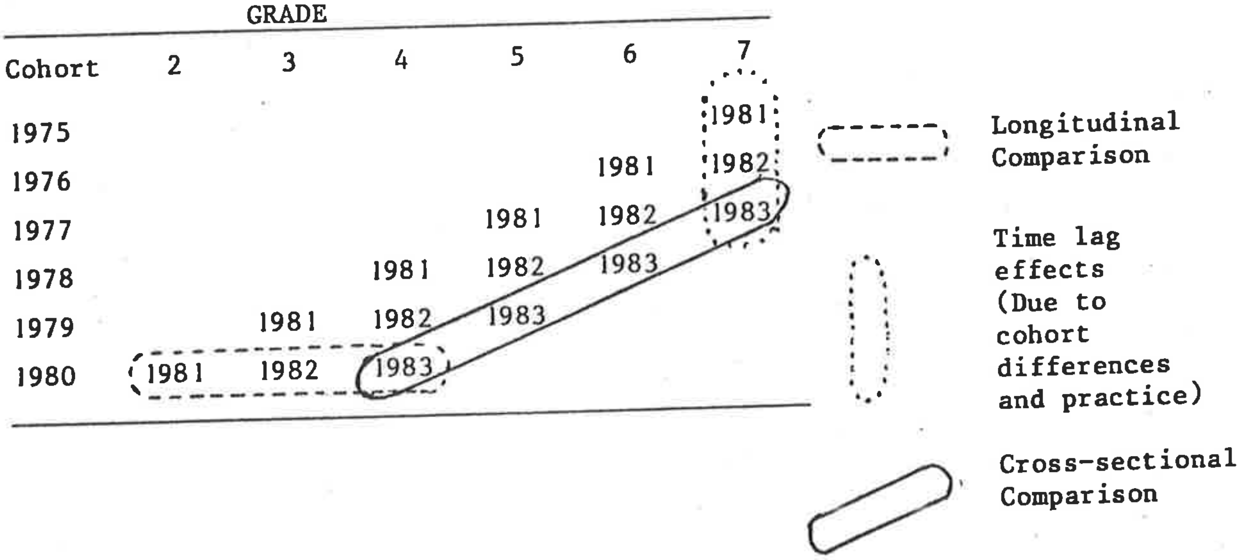
A summary table of the data obtained in the longitudinal study is presented below as Table 3.13. It lists all results in a developmental matrix (following Baltes, 1968), which enables the reader to discern the performance differences that arise from the three factors: Cohorts, Time of Measurement, and Age. The diagonals in the matrix distinguish successive cross-sectional studies between the years 1981 and 1983. Although the range of means decreases as the number of ages involved lessens, all three cross-sections show decreasing IT with increasing age. This is in spite of the time lag

TABLE 3.13. Mean 85% Accuracy Exposure Duration (ms) measured in the years 1981, 1982 and 1983.

COHORT (Year of commencing school)

Cohort (Year of)	GRADE 2	3	4	5	6	7
1975	–	–	–	–	–	70 (n=10)
1976	–	–	–	–	101 (n=10)	53 (n=9)
1977	–	–	–	115 (n=10)	69 (n=8)	55 (n=5)
1978	–	–	125 (n=10)	87 (n=9)	57 (n=9)	–
1979	–	133 (n=10)	89 (n=9)	63 (n=8)	–	–
1980	231 (n=10)	113 (n=10)	80 (n=9)	–	–	–

KEY:



Cohort	GRADE 2	3	4	5	6	7
1975						1981
1976					1981	1982
1977				1981	1982	1983
1978			1981	1982	1983	
1979		1981	1982	1983		
1980	1981	1982	1983			

Longitudinal Comparison

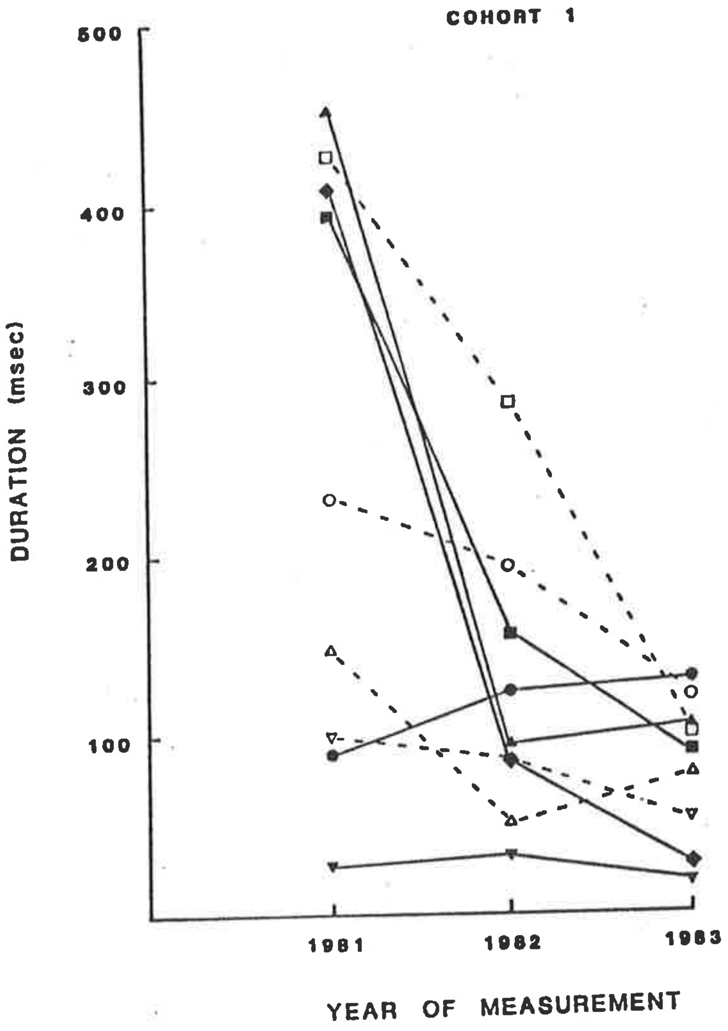
Time lag effects (Due to cohort differences and practice)

Cross-sectional Comparison

effects reflected in the vertical sections which are, at least in part, a function of practice. In other words, over and above performance differences due to practice, groups could still be distinguished by reference to age. Practice never totally eliminated performance differences among children of different ages. The longitudinal comparisons illustrated by the horizontal sections reinforce this finding, illustrating consistent improvement in all cohort groups over the period of 3 years.

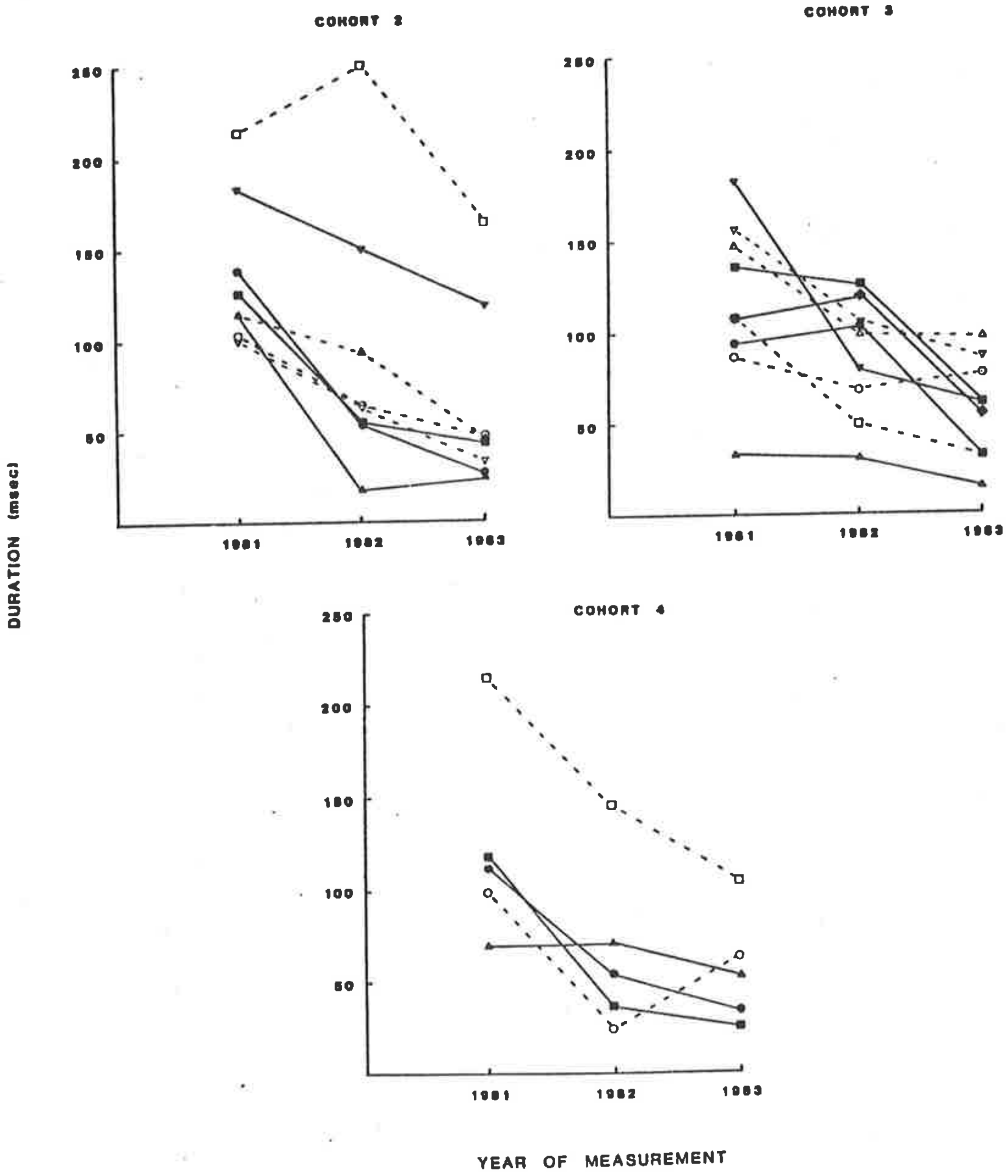
Examination of the individual subject data - a prime advantage associated with the longitudinal developmental design - indicates that averaging data does not appear to have resulted in the confounding of the developmental trend. Figure 3.3 (a, b, c, d) maps individual change within each of the four cohort groups (i.e. commencing school in 1980, 1979, 1978 and 1977). While the slopes of the youngest group are considerably greater than that of the children in the older three cohort groups, the majority of subjects show decreasing IT over the three year period. In the two oldest cohort groups, the changes between the second and third years appear minimal, consistent with the asymptotic nature of development evidenced in the averaged data.

Despite the general similarity of individual and averaged results, the problems of developmental analysis still remain to be solved before any conclusive arguments can be made. Accepting the comparative usefulness of longitudinal, as opposed to cross-sectional data for valid developmental interpretations, even this form of data has been subjected to rigorous attack in recent years. As has already been briefly mentioned, two researchers in particular have examined the nature of the age-behaviour function and subsequently formulated their own detailed research models.



(a) Cohort 1

FIGURE 3.3. 85% Accuracy duration of individual subjects from
(a) Cohort 1 (commencing school in 1980);
(b) Cohort 2 (1979);
(c) Cohort 3 (1978);
(d) Cohort 4 (1977).



(b) Cohort 2, (c) Cohort 3, (d) Cohort 4.

Schaie (1965) was the first to present a detailed developmental methodology which attempted to tackle all of the difficulties associated with the analysis of age effects. Whereas the conventional techniques were based on the formula R(Response) = f (A), where A = Age; Schaie extended this simple function so that R became a function of Age, Cohort and Time of measurement (R = f (A, C, T.)). According to this model, any response and particularly any response that varies through time, may be a function of any or all of the three specified variables. In other words, performance differences may arise from age differences (A), different birth dates (C), or different times of measurement (T). Both the traditional cross-sectional and longitudinal studies, as well as the less common time-lag studies, where subjects of the same age but from different cohorts are compared, confound these variables profoundly.

This methodological confounding is illustrated in the following 3 equations where:

$\text{CSd} = \text{Ad} + \text{Cd}$[1] .... Equation 3.1

$\text{LOd} = \text{Ad} + \text{Td}$ .... Equation 3.2

$\text{TLd} = \text{Td} + \text{Cd}$ .... Equation 3.3

Using these functions as a base, Schaie reformulated the developmental function so that the influence of age on performance differences could be isolated from the other factors:

$$\text{AD} = \frac{\text{CSd} - \text{TLd} + \text{LOd}}{2}$$ .... Equation 3.4

---

[1] CSd = Cross-sectional differences
LOd = Longtidudinal differences
TLd = Time lag differences
Ad = Age difference
Cd = Cohort difference
Td = Time difference

In light of his proposed developmental function, Schaie described what he considered to be the appropriate research design. It involved the "optimal combinations of cross-sectional and longitudinal methods into sequential designs" (Schaie, 1965, p. 99). In subsequent years, the Schaie model was simplified and subjected to slight remodelling by Baltes (1967) who proposed a bifactorial model of development. Baltes cited two main objections to Schaie's existing model. The first concerned the formal definition of the three components. Baltes cogently argued that the developmental model can be adequately described by two factors and that the introduction of a third is redundant. Since the three components display the following formal relationship:

$$A = T - C$$

$$T = A + C$$

$$C = T - A$$

once two components have been defined, the third is 'unequivocally fixed'. Thus the response, rather than being a function described by the equation $R = f(A, C, T)$ could be rewritten as $R = f(A, C, A + C)$.

Secondly, Schaie's interpretation of exactly what the components reflect, involved considerable conjecture. Where Schaie argued that age differences measure maturation, time differences reflect environmental factors and cohort differences arise from hereditary and/or environmental influences, Baltes viewed this as unnecessary extrapolation. Rather, he said ". . . the variables of age, cohort and time, consist only of a classification of individuals into different segments of the time continuum. This classification is derived from two chronological age criteria - time of birth and age. No other characteristics, such as hereditary or environmental conditions, are used." (Baltes, 1967, p. 157). Therefore no methodological manipulation can separate environmental effects from maturation in age differences.

On the basis of this argument, Baltes concluded that two components are sufficient to map the developmental function - cohort and age. In any study, individuals can be assigned to specific levels of both of these factors, and age and generation effects extracted by the appropriate analysis of variance technique (independent observations with a cross-sectional study; repeated measures with a longitudinal study). He viewed the minimum requirement for a valid developmental analysis as a 2 x 2 design in which two groups of cohorts are observed at the same two age levels.

Although the present study was not designed to conform to the Baltes model, a post hoc breakdown of the design provides the possibility for distinguishing the influence of age from generation effects; (refer to Figure 3.4).

Four repeated measures analysis of variance on the factors Grade (age) and Cohort were carried out. Matrix 1 compared children from Grades 3 and 4 commencing school in 1980 and 1979; Matrix 2, Grades 4 and 5 commencing school in 1979, 1978; Matrix 3, Grades 5 and 6 commencing school in 1978 and 1977; and Matrix 4, Grades 6 and 7 commencing school in 1977 and 1976. <u>All</u> four analyses showed a significant Grade (age) effect ($F(1,16) = 11.99$, $F(1,15) = 16.84$, $F(1,15) = 35.94$, and $F(1,12) = 21.30$, respectively; $p < .01$), indicating that IT decreased with age between Grades 3 and 7. Similarly <u>all</u> matrices showed a nonsignificant Cohort effect ($F = .73$; 2.60; 1.12; 1.03). Three of the matrices also showed a nonsignificant interaction effect ($F = .03$; .00; 3.05) with the fourth matrix (Grades 6 and 7 commencing school in 1977 and 1976) just reaching significance ($F(1,12) = 8.15$, $p < .05$). Problems with extensive missing data in this latter matrix may account for this difference. (Refer to Appendix 3.7).

	GRADE					
COHORT (year of commencing school)	2	3	4	5	6	7
1975						1981
					Matrix 4	
1976					1981	1982
				Matrix 3		
1977				1981	1982	1983
			Matrix 2			
1978			1981	1982	1983	
		Matrix 1				
1979		1981	1982	1983		
1980	1981	1982	1983			

FIGURE 3.4. Breakdown of longitudinal design into four 2 x 2 repeated measure matrices.

This re-analysis, when viewed in conjunction with the results of the previous section, provides relatively unequivocal support for the notion that IT does vary with age over and above any effects which can be explained by practice or cohort. Further, the results suggest that IT can be mapped as a developmental function which probably asymptotes at the onset of the teen years, where concrete operations have been achieved.

The cross-sequential study therefore provides strong support for the existence of a developmental component to processing speed, first evidenced in Experiments 1 and 2.1. Taking the results of these studies together, it is argued that the efficiency with which information is processed at a central location improves with age, at least up until approximately 11 years. In addition, while practice does increase performance accuracy by increasing task-specific knowledge, this factor cannot account for performance changes evidenced over a period of 1 year, since such changes are significantly greater than the improvement associated with practice. Similarly, maturational differences cannot be explained as arising from different life-histories since cohort, defined in the study as the year of entering school, does not significantly affect performance.

Providing an explanation of the developmental component to processing speed by reference to existing data alone is difficult. As has been argued (Ross & Ward, 1978) it could be that developmental differences in backward masking tasks reflect attentional factors. If younger children have greater difficulty in sustaining attention throughout the course of a session this should result in inflated estimates of processing speed, given that speed is determined by performance accuracy. The possibility that attentional difference may have been evoked differentially in the Nettelbeck and Lally (1979) study and the studies just described, could account for the lack of congruence in the findings. A study examining the influence of attentional fluctuations on IT performance would provide some light on this issue.

Hoving, Spencer, Robb and Schutte (1978) also postulate that age-related differences in backward masking performance may reflect differences in masking effectiveness (i.e. task equivalence). Masking effectiveness may not be total in the oldest group – the mask may provide some sort of cue, even at very short durations, as to the location of the shorter line. If this is the case, the key assumption that all children, at all ages, should achieve chance accuracy at the lowest target duration may not be met. At the other extreme it could also be argued that the difficulty of the task is such that younger children can never achieve the high levels of accuracy reflected in the upper limits of the normal cumulative ogive. These issues remain to be examined.

9. Conclusion

Disregarding for the present the difficulties listed above, results from the studies described in the preceding chapters offer certain interesting findings. Firstly, and most importantly, inspection time (IT) performance changes with age, showing a decrease at least up until the age of 11 years. At this point the function appears to asymptote. This effect cannot be explained by practice in a longitudinal study and appears to reflect a stable individual difference whereby all children retain their comparative position within a cohort group despite the existence of developmental and practice factors. Generation differences do not significantly affect IT performance.

Reliability of the measure does vary with age; however, even over a period of one year it remains high. Similarly, data on the validity of the measure, although more contentious, suggest that IT is an adequate measure of input processing efficiency tapping central inputting at all ages.

The notion that IT might relate to a more general ability factor such as intelligence, received only cursory examination in the cross-sectional study. There is some evidence that the measure does relate to intelligence, especially at low mental ages, however conclusions are impossible to reach on the basis of the data previously described.

It is obvious that a number of issues remain unanswered. Closer examination of the task is required, as is further analysis of the nature of the relationship of IT to other more general performance variables.

CHAPTER 4

EXPERIMENT 3

The influence of procedural variables, attention and fatigue on group differences in IT

1. The Control of Methodology, Task Comparability and Attention

The findings described in the previous chapter suggest the existence of a developmental component to processing speed as measured by the IT task. However, there are certain variables which may be confounded with a developmental effect and these must be examined before any conclusion can be drawn. Methodological considerations relevant to this suggestion are discussed in the following sections, as well as the issues of task equivalence across age and whether certain aspects of attention remain the same across age.

(i) Methodological Considerations

Measures of IT obtained in the previous studies described in this thesis have all been made using the Parameter Estimation by Sequential Testing (PEST) procedure (Taylor & Creelman, 1968). This is essentially a staircase method, which estimates a "threshold", here assumed to define a single point on a normal cumulative ogive. The procedure presents target stimuli to the subject at exposure durations above and below a critical level defined by the subject's accuracy. The program interacts with the subject, with future trial exposure duration determined by the individual's current accuracy. Thus each new trial is designed to obtain maximum information about the possible location of the dependent variable, with a session being terminated only when the current estimate fulfils strict exit criteria. The PEST method is attractive in psychological research for the four following reasons:

(1) The algorithm is well defined and can be programmed into a computer, thereby keeping subject-experimenter interaction to a minimum.

(2) The program is self-terminating, so that no subject need participate any longer than is necessary to obtain threshold estimates at a pre-defined level of accuracy.

(3) The technique is efficient; in most cases it produces a reliable estimate because the greater proportion of trials involve levels of performance close to the criterion level and this is achieved within fewer trials than would be required using the method of constant stimulus differences. Thus, measurement required a relatively smaller amount of time.

(4) Because the dependent variable (target exposure duration) is linked with a level of accuracy that is constant for all subjects, the program ensures that each subject gets as much practice in the task as is required. Thus, individual differences in learning are accounted for.

Taylor and Creelman (1967) have defined the basic algorithm that describes the PEST procedure, and on which the IT program was based. These are as follows:

(1) The reversal rule states that the magnitude of step size is halved following every reversal in direction.

(2) A second step, in a given direction, if required, is the same size as the preceding step.

(3) Fourth and subsequent steps in a given direction are doubled.

(4) The size of the third step depends on the sequence of steps leading to the most recent reversal. If the step immediately preceding the reversal resulted from a doubling then the third step remains unchanged. However, if the preceding step has not been doubled, then the third step is double the second.

(5) Maximum step size is limited.

(6) If the required step size takes TS duration to below zero, then step size is successively halved until it is above zero.

In addition to the tracking rules described above, certain specifications are required from the experimenter to complete the procedure. These consist of: an exit criterion, a maximum step size, an initial stimulus duration to commence testing, and the level of accuracy required. It is in these arbitrary specifications that the possibility of artifactual performance differences may arise.

Pollack (1968) examined this issue in two experiments which were concerned with the effect of initializing procedure on performance in three different auditory tasks. The three tasks examined consisted of a "same-different" procedure whereby two pulse trains were presented successively, with the direction of change of the pulse differing or remaining the same. The second task involved a single interval forced-choice and required that the subject specify the direction of a glissando. The third task was a combination of the first two, using a two interval forced-choice procedure. Two pulse trains were presented with the direction of the glissando in each differing. The subject's task was to indicate the direction of glissando in the first train. Five highly practiced expert subjects were used in all 3 measures.

Results indicated that the exit criterion selected and the initial starting difference between the two signals produced significant effects on performance measures. The measure of the number of trials required to obtain an estimate was highly sensitive to the exit criterion but was relatively insensitive to the initial starting difference. Furthermore, average gap thresholds yielded by the PEST procedure varied with the exit criterion and the initial starting difference. However, when the three procedures were compared over a wide range of interpulse intervals and number of pulses, only minor differences emerged. These data therefore supported the need for caution in the selection of initializing parameters, illustrating the possible sensitivity of PEST to arbitrary experimenter decisions.

Pollack's results raise the possibility that observed developmental differences obtained in the longitudinal and cross-sectional studies may have been an artifact of decisions made before the experiment was even carried out. For example, it is possible that the selection of an exit step size of 1 ms may have differentially disadvantaged the younger children because of its extreme shortness. Additionally, one aim of the PEST procedure, to maximise the number of trials in the vicinity of the criterion measure ultimately achieved, may have resulted in a task that provided few opportunities for positive feedback, while still requiring sustained motivation. It is certainly possible that a task of that kind could alienate very young children, who can sometimes appear to have little desire to sustain performance in a difficult task.

The possibility that arbitrary experimenter decisions may have influenced the outcome of the earlier studies is particularly pertinent in light of the results of Nettelbeck and Lally (1979). This experiment in which, it will be remembered, no statistically significant developmental differences were observed, made use of the Method of Constant Stimulus Differences (MCSD). The MCSD procedure involved the presentation of the TS at four different exposure durations, randomly shuffled into blocks of 20 trials. The resulting proportion of correct responses made at the different exposure durations by each subject, were used to derive a psychometric function from which IT was derived, as the duration at which probability of accurate responding reached 97.5%.

Nettelbeck and Lally's (1979) results are discrepant with those obtained in the cross-sectional and longitudinal IT studies and, in the light of findings of Pollack (1968) one possibility is that developmental performance differences in the various studies described may reflect methodological differences between them. Specifically, IT estimates obtained from PEST may not be comparable with those obtained by MCSD, particularly for young children where the PEST procedure may artificially inflate input processing speed. A control experiment which compared IT estimates obtained using MCSD and PEST at the critical ages of 8 and 11 was therefore carried out, this providing a means for determining the extent to which differences in obtained developmental trends between the studies reported here and that reported by Nettelbeck and Lally (1979) were a reflection of methodological considerations.

(ii) Task Equivalence Across Age

Although previous developmental backward masking studies have tended to assume that the task is of comparable difficulty across all ages, it is conceivable that differences exist in the nature of the task as it is experienced by subjects of different ages. For example, it has been suggested that mask effectiveness may vary across groups (Hoving, Spencer, Robb & Schulte, 1978). While most studies assume this not to be so, the mask may provide some aid to identification, or simply be less effective with adult subjects or older children. Liss and Haith (1970), for example, argued that performance differences in a backward masking experiment comparing groups aged 4 to 5, 9 to 10, and adults, were due to a comparative advantage among the older subjects in the use of subtle or partial cues. Such cues may be associated with mask onset.

The PEST procedure used in the previous experiments is not amenable to the examination of possible floor and ceiling effects. In other words, it has not been possible to demonstrate the existence of chance and 100% accuracy in all age groups under experimental conditions derived from the PEST method. It is possible, for example, that older subjects may never perform at chance levels of accuracy, with the presentation of a mask always providing cues as to the location of the shorter line. Similarly, it is possible that younger children never achieve 100% accuracy, even at points far above IT, because of some basic limitation to their ability to do the task. Yet, unless both of these points defining difficulty and facility are attainable by both groups, task comparability cannot be established and age-based comparisons cannot be made.

(iii) Attention

One of the most widely documented findings in developmental information processing psychology is the change with age in selective attention. This ontogeny is evidenced in three forms: an increasing ability to focus on relevant cues (Hagen & Hale, 1973), to ignore extraneous stimulus information (Wright & Vlietstra, 1975), and to attend systematically and exhaustively (Vurpillot, 1968).

The notion of an increasing ability to focus attention efficiently with increasing age has important implications for the IT task. Given the severe time constraints under which target presentation occurs, focussing upon irrelevant cues or in an inappropriate manner during target onset will adversely affect performance accuracy and thus lengthen estimates of processing speed.

Hagen and Hale (1973) have examined the ability to focus on relevant cues in their developmental studies of selective attention. In this research they have employed a paradigm in which certain aspects of the stimulus are designated as relevant for task performance, and others as incidental. Performance on the central task is tested, as is later recall of incidental information. Together, these two measures are used to infer selective attention. If incidental learning is high, attention appears to have been focused on cues that are incidental to the primary task; when incidental learning is low and accompanied by high central performance, task relevant selective attention is inferred.

Two developmental hypotheses have been postulated by Hagen and Hale (1973). Firstly, improvement in memory with age is held to reflect the ability of the child to focus on relevant cues and to ignore irrelevant cues. Secondly, when the information overload of the task becomes great, incidental information will be traded off for relevant, and this tradeoff will become more evident as children grow older.

Studies using this paradigm and examining these hypotheses have produced the following results (Maccoby & Hagen, 1965; Hagen, 1967). Central memory task scores have increased regularly with age in studies composed of 7, 9, 11 and 13 year olds. Incidental scores have been found not to increase, decreasing in the 13 year olds. The second hypothesis, that information overload should decrease attendance to incidental information, has received only limited support in these studies, although subjects have appeared to "give-up" both irrelevant and relevant task information under conditions of information overload.

On the basis of their evidence, and of data from other studies, Hagen and Hale have concluded that there is a developmental improvement in the efficiency of attention deployment, with children increasingly concentrating on task-relevant aspects of the stimulus and ignoring extraneous information. Furthermore, "by early adolescence, children are apparently quite flexible in their attention deployment; they modify their approach upon realizing what strategy will maximize their performance." (Hagen & Hale, 1973, page 137).

This increasing ability to focus on the relevant aspects of a situation has also been indirectly illustrated in studies which have mapped the developmental course of distractability, focussing on the ability to ignore extraneous stimulus information. These studies have been extensively reviewed by Lane and Pearson (1982) who describe three possible explanations for developmental differences in distractibility. The first of these is based on the notion of attention allocation. It is possible that the ability of children to allocate limited attentional capacity is far less flexible at young ages and cannot be directed away from extraneous information. A second feasible explanation proposed by Lane and Pearson (1982) is an age difference in the "marginal efficiency" of allocated capacity. This suggestion derives from Norman and Bobrow (1975), who have described the various functions that might relate allocated resources to performance. They argue that this function, although monotonic (i.e. increasing resources, increasing performance) is not necessarily linear and may instead contain a number of plateaux which they describe as "data-limited regions". Within these regions, increased allocation will not increase performance. The other non-platform segments of the function, where performance is affected by allocation, are labelled "resource-limited". Therefore, if in a condition where there is no distraction, with adults performing in a data-limited region while children are in a resource-limited region, then the introduction of distracting material may adversely affect children much more than the adults - even if both groups have allocated an equal proportion of their capacity to the irrelevant stimuli. Lane and Pearson's third alternative is that age differences in the effect of irrelevant stimuli may reflect an inability in young children to inhibit responding. Response competition may simply be more disruptive to the optimal performance of younger subjects. These three suggested explanations for differences in performance across age illustrate the variety of ways in which developmental differences in attention may affect the manner in which a task is performed and concomitantly, performance accuracy.

Attentional age differences are also illustrated in studies that have shown that older subjects attend more systematically and exhaustively than children. This finding has been particularly well illustrated by the visual scanning strategy literature. Reviewed most recently by Day (1975), Vurpillot (1976) and Ross and Ross (1981), visual scanning research indicates that children show an increase in systematic scanning between the age of 3 and 11 years. Younger children are more affected by contextual factors which can aid, by directing vision, or hinder, by distracting. Added to this changing systemization is developing exhaustiveness of scanning, defined as the proportion of the total stimulus array that is scanned. Findings in this regard are ambiguous, the suggesting being that there is a general increase in exhaustiveness with age, but with this tendency tempered by decreasing exhaustiveness which is associated with increasing efficiency of scanning. Day (1975) has also pointed to an enhanced ability with increasing age to focus on the most important, relevant elements of the display. Increasingly selective attention appears to be associated with changes in the pattern of eye movements when scanning. Thus developmental differences in the ability to attend both systematically and exhaustively can produce performance differences in the speed and accuracy with which visual identification tasks are completed.

Another measure illustrative of attentional differences across chronological age, is one labelled "preparatory set" (Elliott, 1970). Used primarily within the context of reaction time (RT) tasks, this measure refers to a readiness to respond to the appropriate reaction signal. Results indicate that younger children are affected to a greater degree than older subjects by aspects of the Preparatory Interval that precedes stimulus presentation in the simple procedure. Elliot has suggested that this outcome could be the result of a number of factors.

> "It seems children are more distracted by a number of novel influences that do not act strongly on adults. They are unaccustomed to prolonged postural restraints, to being tested and taking instructions, and to evaluation; and they have probably not developed the incentive systems of achievement and social approval that often obtains when adults are tested in a laboratory situation."
>
> (Elliot, 1970, page 201)

Thus, the literature briefly described here indicates that there is a close link between chronological age (CA) and the ability to direct attention in a maximally efficient manner, which affects performance on tasks of distractability, attention deployment, scanning and RT.

The possibility that this developmental function may confound the hypothesized developmental processing speed function has yet to be discounted. The nature of the IT task is such that differential attention, whether it be in terms of willingness to persist, scanning strategies or distractability, is likely to produce performance difference in recognition accuracy, particularly in light of the severe temporal constraints acting upon target availability.

(iv) Summary

Results from the longitudinal and cross-sectional studies of IT presented in Chapter 3 cannot be assumed to reflect directly a developmental difference in perceptual processing speed because of the possible contributory effects of other factors to performance differences. It is only by strict control of all possible contaminating variables, that an accurate picture of the IT-Age Function can be obtained.

Performance estimates of IT obtained with the PEST procedure should be compared with estimates obtained by the MCSD in order to test the possibility that methodological considerations may have confounded earlier developmental functions. If ITs obtained under the two procedures were found not to differ significantly within age groups, while across groups significant differences were obtained under both procedures, then it could be argued that the developmental differences previously evidenced were not an artifact of a PEST procedure which diasdvantaged young children more than older subjects.

Similarly, attempts to establish the comparable nature of performance across groups requires more detailed examination of the upper and lower limits of performance. If the task is to be seen as measuring the same "ability" in all groups, accuracy at extremely long durations (effectively equivalent to unmasked) should reach 100% at all ages; or at least should not differ significantly between groups. Conversely, accuracy at very short durations (effectively equivalent in backward masking studies to simultaneous target and mask presentations) should not differ from chance accuracy (50%) in any of the groups measured. Performance in the ceiling trials below 100% accuracy would indicate that the task is simply too difficult for the subjects involved, with the IT procedure requiring a different type of performance across ages. If such a finding were found, it would probably be for younger children. On the other hand, accuracy above 50% in the floor trials of one group (eg. an older group) could indicate the nonequivalence of mask effectiveness in that group. This, of course, would be expected to affect the obtained index of processing speed.

Lastly, the well documented developmental component to attention may conceivably be responsible for observed performance differences in the IT task. Given that the successful completion of the PEST program does depend upon strict attention throughout, while tachistoscopic presentation prevents the experimenter adequately monitoring attentional activity, the long mean IT of the young could result from inconsistent attention during the PEST procedure. The form of this wandering attention may be as gross as the shutting of eyes, or as subtle as a failure to fixate on the appropriate portion of the target; it could involve directing attention to irrelevant components of a display or distractions arising out of novelty within the experimental situation. Although attempts can be made to minimize possible contamination arising from attentional factors by keeping extraneous sound to a minimum, making the child familiar with the apparatus, task and experimenter, and introducing regular rest breaks in which verbal reinforcement and task reminders are given, there remains a need to index possible fluctuating attention throughout the experimental session.

One possible way of detecting any lapses in attention is to introduce randomly presented unmasked trials into the experimental blocks. Such trials would be unpredictable and should be set at low durations (IT or less), that would require attentive observation if perception was to be accurate. If attentiveness during the task is equivalent across age groups, then all subjects should achieve perfect performance on these particular trials.

If it was established that performance differences in IT are not mediated by methodological considerations, floor and ceiling effects, or attention, then the case for the existence of a developmental component in processing speed would be enhanced.

2. Method

(i) Subjects

The failure to find a significant difference between IT performance of adults and 11-year-olds in any of the previous studies was taken as justification for restricting the sample of this study to two groups of 10 children with mean ages of 7 years 8 months (range 7 years 2 months to 8 years 4 months) and 11 years 7 months (range 11 years 2 months to 12 years 8 months). These children were selected randomly by the Principal of the school involved, from two classes, Grade 3 and Grade 7. All children had normal or corrected to normal vision.

(ii) Apparatus and Design

A modified Gerbrands four field tachistoscope was used to obtain three estimates of IT. The same stimuli and presentation technique were used as in the previous studies. (Refer to Chapter 2, Section 2).

After an initial attempt to familizarize the child with the apparatus, practice trials were administered. These involved a minimum of 50 trials for each subject in each group. For the younger children this 50 trials consisted of 10 each at the durations 1000, 500, 250, 100 and 50 ms, with the first two blocks requiring completion at the 100% accuracy level. In the older group practice trial duration was set at 500, 250, 100, 50 and 25 ms, with 100% accuracy required at the two longest durations. Trials were always presented in a descending order of duration to give all subjects an opportunity to gain positive experience of the task before having to tackle the more "difficult" trials.

One PEST and two MCSD measures of IT were obtained from all subjects. The MCSD conditions always followed the PEST estimate, with target stimulus durations determined on the basis of the first IT measure. Blocks of 20 trials, randomly shuffled, were presented at 5 durations of; 5 ms (.50 x initial PEST estimate of IT), (.75 x IT-PEST), IT-PEST and 2000 ms. Because some older children first tested appeared to achieve near-perfect accuracy at the exposure equal to half IT-PEST, an additional 20 trials at (.25 x IT-PEST) were included for this group. In addition to these

100-120 experimental trials, 10 unmasked trials with TS duration equal to IT as estimated by PEST, were randomly presented throughout each MCSD measure providing an estimate of the degree to which attention wandered in the course of obtaining one measure.

(iii) Procedure

Each child participated in 3 sessions lasting approximately 20 minutes each. In the first session, after familiarizing each subject with the apparatus and task, a PEST estimate of IT was obtained. This involved determining the exposure duration at which 85% accuracy was achieved. Initial target duration was set at 500 ms for the younger sample, and 300 ms for the older. The specifications made before commencement of the experiment included an initial step size of 75 ms and an exit step size of 1 ms.

Normal task instructions as previously described were explained before presentation of the practice trials. On completion of these trials, each child paused and was asked if he or she understood the task. The PEST program was subsequently started when the subject expressed the desire to continue. In the following two sessions, two estimates of IT based on the MCSD method were obtained.[1] Half of the children at each age undertook an MCSD procedure with pauses after every 20 trials in the second session. The other half completed all trials without a pause. In the third session, conditions were reversed, with those who had completed the "pause" trials, undertaking the "no pause" and vice versa. Both groups completed a minimum of 30 practice trials at target durations of 250, 100 and 50 ms before commencing either MCSD condition.

The duration of the "pause" varied, with subjects averaging between 1 and 2 minutes. During this break in the session, attempts were made to

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[1] IT was extrapolated from the normal, cumulative ogive in both the PEST and MCSD conditions, as the duration at which 97.5% accuracy was attained.

keep both task relevant attention and motivation high. This was done by emphasizing the importance of concentration, and by high levels of verbal reinforcement in the form of comments such as, "You're doing very well!" or "Try and keep up the good work!". The next block of trials was only commenced after the subject expressed his or her desire to continue.

All children were warned before both MCSD conditions that they would see a number of trials in which no backward masking figure would be evidenced. They were instructed to treat these in exactly the same manner as the other trials.

3. Results and Discussion

(i) Methodological Considerations

Comparison of the three IT estimates obtained (PEST, MCSD with pauses and MCSD without pauses) are listed in Table 4.1, according to Grade. Examination of this table indicates that Grade 7 children had shorter ITs than Grade 3 children under all conditions.

TABLE 4.1. Mean ITs (ms) and Standard Deviations (in parentheses) under three conditions (PEST, MCSD with pauses and MCSD without pauses), for two groups of children.

GROUP	PEST IT	MCSD (pauses)	MCSD (no pauses)
Grade 3 (7 years)	274 (96)	226 (111)	320 (196) 261 (90)*
Grade 7 (11 years)	169 (87)	128 (64)	127 (62)

*Results after deletion of one anomalous subject with an IT estimate of 849 msec - twice the duration of any other estimate.

An analysis of variance of this repeated measures data which examined the between-subject factors, Grade (3 vs 7) and Order (MCSD pause, MCSD no pause vs MCSD no paus, MCSD pause) and the within-subjects factor, Method (PEST vs MCSD pause vs MCSD no pause) found only a significant main effect for grade; (refer to Appendix 4.1); Grade 7 children exhibited significantly shorter IT's than their Grade 3 comparison group under all three conditions; $F(1,16) = 10.0$, $p < .01$ (Order, $F(1,16) < 1$; Method, $F(2,32) = 1.5$). Thus, although PEST did appear to produce a slightly longer estimate according to the table of means, the PEST estimate was not significantly different from either of the MCSD measures. Further evidence confirming the reliability of the initial PEST estimate comes from an analysis of performance under both MCSD procedures. For both age groups, performance under the MCSD procedure at the target duration equal to IT was close to the predicted values of 97.5% correct, being 96.3% for 7-year-olds and 98% for 11-year-olds across both conditions.

This outcome is not changed by the deletion of an extremely high measure of IT obtained from a Grade 3 subject in the MCSD without pause condition. Re-analysis of the data excluding this anomalous case did not produce a significant main effect for any factor other than grade, nor a significant interaction effect; (Main effect for Grade: ($F(1,18) = 11.87$, $p < .01$; Refer to Appendix 4.2 for a summary of this analysis).

Correlation of performance obtained under the 3 conditions indicated, once again, that older subjects produce more reliable estimates than do younger children; (refer to Table 4.2, a, b, c).

TABLE 4.2. Correlation between estimates of Inspection Time obtained with a PEST procedure, and an MCSD with pauses and an MCSD without pauses method.

	MCSD (pause)	MCSD (no pause)
a. Grade 3 (N = 10)		
PEST	.68	.22
MCSD (Pause)		.41
b. Grade 7 (N = 10)		
PEST	.62*	.88***
MCSD (Pause)		.74***
c. Total Sample (N = 20)		
PEST	.73***	.52**
MCSD (Pause)		.74***

* $p < .05$ (one-tailed)
** $p < .01$ (one-tailed)
*** $p < .001$ (one-tailed)

An interesting aspect of these correlations is seen by comparing correlations between PEST and MCSD with pauses, on the one hand, and those between PEST and MCSD without pauses, on the other. While methodological considerations did not appear to account for performance differences across groups, and estimates derived by the PEST procedure correlated positively and significantly in both groups with estimates from the MCSD with pauses method, in the Grade 3 children the MCSD without pauses method produced a less reliable but much faster estimate. (Refer to Table 4.1). It is therefore possible that, for Grade 3 children, the introduction of rest pauses between blocks in some way alleviated fatigue during the task or aided attention.

As a whole, the analysis of variance together with correlational evidence suggests that performance differences between groups cannot be explained by the suggestion that PEST, and more particularly, the arbitrary specifications which it entails, differentially disadvantaged the younger children.

(ii) Task Comparability Across Ages

Since no differences were found between the pause and no pause alternatives of the MCSD procedure, these have been combined for the purposes of the discussion that follows.

Accuracy in the trials in the MCSD conditions involving a TS duration of 5 ms did not differ significantly from chance in either group (mean % accuracy in Grade 3 children was 51%, and in Grade 7 children, 54%). Similarly, all groups performed equally accurately when TS duration was set at 2000 ms. Among the youngest children, only one child made an error at this exposure duration in either of the MCSD conditions (1 error in the MCSD pause condition), with a resultant mean group accuracy of 99.5%. In the older group, 1 error was made by 2 individuals, both in the MCSD pause condition, with a resultant mean group accuracy of 99%.

These results indicate that task difficulty is comparable across age, with masking equally effective with children aged 7 and 11 years. In addition, subjects at all ages appeared to be able to achieve virtually perfect accuracy at long exposures, with very occasional response selection errors the probable reason why 100% accuracy was not exhibited by all participants.

(iii) Attention

Results from the random unmasked trials suggest that attentional problems do not play a significant part in the longer ITs of most young children. Only 2 errors were made within each group on the 19 random unmasked trials. Two Grade 3 children each made 1 error, while one Grade 7 child made 2 errors, 1 in each of the MCSD conditions. Interestingly, it was the child with the longest estimated IT (i.e. the child subsequently deleted from certain analyses), who made an error in the random unmasked trials of the condition from which that estimate was derived (the MCSD without pauses condition). Although these data are too few to permit any conclusion, it is possible that the resultant IT estimate was due, at least in part, to less well sustained attention. In contrast to this hypothesis, however, are the results of the other Grade 3 child who made a random unmasked error. This error occurred in the MCSD with pauses condition and was not associated with an IT estimate in that condition above that of any other. Thus in this case, it would not appear that inattentiveness significantly affected the estimates made of IT.

In the Grade 7 sample, it was the child with the fastest overall IT who made an error in both MCSD conditions. Possibly the very short duration for which the TS was viewed in this case (PEST estimate of IT = 32 ms) required an added degree of concentration which was not called for among the other subjects.

On the whole, results of the random unmasked trials, while not conclusive, do suggest that attentional developmental differences do not account for IT differences across ages, although in some subjects poor attention might result in inflated estimates.

4. Conclusions

The results of Experiment 3 once again indicate that children aged between 7 and 8 years input information into the perceptual processing system more slowly than do children aged 11 years. Further, these results confirm that the PEST methodology does not inflate estimates in the younger group, although there is some suggestion in the data, particularly from the Grade 7 children, that PEST estimates are longer than those made under MCSD. This result is consistent with that of Nettelbeck (1983) who has compared results obtained with different methodologies.

Correlations, while not as strong as those obtained in some previous studies, do reach .88 in the oldest group between an estimate of IT made with PEST and one made by MCSD, and .73 with a sample of 20. In the light of this evidence, IT appears to be a relatively robust measure of input processing speed which is not unduly affected by methodological and procedural manipulations. This conclusion is further supported by analysis of ceiling and floor effects. The fact that chance accuracy was exhibited by both age groups in the 5 ms target duration trials suggests that masking, at least at these very short durations, is equally effective across age groups. In addition, virtual perfect accuracy by these same two groups at extremely long durations indicates that the discrimination task is within the capabilities of both groups.

Thus, in view of performance equivalence in these limiting conditions, it is argued that IT appears to be a task which is simple enough to produce an accurate estimate of processing speed in very young children, and yet sensitive enough to be able to provide an estimate with mature subjects. As such, the developmental trend which it evidences has a validity not always found to apply in more cognitively complex tasks.

Data on developmental attentional differences, and their possible contamination of IT measures, are problematic nonetheless. Assessing the extent to which attentional fluctuations account for obtained performance differences is particularly difficult in the tachistoscopic IT task. The introduction of randomly presented unmasked trials within the two MCSD conditions indicated that performance differences were probably not due to differences in alertness at target onset. There is some evidence in the backward masking literature to support this assertion. For example, Ferreira (1978), examined the backward masking recognition accuracy of 5-year-olds, 8-year-olds and adults. In this study she used a Model 200 Narco Biosystems Eye-Trac Monitor to assess the subjects' eye fixation. This monitor was interfaced with an automated Data process control system which only presented the test stimulus (a letter) when the subject's eye fixation was within the fixation area (a 1° circular area around the point at which the stimulus was centred). If fixation immediately prior to TS onset was unacceptable, the trial was aborted. Results showed that significantly more trials were aborted in the youngest group. However, despite the equivalence of fixation during the non-aborted experimental trials, the youngest children still exhibited a significantly longer critical SOA than the older two samples. A subsequent experiment in which unrestricted fixation was allowed reproduced the developmental difference. Thus, Ferreira's study indicates clearly that the longer processing speeds of the very young cannot be interpreted as reflecting an inefficient attentional mechanism, at least within the context of eye fixations at target onset.

Ferreira's results support an interpretation from unmasked trial performance in the present study of attentional equivalence across ages. There are, however, certain difficulties associated with the interpretation of these results. Problems in efficiently directing attention may not have been successfully tapped by these random unmasked trials which, it will be remembered, were presented at a duration equivalent to IT as estimated by PEST. In most cases, this trial would have involved a significantly longer duration for a Grade 3 child than for a Grade 7 child, so that such trials may therefore not have been of comparable difficulty for both groups of children.

Having acknowledged the limitations of evidence on attentional equivalence in the IT task, it is possible to draw a number of conclusions from the other evidence described. Developmental differences in IT performance cannot be explained by differences in mask effectiveness or differences in task difficulty arising out of methodological factors. Age differences are not only reliable; they are robust, being found under a variety of procedurally variable conditions. Whether the differences ultimately reflect a less mature ability among the very young to perform the task, or sustain performance as efficiently as their older counterparts, remains to be decided.

CHAPTER 5

EXPERIMENTS 4 AND 5

The influence of intra-individual variability, registration and rate of processing on developmental differences in IT

Results of the experiments described in the previous chapters have consistently reflected decreasing inspection time (IT) with increasing age. However, although little difficulty is associated with demonstrating this finding, which is both robust and reliable, specifying the source of differences across ages does involve conjecture. Previous studies have supported the hypothesis that these developmental differences in performance have a central locus (Experiment 1), suggesting in addition that such differences cannot be explained as arising out of differences in task-specific knowledge or cohort (Experiment 2.2). More specific hypotheses about the source of these performance differences can be suggested. For example, although results from Experiment 3 in the previous chapter suggested indirectly that attentional differences do not account for longer mean ITs in young children, it is still possible that these children may be differentiated from older children and adults by an inability to sustain performance at a consistently high level throughout a session. Assume, for example, that the performance of younger children in unmasked trials is not comparable to masked trial accuracy, then the use of random unmasked trials presented at a duration equal to IT as estimated by the PEST procedure, may not have accurately assessed possible age differences in attention.

A more accurate estimate of possible age difference in the ability to maintain high levels of attention may be provided by estimates of intra-individual variability. If performance variability was greater among younger children, then estimates of IT would be inflated, and group differences evidenced. The following experiment represented an attempt to distinguish the possible contribution of performance variability to age differences in IT.

1. Experiment 4. The Influence of Intra-individual Variability on Age Differences in Input Processing Speed

One of the most pervasive findings in developmental psychology is the decreasing between-subject performance variability associated with increasing age. At least in part, this trend undoubtedly reflects individual differences in the rate of development, the range of such differences becoming attenuated over time as children approach adolescence and eventually asymptotic levels of performance. In empirical terms, this trend is evidenced as a decreasing standard deviation in group performance with increasing age. While the IT data have generally reiterated this finding (cf. Tables 3.7, 3.8, 4.1), such differences have not always been found (Table 3.2).

Although considerable research has been directed to the study of general within-group variability, the influence on performance variability within-subjects to group differences has only rarely been considered. However, given that the latter may contribute significantly to the former, and hence to overall differences between groups, the issue would seem to be worthy of consideration. Variability of performance within a subject throughout the course of one measure may account for group performance differences by inflating the overall performance estimates derived from all trials. It is possible that, just as individuals within age groups exhibit considerable variability, at the level of the individual, performance accuracy may vary throughout a session, with age differences reflecting greater performance variability in younger subjects.

Possible sources of intra-individual variability are numerous and it is extremely difficult to differentiate one from the other, either empirically or theoretically. However, among the factors contributing to intra-individual variability can be included the following.

(i) Attention

Developmental differences in attention — in particular, the ability to maintain task-appropriate attention throughout the course of one session — may be reflected in age differences in intra-individual variability. While failure to find a significant difference between age groups in the unmasked trial accuracy of Experiment 3 was thought to illustrate equivalence in task appropriate attentiveness, there is a certain amount of interpretational difficulty associated with these data. It can be argued that accuracy in random unmasked trials is not necessarily comparable with experimental trial performance in which a backward mask is presented at target offset. For example, Ross and Ward (1978) have suggested that eye fixations that deviate from the position of the TS may still provide sufficient accurate information for target recognition under no mask conditions, whereas when a mask is present far greater performance precision may be required. It is also possible that developmental differences in tolerance for ambiguity may also affect intra-individual performance variability. If younger children do find trials involving short target stimulus duration more difficult than their older counterparts, this may be reflected in greater performance variability.

(ii) Noise

Involuntary, systemic factors may contribute to intra-individual variability. The term "noise" has been used to describe such variability, particularly in relation to observed probabilistic fluctuations in signal detection (Tanner & Swets, 1954; Welford, 1968). Although noise cannot be distinguished from performance variability arising from factors like fatigue, motivation, attention and interest, the term is generally used to refer more specifically to background cortical activity and it is possible that noise may have a developmental component.

A theoretical distinction can be drawn between two sources of noise in the information processing system. The first, visual noise, refers to external sources of irrelevant visual input which affect the probability of accurately detecting the signal. The second, neural noise, is most commonly thought of as an internalized source of disruption to performance, with ongoing cortical processes resulting in random firing in the sensory pathways and brain. Such activity would be in competition with the signal, thereby affecting probability of detection. Thus noise, like attention, may vary throughout the course of a session as well as between age groups. If this were the case, then a greater influence of noise on the maintenance of performance in a younger group could act to inflate estimates of IT from that group.

(iii) Fatigue.

Mental and physical fatigue can also contribute to performance variability over time. As with the other factors described, it is very difficult to isolate the influence of this variable from that of others, such as motivation, attention and noise. However, it is reasonable to suppose that performance impairment would occur following prolonged exposure to a task. Furthermore, the extent of any such impairment could vary between age groups, resulting in group performance differences.

While a number of studies using adult populations have indicated that fatigue of the eye muscles and eye strain can reduce accuracy on perceptual tasks (Bartley & Chute, 1947), other studies have suggested that fatigue is not limited to eye muscles. Berger and Mahneke (1954) showed that visual acuity and Critical Flicker Frequency (CFF) both fell when tests were made continuously for 55 minutes, but rose again after 5 minutes of rest. Similarly, Haider and Dixon (1961) found that the threshold for detecting a difference in intensity between two spots of light rose substantially during the course of a 14 minute session. Welford (1968) has argued that these decreases in performance accuracy can be interpreted as reflecting a temporary central impairment induced by fatigue and comparable with decreases in CFF brought about by the use of depressant drugs.

In light of the well documented deterioration in performance associated with fatigue, it is hypothesized that developmental IT differences reflect the differential influence of fatigue on performance variability at various ages. If children aged 8 years experience fatigue at shorter "time-on-task" durations or, alternatively, exhibit greater fluctuations in levels of fatigue during the course of one session, developmental differences in IT may be evidenced. Although an attempt was made in Experiment 3 to minimize the possible contribution of fatigue to performance differences by the introduction of regular rest pauses, as described in Chapter 4, fatigue may be evidenced more clearly as differences in intra-individual variability.

All three factors described above — attention, noise and fatigue, as well as others not included, such as motivation — may contribute to within-subject performance variability. The existence of a developmental difference in the influence of such factors on IT performance may account for the developmental trend evidenced in past studies.

The contribution of variability to task performance has been investigated most frequently within the context of the vigilance paradigm. Vigilance is defined as "the attentiveness of the subject and his capacity for detecting changes in stimulus events over relatively long periods of sustained observation" (Frankmann & Adams, 1962, p. 257). Vigilance, and more particularly "vigilance decrement", was first investigated in the 1940s and was concerned with the fall in signal detection accuracy from the beginning to the later stages of a session (J.F. Mackworth, 1968; N.H. Mackworth, 1948). A wide variety of experimental tasks have been used in the examination of this phenomenon, with the effect demonstrated in both the visual and auditory modalities. A number of variables have been found to influence adult detection rate, among which can be included task characteristics (Baker, 1963), personality style (Eysenck, 1957), arousal level (J.F. Mackworth, 1968) and task-oriented motivation (Smith & Lucaccini, 1969).

In developmental research, the vigilance paradigm has largely been used in the investigation of aging and attentional problems in behaviourally disordered populations. Studies concerned with old age and vigilance performance have shown that both overall vigilance and vigilance decrement change with age, old subjects (aged 71 years) exhibiting lower levels of vigilance overall (compared to 44 year olds), with larger levels of performance decrement over the session (Surwillo & Quilter, 1964). Similarly, vigilance studies interested in behaviourally disordered children have indicated that such populations tend to show both poorer vigilance, and a larger vigilance decrement with time, than chronological controls of normal children (Grassi, 1970; Kupietz, 1976; Sykes et al., 1973). In the few studies concerned primarily with normal children, vigilance performance has been shown to vary with age. Gale and Lynn (1972) tested 612 children aged between 7 and 13 years on a 40 minutes auditory vigilance task and found that performance improved with age, with greatest improvement between the years 8 and 9. All groups showed a vigilance decrement throughout the course of the task.

(iv) Summary and Conclusion

It would seem reasonable to suppose that sustained performance in the IT task would require a considerable degree of vigilance. Results from vigilance studies suggest that intra-individual variability in performance, whether it be due to factors such as noise, attention or fatigue, does affect task performance and may vary with age. If such variability is a significant influence on measures of IT then it may account for the documented developmental difference in processing speed. The aim of Experiment 4 was to test whether differences in intra-individual variability when making the discriminative judgements required when estimating IT were associated with differences in IT and, if so, to what extent intra-individual variability could account for these differences.

2. Method

(i) Subjects

Subjects were 2 groups of 12 children with mean ages of 8 years 0 months (range 7 years 7 months to 8 years 5 months) and 11 years 10 months (range 11 years 0 months to 12 years 9 months). These children were selected from school Grades 3 and 7 by the school Principal as having at least average intellectual ability and normal or corrected-to-normal visual acuity.

(ii) Apparatus and Design.

A Northstar computer was used to present the stimulus and masking figures described in Experiment 1 (Chapter 2, Section 2(ii), Figure 2.1) on a visual display. Thus, presentation was binocular. The target stimulus (TS) was preceded by a cue figure, a cross, which was presented for a duration of 1000 ms and followed at offset by a mask of 500 ms duration. Use of a computer presentation technique, rather than the tachistoscopic procedure described in the previous studies, did not substantially change the actual task, but allowed the experimenter greater opportunity for observing subject activity.

Practice for the younger group consisted of a minimum of 5 blocks of 10 trials; 10 each at 1000 and 500 ms (requiring completion at 100% accuracy), and 10 at 250, 150 and 100 ms. In the older group practice trial duration was set successively at 500, 250, 150, 125 and 100 ms, with 100% accuracy required at the two longest durations.

Estimates of intra-individual variability were obtained at three levels of stimulus onset asynchrony (SOA). SOA was always equal to TS duration. These three durations were derived from data to be described in Experiment 6. Thus, although Experiment 6 was actually completed prior to the investigation of intra-individual variability discussed in this chapter, it is described in Chapter 6 which follows since it examined developmental IT differences from a broader perspective than that represented by Experiments 1 to 5, attempting to relate differences in processing efficiency to general ability factors. In Experiment 6, ITs were estimated using the Method of Constant Stimulus Differences and TS durations of 5, 25, 50, 100, 150, 250, 400 and 2000 ms, in a sample composed of 24 children with an MA of 8 years, and 24 with MA 11 years. Analyses of accuracy at these eight durations established that differences between groups were significant at the .01 level at TS durations of 100 and 150 ms.[1] Since these durations most markedly distinguished the performance of the two groups, they, in addition to a duration mid-way between the two points (125 msec), were selected to examine possible group differences in intra-individual variability.

(iii) Procedure.

Each child participated in two sessions, a session consisting of 150 experimental trials, 50 at each of the three durations (150, 125 and 100 ms), randomly shuffled. Subject accuracy was assessed in terms of the number of correct responses within 10 trials at the same target exposure duration, there being 5 such blocks of 10 trials at each duration. The second session, completed approximately 3 days after the first, was a repetition of the first so that, in all, 10 measures of accuracy were obtained for each child at each of 3 exposure durations. This procedure therefore permitted the estimation of a mean and

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[1] Differences, significant at the .05 level were also observed at TS durations of 50, 250 and 400 ms. (Refer to Appendix 5.1.)

standard deviation describing the distribution of the 10 measures of accuracy at each of 150, 125 and 100 ms target duration.

Task instructions did not differ from those of previous experiments. Experimental trials were commenced immediately following the completion of practice.

3. Results and Discussion

(i) Intra-individual Variability

The standard deviation of each child's accuracy at each of the three durations was assessed over the 5 blocks of each session and over the total 10 blocks. Mean standard deviations are set out in Table 5.1. A repeated measures analysis of variance on variability over 5 blocks examined the within-subject factors Session (1 and 2) and Duration (100, 125 and 150) and

TABLE 5.1. Mean Standard Deviations of the samples for Grade 3 and 7 children aged approximately 8 and 12 years in Sessions 1 and 2, over all Blocks, at TS durations of 100, 125 and 150 ms.

GROUP	MEAN STANDARD DEVIATION		
	Session 1 (Blocks 1 to 5)	Session 2 (Blocks 6 to 10)	Session 1 & 2 (Blocks 1 to 10)
Grade 3			
100 ms	1.43	.86	1.35
125 ms	1.05	.52	1.01
150 ms	1.01	.69	1.09
Grade 7			
100 ms	1.39	.23	.98
125 ms	.58	.23	.54
150 ms	.61	.12	.55

the between-subject factor Grade (3 or 7). This analysis produced significant results for all main effects. Estimated SDs for each child are listed in Appendix 5.2 with the details of the analyses of variance provided in Appendix 5.3. The significant Grade effect ($F(1,22) = 5.26$, $p < .05$) indicated the existence of greater variability in the performance accuracy of the Grade 3 children than in the Grade 7 children, while the significant Duration effect ($F(2,22) = 11.43$, $p < .01$) reflected the positive relationship between task difficulty and performance variability. Finally, the significant Session effect ($F\ (1,22) = 25.47$, $p < .01$) was illustrative of the beneficial effects of practice on performance stability. Thus, in the first session both groups exhibited greater variability than in the second, at which time performance appeared to stabilize. A significant Duration x Session interaction ($F\ (2,44) = 3.66$, $p < .05$) indicated that the effects of practice varied with task difficulty, being most marked at the shortest target exposure duration of 100 ms.

This analysis suggested that variability only reliably discriminated between children of different ages in the first session of 5 blocks. As an additional check intra-individual variability was also examined over both sessions combined; i.e. with the standard deviation of each child's accuracy estimated from performance over blocks 1 to 10 and with Session eliminated as a factor in the analysis. (The summary of this analysis is included in Appendix 5.4). When variability was examined in this way, Grade no longer produced a significant difference ($F\ (1,22) = 3.79$, $p > .05$). Variability did, however, vary across duration being highest at the shortest duration ($F\ (2,44) = 10.21$, $p < .01$).

Explanation for the discrepancy between the two analyses of intra-individual variability rests in the convergence of both groups upon ceiling performance over blocks. In the second 5 blocks performance improvement was such that both groups converged upon perfect performance and no significant group difference emerged. Thus, although Table 5.1 indicates that there was still a trend towards greater performance variability among the younger children variability did not reliably distinguish between the two age groups beyond the first session.

(ii) Performance Accuracy

Analysis of performance accuracy at each duration was undertaken in a multi-factorial repeated measures analysis of variance examining the within-subject factors Duration (100, 125 and 150), Session (1 and 2), and Block (1 to 5), and the between-subject factor, Grade (3 and 7). (Refer to Appendix 5.5 for the Analysis of Variance table). Results showed a significant effect for Grade (F (1,22) = 7.24, $p < .05$) confirming that, consistent with past results, 8-year-old children performed significantly less accurately than 12-year-olds. This may be seen from Table 5.2 where mean accuracy scores at each duration are set out for both age groups.

TABLE 5.2. Mean Percentage Accuracy for Grade 3 and 7 children aged approximately 8 and 12 years in Session 1 and 2, over all Blocks, at TS durations of 100, 125 and 150 ms.

GROUP	MEAN PERCENTAGE ACCURACY		
	Session 1 (Blocks 1 to 5)	Session 2 (Blocks 6 to 10)	Sessions 1 and 2 (Blocks 1 to 10)
Grade 3			
100 ms	78.5	91.3	84.9
125 ms	84.0	94.3	89.2
150 ms	84.2	95.7	89.4
Grade 7			
100 ms	90.3	98.8	94.6
125 ms	95.7	99.0	97.3
150 ms	94.2	99.2	96.7

A significant main effect for Duration (F (2,44) = 16.38, p < .01) reflected the increase in performance accuracy associated with increasing target duration. Similarly, a significant main effect for Session (F (1,22) = 22.90, p < .01) and Block within Session (F (4,88) = 4.93, p < .01), reflected the beneficial effect of practice on performance accuracy. A significant Duration x Session interaction (F (2,44) = 6.38, p < .01) further suggested that differences in accuracy between durations varied across sessions. Lastly, a significant Block x Session interaction (F (4,88) = 6.72, p < .01) indicated that the degree of change over blocks varied across Sessions, possibly as a result of ceiling effects.

These results indicate that performance accuracy was dependent upon a number of variables including Duration, Grade and Practice. The absence of a significant Grade x Session interaction suggests that both groups exhibited comparable amounts of improvement in accuracy over sessions (cf. Experiment 2.2, Table 3.7, p. 85). If the accuracy data are viewed in conjunction with the variability data it can be argued that the Group difference in performance accuracy across target durations was associated with greater performance variability at these same durations in younger children. However, variability was only clearly associated with accuracy differences in the first session, although accuracy calculated over both sessions was significantly different between groups. Thus, while greater variability is associated initially with the performance of younger children, the difference may not account for all differences in performance accuracy, particularly when the younger children are afforded the opportunity to become more familiar with the task.

Correlations between the levels of accuracy measured in the two sessions are listed for each of the three durations separately in Table 5.3. Failure to find a significant correlation in the Grade 7 data probably reflects the predominant influence of ceiling effects in this group.

TABLE 5.3. Correlation between Accuracy in Sessions 1 and 2 at Durations of 100, 125 and 150 ms in Grade 3 and 7 children aged about 8 and 12 years.

GROUP	DURATION		
	100	125	150
Grade 3	.95***	.83***	.59
Grade 7	.26	-.26	.21

***p < .001 (one-tailed)

The correlation coefficients of intra-individual variability and performance accuracy at each duration were also calculated for both groups and these are set out in Table 5.4. The negative direction of the correlations indicated that increases in performance accuracy were associated with decreases in variability. In other words, the least variable subjects were those with the highest levels of accuracy, possibly performing at asymptote on the cumulative normal ogive.

TABLE 5.4. Correlation between Accuracy and Intra-individual variability at Durations of 100, 125 and 150 ms in Grade 3 and 7 children aged about 8 and 12 years.

GROUP	CORRELATIONS		
	Duration		
	100	125	150
Grade 3	-.99***	-.86**	-.90***
Grade 7	-.82**	-.98***	-.89***

** p < .01 (two-tailed)
*** p < .001 (two-tailed)

4. Conclusions

The attempt to distinguish the contribution of age-based differences in intra-individual variability to differences in the performance accuracy of children aged 8 and 12 years suggested that developmental differences in IT may be due, at least in part, to factors that influence performance variability, like noise, attention, fatigue. The association of performance variability with target duration in both groups indicated that variability increased with perceived task difficulty, although this effect was reduced by practice.

The high levels of accuracy exhibited, in particular among the 12-year-olds, together with the failure to find a correlation between accuracy in session 1 and 2 in this same group, raises the possibility that the variability — accuracy association was confounded by a ceiling effect within this age group. Thus, the selection of TS durations of 100, 125 and 150 ms may have provided the 12-year-old children with a task that resulted in performance among these children that was near their asymptote on the cumulative normal ogive and considerably below this point for the 8-year-olds. The significant differences in IT found between these groups is consistent with this suggestion. If this were to have been the case, then comparison of variability at these durations would have artificially inflated group differences, by decreasing the possibility for individual fluctuations in performance among the older children.

An experimental design in which intra-individual variability was assessed at durations involving the same level of performance accuracy in each group would provide a test of variability which would reduce the possibility of confounding from ceiling effects. Whereas in Experiment 4 the strategy was to hold target exposure duration constant across age and allow accuracy to vary, the suggested design would equate children having different ages for accuracy (eg. 85% correct responses) but allow target exposure duration to vary across groups. However, this line of research has not been pursued further in this thesis. Instead, an attempt has been made to distinguish the possible contribution of other factors usually regarded as operating at a level beyond direct executive control; specifically registration and rate of input processing.

5. Experiment 5. The Influence of Registration and Rate of Processing on Age Differences in Input Processing Speed

Results from the IT studies described in the previous chapters have consistently indicated that the SOA at which a comparably high level of target recognition accuracy is achieved varies with age. As has been emphasized in the foregoing discussion, an explanation of this finding involves some difficulty since the finding can be explained by any one of a number of variables, or by some unspecified combination of these. Research described in Experiments 2, 3 and 4 suggests that developmental differences are not predominantly attributable to differences in task-specific learning, masking, or life-histories. Attention may influence group differences to some extent, but evidence from Experiment 4 suggests that this influence may not endure beyond some initial familiarization with the procedures employed. Backward masking theorists have generally argued that developmental differences in recognition accuracy are attributable to differences in the rate at which the TS is processed - i.e. encoded from registration to some more central location within the system. The fact that the masking stimulus (MS) produces greater disruption at short SOAs in younger children is interpreted as indicating that these children have not processed the first arriving stimulus as quickly as the older children. Despite wide acceptance of this view of the developmental results, research has yet to determine whether age differences in backward masking and IT studies reflect the actual quality of the input material (i.e. its detail and accuracy) or the uninterrupted time necessary to accurately process it.

In backward masking and IT research, the notion of speed and its determination is inextricably linked to accuracy. Speed in these paradigms is not measured directly but is inferred from recognition accuracy. Thus, any developmental variables which reduce the accuracy of performance will inflate estimates of processing speed. Developmental differences in accuracy can emanate from three locations within the input processing mechanism. At the first, an executive level directing behaviour, age differences in the efficiency of control mechanisms, particularly attentional variables, will influence performance accuracy (Nettelbeck & McLean, 1984). At the next level, that of initial peripheral registration, differences in efficiency, whether they be due to retinal sensitivity or control variables which affect the quality and detail of the input material, will result in differences in accuracy. Lastly, differences in the actual rate at which material is processed centrally into an identifiable form will result in differences in performance accuracy when processing time is restricted by the use of an appropriate masking stimulus.

Determining the influence of these particular factors upon the input processing model is extremely difficult. In Experiments 3 and 4 developmental differences were assessed on random unmasked trials and in terms of the influence of fatigue and intra-individual variability. Results suggested that attentional executive control variables may play some small part but that, nonetheless, such variables were not predominant in the causation of performance differences. Similarly, the finding that practice and task-specific knowledge could not account for longitudinal improvement over the period of 1 year (Experiment 2.1) indicated that accuracy differences were not due to these factors.

While the above results indicate that performance differences probably do not arise at the executive control level, at least with regard to the specific factors tested, it is possible that performance differences arise at the level of target registration. Data described in Experiment 1 indicated that a TS duration shorter than the SOA had a significant effect on the performance of all groups over and above the absolute length of the SOA, since lower accuracy was found for the ISI > 0 condition than for the ISI = 0 condition (Table 2.1, p. 50). Post hoc comparisons further indicated that the influence of an ISI was most pronounced in the youngest group. This finding suggests that young children may register a TS more slowly or more inaccurately than older subjects. This may in turn be due to either an executive control mechanism responsible for fixation at target onset or, alternatively, to the sensitivity of visual registration. However, results from Ferreira's (1978) study showed that deviate fixations could not account for age differences in performance accuracy, suggesting that this former explanation is probably not tenable. By this reasoning then, the most likely source of age differences associated with a registration stage is visual sensitivity.

The visual sensitivity proposition has been examined in a developmental context by Haith, Morrison and Shiengold (1970). They evaluated the notion that young children are differentially hampered by a TS of short duration by testing unmasked threshold recognition time in children aged 4 and 5 years, and in adults. On each trial, a single item was tachistoscopically presented at the centre of the visual field for a duration varying between 5 and 40 ms. While age differences were observed at durations below 20 ms, Haith et al. contended that these were minor and that the overall results indicated that very young children could not be described as "perceptually sluggish". Despite their conclusion, however, the fact that unmasked recognition accuracy at very short TS durations (i.e. less than 20 ms) did differentiate adult performance from that of children aged 4 or 5 suggests that visual sensitivity may vary ontogenetically. This interpretation is supported by the results of Experiment 1 which showed that when TS duration is reduced while maintaining SOA, then the accuracy of young children compared with older children and adults is differentially reduced.

The third location for possible IT differences, namely the rate of encoding registered input, is that generally favoured by backward masking theorists. According to this argument developmental differences in IT may reflect differences in the actual rate at which the TS is initially processed from registration to a central location. However, before it can be argued that the age differences arise solely from this factor, registration efficiency must be separated from processing efficiency. A study which manipulates target duration and amount of stimulus information to be processed provides the opportunity for attempting such a separation. If TS duration is manipulated (with SOA held constant) and this manipulation affects performance accuracy differently across ages, it can be argued that developmental IT differences may be due, at least in part, to variables influencing registration since processing rate is critically dependent on the period between target mask onset and independent of TS duration (Turvey, 1973). Increasing the amount of information to be encoded from registration may similarly indicate that the difference rests in the processing rate of the respective age groups.

6. Method

(i) Subjects

Two groups of 10 children with mean ages of 8 years 0 months (range 7 years 4 months to 8 years 7 months) and 12 years 2 months (range 11 years 6 months to 13 years 6 months) participated in the study. The children were selected from Grades 3 and 7 by the Principal of the school from which they were obtained. As in previously reported experiments, all participants were assumed to have at least average intellectual ability and their eyesight was checked prior to participation.

(ii) Apparatus, Design and Procedure

A Northstar Advantage computer was used to present the stimulus and masking figures as described for Experiment 4. In addition to the two target stimuli used previously (i.e. shorter line on right or shorter line on left), four additional stimuli were presented. These consisted of the four-legged target figures shown in Figure 5.1. The short line was located equiprobably in one of the four possible positions. The masking figure, four lines of equal length, totally overlapped the TS. Thus, six different stimuli were presented, followed some time after offset by one of two possible masking figures, depending upon whether a 2 or 4 choice TS was presented. Each TS was preceded by a cue figure, a cross, for a duration of 1000 ms.

Practice consisted of a minimum of 48 trials (6 blocks composed of 8 trials each). The composition of each block was as follows: 200 ms SOA (ISI = 0), 2 and 4-choice; 100 SOA (ISI = 0), 2-choice; 100 SOA (ISI = 0), 4-choice; 100 SOA (ISI = 90), 2-choice; 100 SOA (ISI = 90), 4-choice; 100 SOA (ISI 0 or 90), 2 and 4-choice. Practice was primarily aimed at familiarizing the subject with the general form of the experimental trials involving the alternatives of a 2 or 4-choice decision with an ISI of 0 or 90 ms.

Experimental trials followed the satisfactory completion of practice. An experimental session consisted of 160 trials; 80 involving 2-choice, 40 with an ISI of 0, and 40 with an ISI of 90; and 80 requiring 4-choice, 40 in both of the ISI conditions. SOA was constant at 100 ms on all trials, an SOA which successfully distinguished the performance of 8 and 11-year-olds in

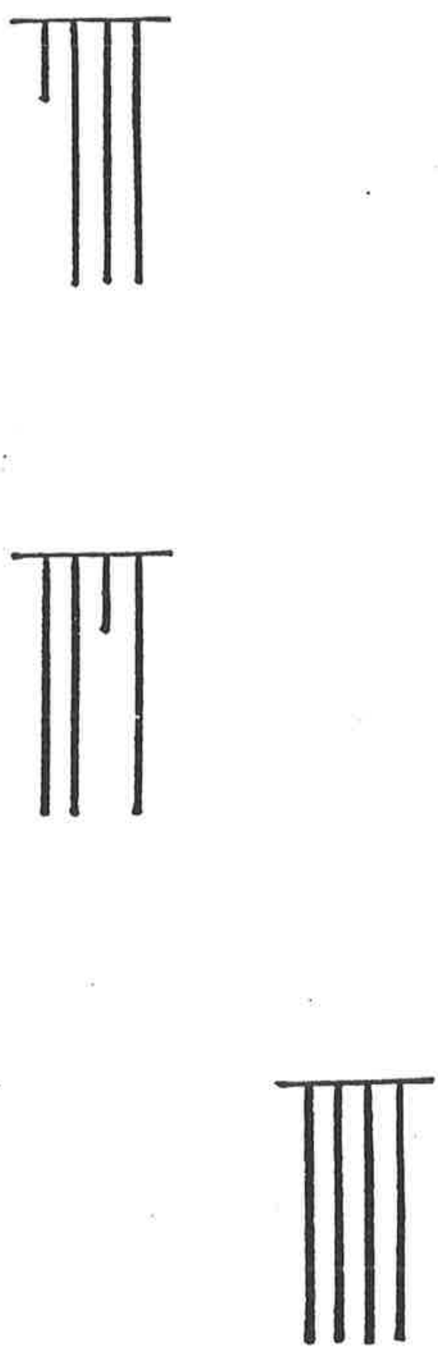

FIGURE 5.1. Target stimuli and the masking stimulus for the 4-choice task of Experiment 5.

Experiments 4 and 6. As in previous experiments, instructions to the subjects were to attend at cue onset. Each child was instructed to determine the location of the short line of the TS and to guess the location when they weren't sure. The child pointed to the appropriate figure drawn on a response selection array located to the immediate left of the computer screen. The experimenter then recorded the response by a key press, and initiated the next trial. Because of the more complex nature of the possible responses of this experiment in comparison with past studies (i.e. 6 alternative target figures), it was felt advisable to forego the key pressing procedure required of children in the previous experiments and to substitute a pointing response.

7. Results and Discussion

Table 5.5 lists the mean number of trials correct out of 40, according to ISI and type of choice. These means shown that the Grade 7 children were operating at near perfect accuracy in the 2-choice task with the Grade 3 children exhibiting more errors in all conditions.

TABLE 5.5. Mean number of correct trials (out of 40) and Standard Deviations (in parentheses) in a 2 and 4-choice task with SOA equal to 100 ms and an ISI of 90 or 0 ms, in Grade 3 and 7 children aged 8 and 12 years.

GROUP	2 choice	4-choice
Grade 3		
ISI 90	34.2 (5.5)	27.5 (7.0)
ISI 0	35.0 (5.1)	30.3 (7.8)
Grade 7		
ISI 90	38.7 (1.4)	35.6 (2.8)
ISI 0	39.1 (1.2)	35.3 (5.6)

A repeated measures analysis of variance examining the between-subject factor Group (Grade 3 vs Grade 7) and the within-subject factors ISI (0 and 90) and Choice (2 and 4) produced a significant effect for both Group and Choice; (refer to Appendix 5.6 for the Analysis of Variance summary table). The Group effect (F (1,18) = 7.46, p < .05) indicated that Grade 3 children were significantly less accurate at an SOA of 100 ms than Grade 7 children. This result is consistent with those reported in previous chapters, where the accuracy of young children aged 8, has always been significantly less than that exhibited by children aged 11 years. The significant main effect for Choice (F (1,18) = 26.09, p < .01) reflected the decrease in accuracy in both groups associated with the progression from a 2-choice to a 4-choice task. Thus, increasing the complexity of the discrimination by increasing the "bits" of information to be input and holding SOA constant increased the difficulty of the task for both groups. Failure to find a significant Group x Choice interaction (F (1,18) = 1.58) indicated that neither group was significantly more disadvantaged by the increase in information to be processed, as may be seen in Figure 5.2.

A nonsignificant main effect for ISI (F (1,18) = 3.61, p < .10) indicated that for both groups performance in the 2 and 4-choice task was not significantly dependent upon the actual duration of the TS. Thus, a TS of 10 ms duration appeared to provide adequate opportunity for effective registration in both the Grade 3 and Grade 7 children, although the means listed in Table 5.5 and described pictorially in Figure 5.2., do suggest some small performance decrement in the performance of the younger children associated with the offset of the TS after 10 ms (i.e. ISI = 90 ms). However, as with the main effect, the Group x ISI interaction effect was not significant (F(1,18) = 3.23, p < .10). The Group x Choice x ISI interaction also failed to reach significance (F(1,18) = 1.90, p > .05).

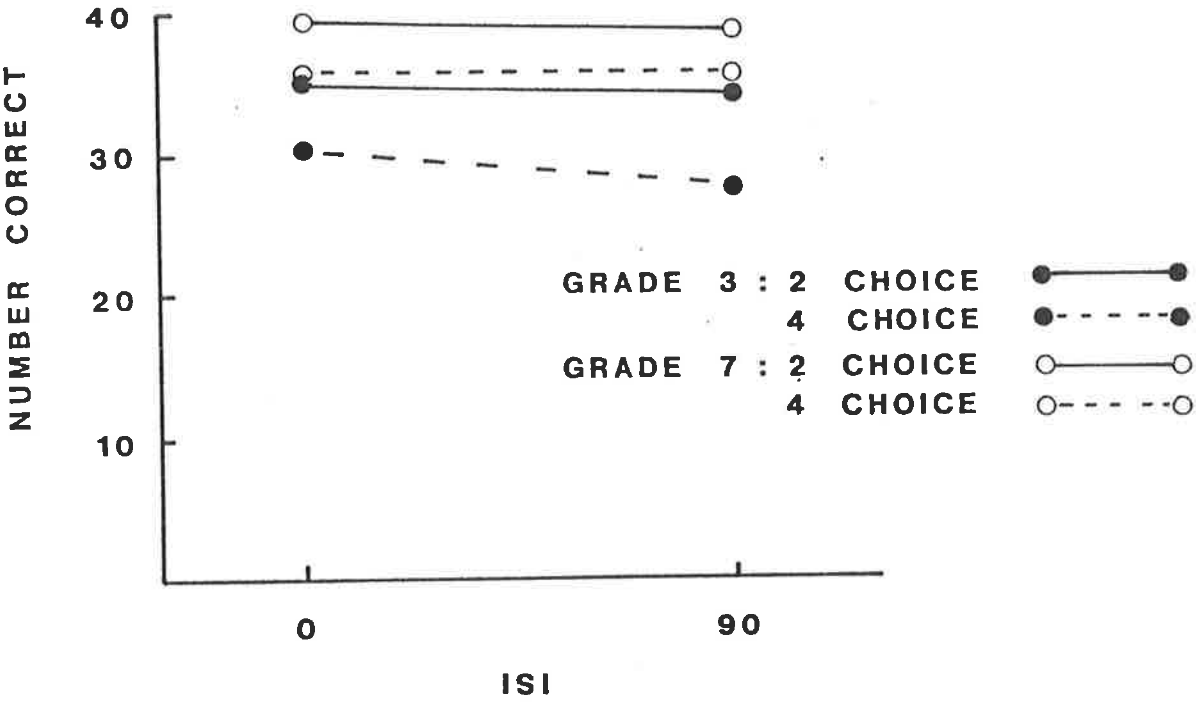

FIGURE 5.2. Number of correct trials (out of 40) with an SOA of 100 ms, in a 2 and 4-choice task with an ISI of 0 or 90 ms, in groups composed of Grade 3 and 7 children aged 8 and 12 years.

Correlations between performance in each of the four Choice by ISI combinations are presented in Table 5.6. Presumably the SOA of 100 ms duration with the associated ceiling performance among the Grade 7 children prevented the majority of correlations involving this group from reaching significance. However, the results from the younger group do indicate high performance consistency across conditions.

TABLE 5.6. Correlations between Accuracy at an SOA of 100 ms in 2 and 4-choice conditions, with an ISI of 0 and 90 ms, in Grade 3 and 7 children aged 8 and 12 years.

GROUP	2-Choice ISI 0	4-Choice ISI 90	4-Choice ISI 0
Grade 3			
2-Choice ISI 90	.92***	.85***	.78**
2-Choice ISI 0		.78**	.77**
4-Choice ISI 90			.84***
Grade 7			
2-Choice ISI 90	.67*	.24	.12
2-Choice ISI 0		.18	-.24
4-Choice ISI 90			.82**

*	$p < .05$	(one-tailed)
**	$p < .01$	(one-tailed)
***	$p < .001$	(one-tailed)

8. Conclusions

Results of this experiment suggest that neither differences in registration efficiency nor input processing rate successfully account for accuracy differences across ages. This result is difficult to explain when viewed in conjunction with the outcome from Experiment 4. On first appraisal, the present results appear to indicate that developmental differences do not arise at any of the three levels hypothesized. Data from the intra-individual study (Experiment 4) suggested that while influences at the executive control level may account, in part, for accuracy differences, age-based differences in performance exist over and above this factor. However, the failure in Experiment 5 to find a significant Group x ISI or a Group x Choice interaction indicates that the lower accuracy exhibited by the 8-year-old children was not a reflection of either less efficient registration in this group, or of slower rates of input processing when compared with 12-year-olds.

Two possible explanations for this result can be hypothesized. Firstly, it is possible that performance differences between 8 and 11-year olds arise out of a fourth variable not distinguished by either Experiment 4 or 5. One such variable could be a factor of general noise in the processing system, not successfully identified by the experimental manipulations of Experiment 4. Thus, accuracy differences may arise out of age differences in the general efficiency of the processing mechanism which may be reflected, in part, in greater intra-individual variability, but may also exist in situations where variability is minimal. Processing noise would have a generalized influence on performance at all levels of the processing system, thereby accounting for the consistent accuracy difference between 8 and 11-year-olds, found to exist independent of stimulus complexity. At the same time, it would account for the differences in variability found in Experiment 4, and the slight, though nonsignificant, differences in registration efficiency found in Experiment 5. However, further experimental work is needed, firstly, to verify the existence of an overriding influence of this kind, and, subsequently, to establish its relationship to IT differences.

A second possible explanation for the results of Experiment 5 rests in possible inadequacies of the experimental design, particularly in relation to the manipulation designed to distinguish rate of encoding from registration to a central location. Increasing the complexity of the discrimination from a 2 to 4-choice task may not have doubled the bits of information to be processed, as was hypothesized at the outset. This is because using a masking figure matched to the target provided the subjects with a post-target cue as to the general form of the target figure (2 or 4 lines), and this may have aided identification. Subjects may have found the task to be essentially one of recognition, particularly after prolonged exposure to the target stimuli, whereby no comparison of line length need be made for accurate target identification. However, though possible, this second suggestion seems less likely than the first. This is because in both age groups, increasing stimulus complexity did actually decrease performance accuracy, so that input processing speed was affected by the increasing degree of choice. It would therefore seem more likely that accuracy (and IT) differences arise out of some factor not clearly identified to date but which is plausibly hypothesized to relate to the level of noise present within the processing system.

CHAPTER 6

EXPERIMENT 6

The relationship of Inspection Time to MA, IQ and Impulsivity in response style

1. The Relationship of Inspection Time to Tests of Intelligence and Conceptual Tempo

Studies described in the previous chapters have mapped the development of inspection time (IT) throughout childhood and attempted to localize the origins of the developmental differences found in speed of information processing at the levels of executive control, registration, and central processing. While some consideration has been given to the IT - IQ relationship, the possibility that IT might reflect an interaction between age and general ability factors remains to be considered.

It is noteworthy that the progression from a slow to a faster and asymptotic IT between the ages of 8 and 11 years parallels the progression from an impulsive response style (fast with many errors) at a younger age, to an increasingly reflective one (slow with few errors) at an older age. Since response style is hypothetically reflected in any problem solving task in which some response uncertainty is involved, it could be argued that IT differences reflect age based variation in the speed-accuracy trade-off, since quick responding associated with a higher error rate would necessarily inflate IT. Certainly, as the models of Furneaux (1960) and White (1973, 1982) illustrate, individual differences in task persistence and error checking behaviour have an effect upon the speed and accuracy with which problem solving behaviour is undertaken.

According to Furneaux (1960), performance on a problem solving task is dependent upon speed and accuracy of individual responses and on the individual's propensity for "continuance".[1] White (1973, 1982), who developed

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[1] Continuance refers primarily to persistence, but also includes other factors which may induce a person to abandon a problem.

a probabilistic latent trait model of intelligence on the basis of the Furneaux paper, argued that performance in problem solving is a function of latent ability variables (speed and accuracy), latent continuance variables (including persistence), as well as a dimension of problem-solving task parameters, such as difficulty level and discriminating power.

The two main influences on performance in a problem-solving task identified by Furneaux (1960) and White (1973, 1982) as speed and accuracy, may have implications for the developmental IT differences evidenced in Experiments 1, 2.1, 2.2 and 3. Firstly, the contribution of speed to IQ is of paramount importance in Furneaux's model of intelligence. IQ differences are viewed primarily as reflections of differences in the efficiency of the problem solving (or information processing) mechanism. When item difficulty is negligible, performance speed alone differentiates individuals. As difficulty increases, accuracy comes increasingly to reflect the intellectual ability of the individual. In the IT task, speed cannot be differentiated from accuracy since the latter defines the former. However, to the extent that IT reflects individual differences in processing efficiency, it is possible that it also relates to individual differences in intelligence both within age groups (by reference to IQ) and between age groups (by reference to MA). Secondly, developmental differences in IT may reflect the progression from impulsivity to reflectivity in response style. Furneaux has suggested that it is continuance which accounts for the form of the speed-accuracy trade-off in tests of intellectual ability. Similarly, it is possible that willingness to withhold responding in order to achieve high levels of accuracy may influence IT. Thus, the models of Furneaux and White raise the possibility that IT differences relate to factors like intelligence and conceptual tempo, both developmentally and individually.

(i) The IT - IQ Relationship

The attempt to illustrate a causal relationship between speed and intelligence has had a history of varied success. Galton's (1883) initial attempt to relate the efficiency of sensory processes to individual differences generated a considerable amount of interest and subsequently several attempts were made to verify the belief that, ". . . the essence of the intelligent reaction seems to be the solution of a problem against time." (Peak & Boring, 1926, p. 73). Even after the initial enthusiasm had diminished and the interest in intelligence was redirected towards educational achievement, speed continued to play an important part in defining ability (cf. Thorndike, 1925).

With the development of the information processing approach in psychology, and the predominant part that speed has played in the various procedures developed to index processing, individual differences have been increasingly defined in temporal terms. Various kinds of response time measures, from those involving a simple button press reaction to those involving sentence verification, have been shown to correlate with intelligence as measured by conventional IQ tests (eg. Hunt, Lunneborg & Lewis, 1975; Jensen, 1979).

While studies have consistently reported correlations of approximately .3 to .4 between RT and intelligence, there are data which indicate that the relationship may be confounded by task complexity. A study by Hoosain (1980) in which speed on a word-judgement task was correlated with Raven's Progressive Matrices scores obtained coefficients contradicting those of most past studies; faster subjects had lower IQs. Hoosain suggested that this result illustrates the possibility that "mental speed" as such is not necessarily accurately measured by response time. Furthermore, the complex nature of the task in Hoosain's study, which required identification of the "positive" or "negative" nature of the Chinese and English words, raises the possibility of mental speed being confounded by other more subjective factors involving judgement. A similar finding was reported when RT was measured in the IT task, comparing samples of retarded and nonretarded subjects (Lally & Nettelbeck, 1977). In this study failure to observe a decrease in RT across durations in a sample of retarded adults, in contrast to a consistent decrease among the nonretarded participants, indicated the difficulties associated with interpreting RT purely as a measure of mental speed and the confounding of this measure with response strategies.

The finding that more complex cognitive tasks may correlate less well with IQ than simple information processing tasks has been well documented. Jensen (1982) has argued that the RT - IQ correlation increases with task complexity only up to reactions requiring about 1 sec. However, if the task requires longer than 1 sec to complete, the correlation between performance and IQ decreases (Spiegel & Bryant, 1978). Presumably, this decrease reflects the increasing tendency of factors over and above mental speed to confound RT.

Obtaining an unconfounded measure of mental speed has been the goal of many researchers. Brand and Deary (1982), who have investigated the relationship between intelligence and processing speed, postulate that IT may provide an unconfounded estimate of mental speed. As evidence they cite correlations between IT and IQ from their own studies which average .8, and consequently they conclude that IT may provide an estimate of intellectual potential.

Detailed examination of the IT - IQ correlation has followed Brand's initial proposal in a number of experiments. It has been noted (Brand & Deary, 1982; Nettelbeck, 1982; Nettelbeck & Kirby, 1983a; 1983b) that the inclusion of mentally retarded adults among the subjects sampled in the original experiments by Nettelbeck and Lally (1976), Lally and Nettelbeck (1977), and Anderson (1977) may have inflated the correlations, in view of the generally poorer performance of retarded individuals on all tasks. Brand and Deary (1982), while reporting that the strength of the correlations have been substantially reduced when mentally retarded subjects were excluded from the sample, have argued that the significance of the coefficients have not been critically dependent upon the inclusion of retarded subjects. For example, when the sample of the Anderson (1977) study was restricted to subjects ranging in IQ from 99 to 133 the resultant coefficient of -.64 remained significant. Nettelbeck (1982) also re-examined the correlation reported in the Lally and Nettelbeck (1977) paper in an attempt to elucidate the earlier results. In the 1977 experiment, 3 groups composed of 16 undergraduate university students, 16 nonretarded adults and 16 mildly retarded workshop trainees were tested on the WAIS and IT task. The resultant within-group Performance IQ (PIQ) as estimated on the WAIS, and IT correlations measured -.17, -.50 and -.45 respectively. When the two non-retarded groups were combined, the resulting coefficient was -.23. In the same paper, the IT - IQ relationship among a nonretarded population was assessed in a sample composed of third-year psychology students whose IQs were measured on the Raven's Advanced Progressive Matrices and the ACER Advanced AL Test.[1] The correlation between Raven's IQ and IT failed to reach significance (r = -.20), with the AL - IT coefficient just reaching significance (r = -.34, but increasing to -.52 with the exclusion of 2 atypical outlying scores).

Thus, in light of the Anderson (1977) and Nettelbeck (1982) results the IT - IQ correlation reduces substantially from -.8 to approximately -.4 to -.5 when the sample is restricted to subjects with average to above-average IQs. Nettelbeck and Kirby (1983a) attempted to overcome some of the difficulties associated with past studies by assessing the correlation in a sample approximating the normal distribution. An initial sample of 181 undergraduates, apprentices

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1. The AL Test is a multiple-choice test of verbal reasoning developed by the Australian Council for Education Research. It is designed for use with senior secondary school and university students, with an upper IQ estimate of 135.

and workshop trainees was reduced by selective deletion to a sample of 91 with approximately normally distributed IQs. The resultant coefficient of -.50 perhaps provides the best available estimate from adults of the extent of the relationship between IT and IQ.

The limited evidence available suggests that the IT - IQ association among children may be even smaller. In the first of two studies, Hulme and Turnbull (1983) tested a large group of normal children between the ages of 6 and 7 years, reporting a low but statistically significant correlation between IT and PIQ of -.29. In the subsequent experiment, involving a sample of adults with below average intelligence and tested on the same IT task, the coefficient increased to -.71, approximating earlier results. On the basis of these data, Hulme and Turnbull suggested that the nature of the IT - IQ relationship varied across samples distinguished by age and IQ and was strongest in those adult subjects with IQs below average.

Thus, the studies examining the IT - IQ relationship described above are illustrative of three main findings. Firstly, in samples with IQ ranging from below to above average the coefficient approximates -.5 (Nettelbeck & Kirby, 1983a). Secondly, if the sample is restricted predominantly to below average IQs, the coefficient may be as high as -.8. Thirdly, in a sample restricted to average and above average participants the correlation decreases to -.2 to -.3. It could be argued that these results indicate that a fast mental speed is necessary but not sufficient for high IQ. In other words, as suggested by Brand and Deary (1982) and Hulme and Turnbull (1983), mental speed may determine intelligence up to some threshold level, after which point other factors may come to play an increasingly important role in determining a general or comprehensive IQ score. IT may therefore be reflected in measures of fluid intelligence and less so in measures of crystallized intelligence, especially among children.

The concepts of fluid and crystallized intelligence stem from the work of Cattell (1963, 1971) who argued that abilities which involve intelligence to any degree can be described on the basis of these two principal dimensions. The fluid component was hypothesized to reflect biological intellectual capability, while the crystallized component, as the name implies, referred to more concrete, performance variables as measured by more achievement-orientated tests. In particular, crystallized intelligence has been thought to be most clearly reflected in those tests in which performance is based upon knowledge of the content, such as is acquired through education. Fluid ability, on the other hand, should be tapped most clearly by "culture-fair" tests of reasoning ability. Although theoretically and operationally independent, correlations between the two components have been found to range between .4 and .5 (Cattell, 1971), presumably as a result of the investment of fluid abilities in the acquisition of crystallized skills including, but not restricted to, those measured in intelligence tests.

Hunt (1978) has hypothesized that efficiency of the basic information processing mechanism provides a measure of fluid intelligence. Jenkinson (1983) attempted to examine this hypothesis by testing the correlation between speed of information processing on a number of simple tasks and estimates of fluid and crystallized intelligence. In light of work by Hunt (1978) and Cattell (1971), Jenkinson suggested that speed should exhibit a stronger association with tests of fluid intelligence than with crystallized intelligence, where processes other than the ability to acquire knowledge would influence the total score. Measures of fluid and crystallized intelligence were obtained using Raven's Standard Progressive Matrices and the Mill Hill Vocabulary Scale respectively. Estimates of processing speed were made on the basis of performance on a memory scanning task (after Sternberg, 1969), a picture identification task in which the subject had to judge whether a test item matched one of a simultaneously presented series of 1 to 8 pictures (devised by Jenkinson, 1983), and a sentence-picture comparison task in which the truth of the presented sentence was verified by a subsequent pictorial presentation (after Clark & Chase, 1972). Correlations between RT in these tasks and scores on both IQ tests did not surpass those from past RT studies, ranging between -.3 and -.4. Furthermore, the correlations with fluid intelligence were not significantly greater than those with crystallized intelligence and it could therefore be argued that processing speed was not necessarily more strongly associated with estimates of fluid abilities.

However, the confounding of mental speed with other factors, like those concerned with response organization in this study, may have masked the relationship between processing efficiency and fluid intelligence. Brand and Deary (1982) have suggested that the IT measure may provide an estimate of fluid intelligence or intellectual potential which can be differentiated at a very early age. Thus IT may provide the "foundation for the development of quantitative differences in crystallized intelligence." (Brand & Deary, 1982, p. 141). At early MAs IT would therefore provide an accurate prediction of performance on an IQ task, while at later MAs, as educational experience increased, measured intelligence on traditional psychometric tests would become increasingly affected by factors other than speed. In light of the work of Brand and Deary (1982) the IT - IQ correlation would be predicted to vary across MAs, with larger coefficients found among younger samples. While results obtained in the experiments of Hulme and Turnbull (1983) do not support this hypothesis, failure to test a range of ages may hide the developmental progression from a low to higher correlation with decreases in MA.

(ii) The Mental Age Deviation Hypothesis

Spitz (1981, 1982) has provided a framework for equating the g loading of various ability tests with the MA deviation associated with performance.

According to this model, the tasks which load most heavily on g are those in which the gifted perform in a significantly superior manner, and the retarded significantly more poorly, in comparison to normal MA controls. Furthermore, quantifying the actual MA deviation provides an estimate of the relative importance of the measure to retarded - nonretarded differences.

Spitz has attempted to specify those tasks in which a significant MA deviation is observed. On the basis of this evidence he has concluded that,

> ". . . the immediate deficiency of the retarded alerts us to the fact that they do not process incoming information as efficiently as do the non-retarded [while] . . . their normal decay rate tells us that the memory systems are operating adequately. They have trouble in processing material, not in maintaining it once it is processed."
> (Spitz, 1982, p. 175)

At this time nothing is known concerning a possible relationship between IT and IQ tests having a high g loading although Jensen and Vernon (in press) have found that RT is more strongly associated with conventional tests high on g. However, processing speed as measured by the IT task may exhibit a significant MA deviation which will indicate its g loading. Furthermore, in light of the hypothesis of Brand, this deviation should be significantly larger at younger MAs where intelligence is held to be less confounded by experiential and educational factors.

(iii) The IT - Conceptual Tempo Relationship

While Furneaux (1960) attached paramount importance to speed of the problem-solving mechanism as a determinant of individual differences, he also distinguished a continuance factor. Continuance in any task is defined as the propensity of an individual to persist in the face of some difficulty and to response-checking behaviour. Empirically, this factor refers to the tendency of a subject to either delay or to provide a response quickly when presented a task in which some uncertainty is involved. (It also refers to the abandonment of a problem when this is a viable alternative within the context of the task requirements.)

The well-documented speed-accuracy trade-off in RT studies is illustrative of this tendency. To the extent that a decision will have to be reached in any task which involves some response uncertainty, even the most simple, the speed at which a response is initiated will depend at least in part upon the cautiousness of the subject. In the IT task, developmental differences in responding style may affect accuracy and concomitantly, estimates of input processing speed.

The reflection - impulsitivy dimension, or "conceptual tempo", as it has also come to be known, was first identified by Kagan and his associates (Kagan, Rosman, Day, Albert & Phillips, 1964). In their cross-sectional study, two dimensions of conceptual style were documented, these exhibiting a linear developmental trend between the ages of 6 and 12 years. The first dimension isolated was analogous to Witkin's distinction between field dependence and independence (Witkin, Dyk, Faterson, Goodenough & Karp, 1962), expressed in the Kagan et al. study as a tendency to differentiate small details in a visual array. The second dimension was new, identifying the tendency to reflect upon alternative solutions to problems in which a number of responses were possible, as opposed to a tendency to act impulsively.

The primary instrument used to assess the reflectivity - impulsivity dimension is the Matching Familiar Figures (MFF) test. In the MFF the child is required to identify a matching figure from an array of 6 highly similar variants. If correct, the child progresses to the next item; if incorrect, another choice is made. Scoring consists of total errors across 12 items, and latency (i.e. RT) to the initial response averaged across items. On the basis of these two scores children are classified as "impulsive" if they exhibit shorter than median latency and higher than median errors, and "reflective" if latency is longer than the median value, with errors lower than the median value. In most studies this technique has served to classify approximately 70% of all subjects. The remaining 30% (i.e. fast/accurate and slow/inaccurate subjects) were generally excluded from analyses in early studies. In recent years the scoring procedure has been modified. Salkind and Wright (1977) have identified two independent dimensions of conceptual tempo; impulsivity and efficiency. Scores on the two scales are generated from raw latency and error scores by the following formulae:

$$\text{I (impulsivity)} = Ze - Zl \quad \ldots\ldots\ldots\ldots \quad \text{Equation 6.1}$$

$$\text{E (efficiency)} = Ze + Zl \quad \ldots\ldots\ldots\ldots \quad \text{Equation 6.2}$$

where Ze = standard score for total errors

and Zl = standard score for mean latency

A high positive score on the Impulsivity dimension describes impulsive subjects who score above the median for errors and below the median for latency. A high positive score on the efficiency measure, however, is achieved by <u>inefficient</u> subjects, that is, those who score above the median for errors and latency. Thus, while the dimension was labelled "Efficiency" by Salkind and Wright (1977), it is probably more sensibly viewed as a scale of "Inefficiency". Despite the possible confusion associated with the labelling of this dimension, the term "efficiency" is used in the discussion to follow so as to maintain consistency with Salkind and Wright's practice. In other words, those subjects exhibiting a high <u>negative</u> score on this dimension (i.e. below the median on errors and latency) have been defined as efficient.

The conceptual tempo literature has been reviewed extensively in recent years (Arizmendi, Paulsen & Domino, 1981; Duryea & Glover, 1982;

Messer, 1976). Developmental studies following the original Kagan et al. (1964) paper have indicated that children, between the ages of 5 and 12 years, typically become more reflective (i.e. less impulsive) with age, exhibiting decreasing errors and increasing response time (Ault, 1973; Campbell & Douglas, 1972; Kagan, 1965). Some confusion, however, is associated with this outcome since the relationship with age appears to hold more strongly for errors, which decrease with age, than with response time, in which the increase with age is not so convincing (Cairns, 1978; Harrison, 1971; Juliano, 1974). In fact, latency appears to exhibit an inverted U-shaped function, peaking between the ages of 9 and 10 years, and decreasing subsequently (Salkind & Nelson, 1980).

Similarly, the relationship between IQ and performance on the MFF test is better described by speed and accuracy separately than by overall impulsivity, which correlates only between .1 and .2 with IQ (Finch, Spirito & Brophy, 1982; Messer, 1976). While errors and IQ are negatively related, latency is more accurately mapped by a U-shaped function in which both high and low IQ subjects exhibit longer mean response times (Paulsen & Arizmendi, 1982).

Other studies have attempted to assess the relationship between MFF test performance and general scanning strategies (Ault, Crawford & Jeffrey, 1972; Wright & Vlietstra, 1975). These studies suggest that the developmental progression from impulsivity and inefficiency to reflectivity and efficiency maps the change from primarily exploratory scanning behaviour to an increasingly selective and systematic search strategy. Furthermore, Wright and Vlietstra argue that this development is an imperative progression.

> "Exploratory behaviour is a necessary precursor to, and stimulator of, systematic search strategy . . . . . Each advance in the child's understanding of how his environment is organized enables him to structure a greater portion of his exploratory response repertoire into the format of systematic search."
>
> (Wright and Vlietstra, 1975, p. 198)

Such a developmental trend in scanning behaviour and test taking style would have implications for performance in a variety of tasks apart from the MFF. In a study by Weiner (1975) in which visual information processing speed was measured using a backward masking procedure, results suggested a relationship between conceptual tempo and processing speed. Two groups of children aged 8 and 10 years were categorized as reflective and impulsive on the basis of the within group medians for mean latency and total errors. Analysis indicated a tendency for the younger children to exhibit slower processing speed while reflective children within each age group had a significantly shorter critical SOA.

Thus, it might be argued that developmental differences in processing speed arise out of the developmental progression from impulsivity to increasing reflectivity in response style, at least between the ages of 8 and 11 years. In other words, the longer ITs of the younger children found in Experiments 1, 2 and 3, may reflect greater inaccuracy in performance resulting from faster or less considered performance. However, a conclusion cannot be reached on the basis of Weiner's (197) study alone, for three main reasons. Firstly, the method of classifying Impulsivity in the experiment did not allow for analysis of individual differences in processing speed and conceptual tempo. Secondly, adoption of the traditional classification technique also resulted in the deletion of children who did not meet the impulsivity or reflectivity criteria, thereby excluding all fast, accurate and slow, inaccurate children. As a result, the representativeness of the sample is questionable, and the nature of any relationship between efficiency and processing speed cannot be examined. Thirdly, difficulties previously described, in Chapter 1 (Section 2(iii), p. 13-18; p. 24) associated with the backward masking procedure, warrant replication of the finding using the IT task.

(iv) Summary

While studies described in the previous chapters have attempted to localize the source of developmental IT differences within specific processing variables, the possibility that input speed may relate to general intellectual ability and conceptual style factors requires consideration. A documented IT - IQ correlation, which appears to depend for its magnitude on the nature of the sample tested, suggests that IT relates in some way to intelligence. Moreover, the consistently larger size of the coefficient in studies involving retarded rather than nonretarded subjects is consistent with the hypothesis that a certain critical processing speed is necessary, but not sufficient, for high IQ, serving to discriminate those with higher fluid intellectual potential for a normal to high IQ from those without. It is therefore hypothesized that IT will correlate significantly with measures of fluid intelligence, particularly at lower MAs where general ability is less confounded by experiential and environmental factors. Furthermore, assuming that IT provides an estimate of g, it is predicted that IT will exhibit a significant MA deviation, with low IQ subjects in particular performing significantly poorer than MA matched controls of average or above average intelligence.

In addition, the possible contribution of conceptual tempo differences to the developmental IT trend requires some elucidation. The progression from a slow to increasingly fast IT between the ages 8 and 11 years may reflect the development of an increasingly reflective response style whereby increasing consideration is given to the selection of an appropriate response. The following study attempts to clarify the contribution of both intelligence and conceptual tempo to the development of IT.

2. Method

(i) Subjects

Subjects were 40 primary school children and 8 workshop trainees who were selected for inclusion on the basis of their performance on Raven's Coloured Progressive Matrices (CPM). An initial subject pool of approximately 260 school children and 60 workshop trainees was tested on the CPM in groups varying in size between 10 and 20. Subjects performing at a MA level of 8 or 11 years were selected for closer examination. The final sample consisted of 24 subjects at a MA of 8; 8 with above average IQs, 8 average and 8 below average, and 24 with a MA of 11 years; 8 above average, 8 average and 8 below average. Because of difficulties involved in obtaining children with IQs below about 80, the latter group was defined as falling below an IQ of 90, with the average group falling between 95 and 114, and the above-average group, 122 to 135; (135 is the upper limit of the IQ as estimated by the CPM and the 2 children from the MA 8, above average IQ group, scoring above the limit were assigned an IQ of 135). Table 6.1 provides a breakdown of the resultant sample.

TABLE 6.1. Breakdown of sample by IQ, Sex and Mean CA.

GROUP MA	IQ	MEAN IQ	MEAN CA y/m	SEX f/m
8	Below average	84	10.2	5m 3f
8	Average	99	8.2	2m 6f
8	Above average	126	5.10	6m 2f
11	Below average	86	18.2	7m 1f
11	Average	110	10.6	3m 5f
11	Above average	124	8.0	2m 6f

(ii) Apparatus and Design

The tachistoscopic presentation technique described in previous experiments was used to obtain estimates of IT; (refer to Chapter 2, Experiment 1 for further details). A method of constant stimulus differences was used to measure the number of correct trials at trial durations of 5, 25, 50, 100, 150, 250, 400 and 2000 ms. Twenty trials at each duration, randomly shuffled were incorporated into the experimental measure for a total of 160 trials. A cumulative normal ogive with mean equal to 0 ms coincident with the 50% correct point was fitted to the data obtained and an IT estimate made from this function as the TS duration (i.e. SOA) at which 97.5% accuracy was achieved. Reaction time was also recorded as the time between the onset of the TS and the pressing of the response key.

Estimates of IQ were obtained for each subject as were estimates of impulsivity, efficiency, Perceptual Speed (a subtest from the Primary Mental Abilities test) and Speed of Information Processing (from the British Ability Scale).

(iii) Procedure

Each child participated in 2 experimental sessions. Prior to the first session, the CPM was administered to each class of children at the school. On the basis of these results, subjects were selected for participation in the experiment. In the first experimental session, lasting approximately 1 hour, the MFF test, Perceptual Speed test and the Speed of Information Processing subscale were administered in the order listed. The elementary version of the MFF involves 2 practice items and 12 test items of the kind pictured in Figure 6.1. Total errors and mean latency to the first matching response were recorded for each subject. Upon completion of the MFF test, a 5 minute rest break followed, after which an estimate of Speed of Information Processing was obtained (refer to Experiment 2.1, Section 1 (iv), p.60, for a description of

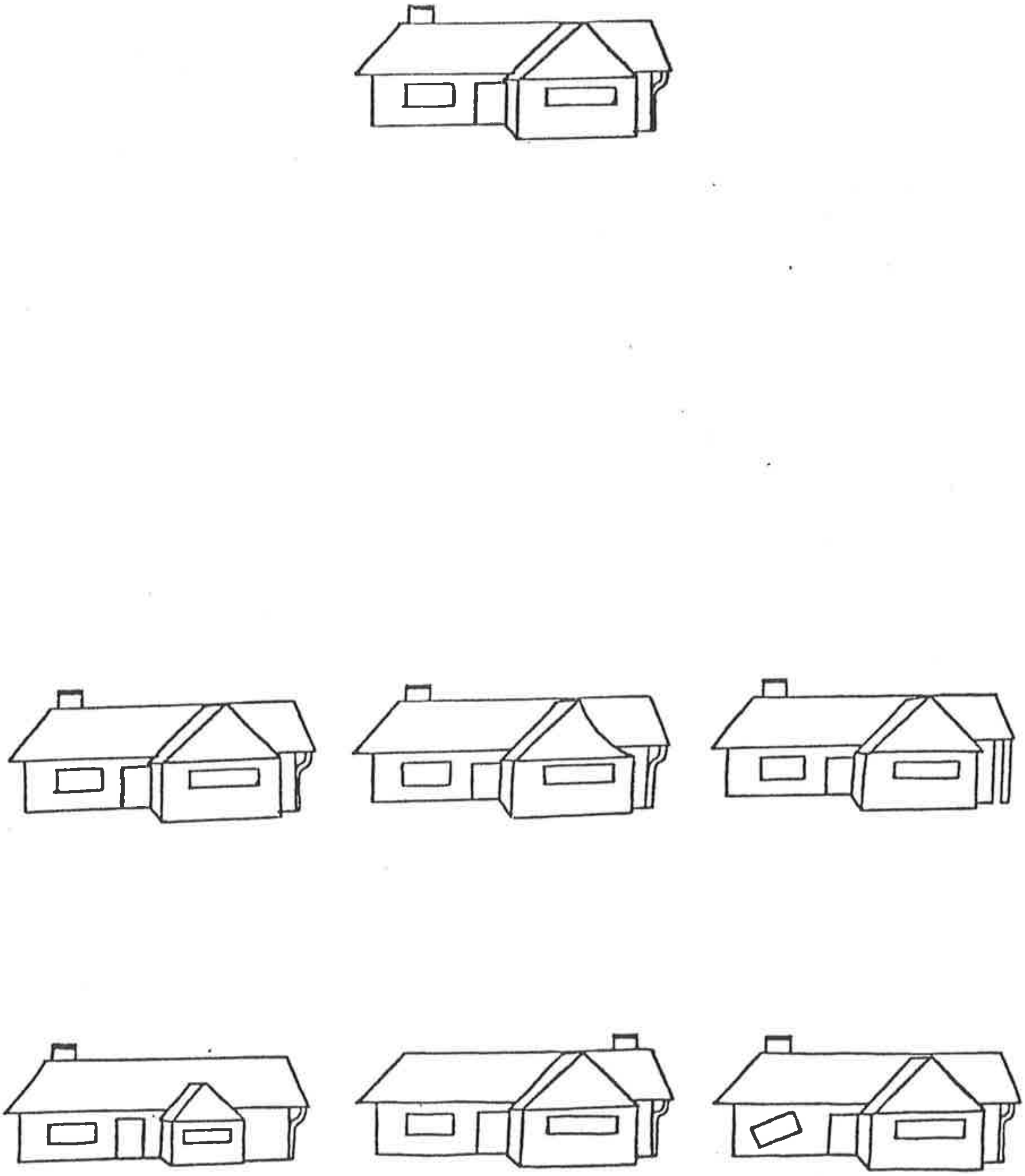

FIGURE 6.1. Sample item from Kagan's Matching Familiar Figures Test.

the scale). Lastly, perceptual IQ was measured using the Perceptual Speed sub-test from Thurstone's Primary Mental Abilities test. In this task the subject is required to select an identical item to match a target figure from a display of 4 variants within a critical time period. The task has been standardized on age-based norms and provides items of different complexity levels for children of differing chronological age.[1] Given the wide range of ages tested in the experiment, 3 different versions of this test were administered to the sample (the K - 1, 2 - 4 and 4 - 6 versions) designed for Grades Kindergarten to 1; Grades 2 to 4 and Grades 4 to 6 respectively.

In the second session an estimate of IT was obtained. Before commencement of the experimental trials, a minimum of 50 practice trials was completed by each subject. These consisted, in the MA 8 group, of 10 trials each at the durations of 1000, 500, 250, 100 and 50 ms, with the first two blocks requiring completion at an accuracy of 100%. In the MA 11 group, trials were administered at durations of 500, 250, 100, 50 and 25 ms, with 100% accuracy required at the two longest durations. As in previous experiments, trials were presented in a descending order of duration to provide each child with a positive experience of the task. One major procedural factor distinguished this study from past studies; in this study no comment was made about the need for accuracy rather than speed. It was thought that such a comment might confound the natural conceptual tempo of the child and it was therefore left up to the individual subject to ascertain his/her own acceptable speed-accuracy trade-off.

3. Results and Discussion

(i) The Mental Age Deviation Hypothesis

The hypothesis that IT should reveal a significant performance difference among samples matched for MA and differentiated by IQ was tested in a

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[1] Norms are provided in Thurstone, L.L. and Thurstone, T.G. (1963) Examiner's Manual: PMA Primary Mental Avilities. Chicago, Illinois: Scientific Research Associates. Version K-1, 2-4, 4-6.

repeated measures analysis of variance; (refer to Appendix 6.1 for the summary table). Variables were one within-subject variable, Duration (5, 25, 50, 100, 150, 250, 400 and 2000 ms) together with the between-subject variables, MA (8 or 11) and IQ (Above average, Average and Below average).[1] Results showed a significant difference in accuracy across durations, with longer durations producing greater accuracy (F (7,287) = 194.04, p < .01). A significant MA effect (F (1,41) = 10.48, p < .01) reflected the more accurate performance of the MA 11 sample than the MA 8 sample (refer to Figure 6.2, a and b), while the MA x Duration interaction (F(7,287) = 2.78, p < .01) indicated that the difference between groups varied with duration. As can be seen from Figures 6.2 a and b, approximately 50% accuracy was evidenced by all groups at very short durations, while at the longest duration of 2000 ms, performance in all groups approached ceiling. A nonsignificant IQ effect, (F (2,41) = 1.52, p > .05) indicated that IT did not successfully discriminate between subjects of different IQs within the same MA. This failure to observe a MA deviation would therefore suggest that the IT task does not provide a reliable estimate of g, at least within the context of the Spitz (1981, 1982) model of intelligence, and within the limitations of the IQ range tested.

Analysis of estimated IT derived from the cumulative normal ogive best fitting individual data reproduced the findings described above with a significant MA effect (F (1,41) = 6.00, p < .05) and a nonsignificant IQ effect (F (2,41) = 0.72, Appendix 6.2). As may be seen from Table 6.2, mean ITs were considerably greater than those observed in past studies, as were the standard deviations. This difference may be due to the fact that accuracy was not stressed in this experiment as it had been in the past, or possibly to

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1. Total N = 47. One subject from the youngest group (i.e. MA 8, above average IQ) was unable to perform the task and therefore deleted from this analysis and all subsequent analyses involving IT, or RT in the IT task.

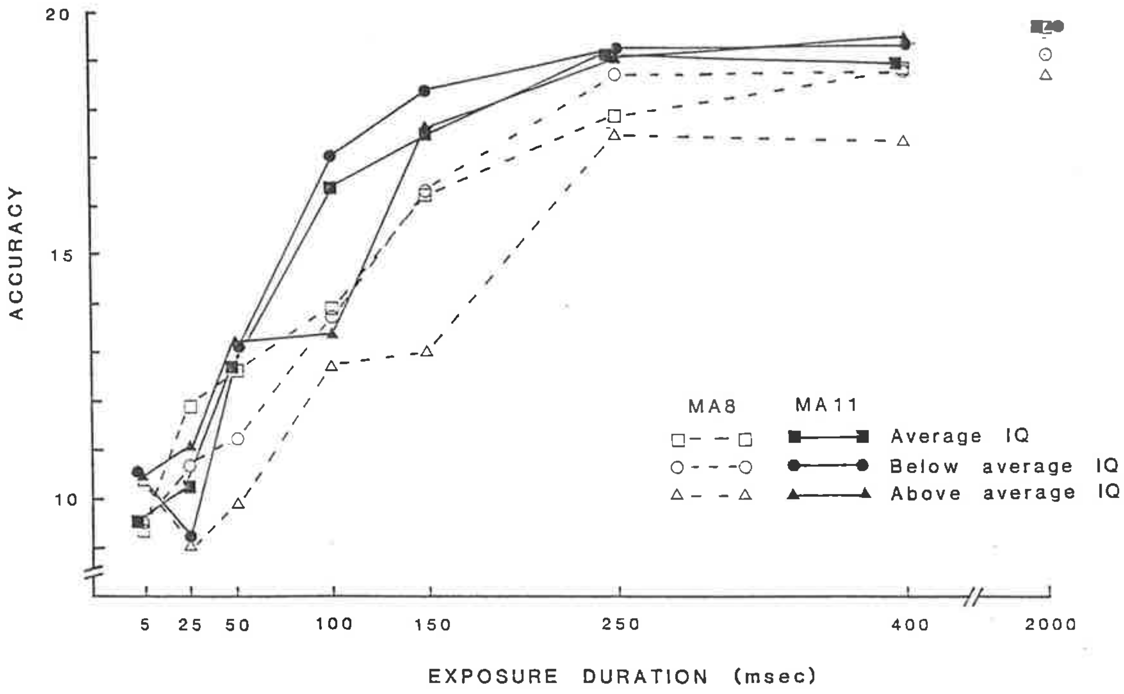

FIGURE 6.2. a. Mean Accuracy across Target Duration in groups distinguished by MA and IQ.

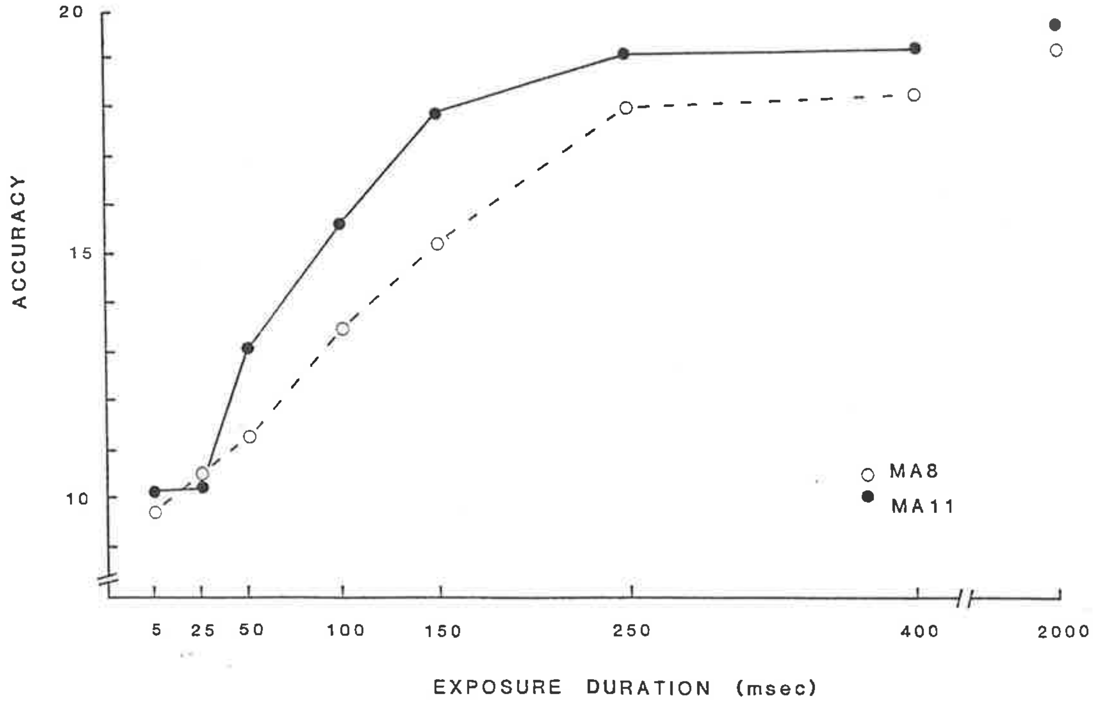

FIGURE 6.2. b. Mean Accuracy across Target Duration in groups distinguished by MA and collapsed over IQ.

the length of the sessions (which consisted of considerable practice, together with 160 experimental trials). In all age groups, the small number of subjects (n = 8 or 7) tended to accentuate the influence of high estimates on the overall mean.

TABLE 6.2. Mean IT and Standard Deviations (in parentheses) among groups with MA of 8 or 11, and IQ above average, average or below average.

	IQ		
	Above Average	Average	Below Average
MA	Mean	Mean	Mean
8	514 (191)	411 (255)	400 (136)
11	325 (171)	329 (180)	280 (181)
Overall	420 (191)	370 (221)	340 (127)

Mean correct RT was also examined in a repeated measures analysis of variance examining the within-subject variable, Duration, and the between-subject variables IQ and MA; (refer to Appendix 6.3 for the summary table). A significant main effect for Duration (F (7,287) = 26.59, p < .01) reflected decreasing RT with increasing target duration, as can be seen clearly in Figure 6.3. In contrast to the accuracy data, the MA effect was not significant (F (1,41) = 2.45, p > .05), with IQ producing a significant difference between groups (F (2,41) = 4.38, p < .05). In Table 6.3, in which RT has been collapsed across MAs, it can be seen that low IQ subjects responded faster than higher IQ subjects (cf. the result reported by Lally & Nettelbeck, 1977, referred to in Section 1 of this chapter, p. 155).

In summary, the IT and RT data suggest that while the former distinguishes subjects at different stages of cognitive development (i.e. MA), the latter distinguishes IQ groups within MA. The faster mean RTs of the below average IQ group (refer to Table 6.3) are consistent with the results obtained in the other IT study in which RT has been included (Lally & Nettelbeck, 1977). Thus, while IT data indicated that the MA 11 children processed input significantly faster than MA 8 children, the former group did not appear to organize and complete the response significantly faster (i.e. RT did not differ significantly). Thus these results highlight the problems associated with the equating of RT with mental speed.

TABLE 6.3. Mean Correct RT (ms) for subjects distinguished by IQ (Raven's Coloured Progressive Matrices) across durations.

	IQ		
	Above Average	Average	Below Average
DURATION (ms)			
5	2407	1728	1904
25	2112	1557	1614
50	1777	1367	1164
100	1539	1148	886
150	1357	1166	804
250	1310	916	824
400	1151	906	771
2000	1455	1000	909
Overall	1639	1124	1110

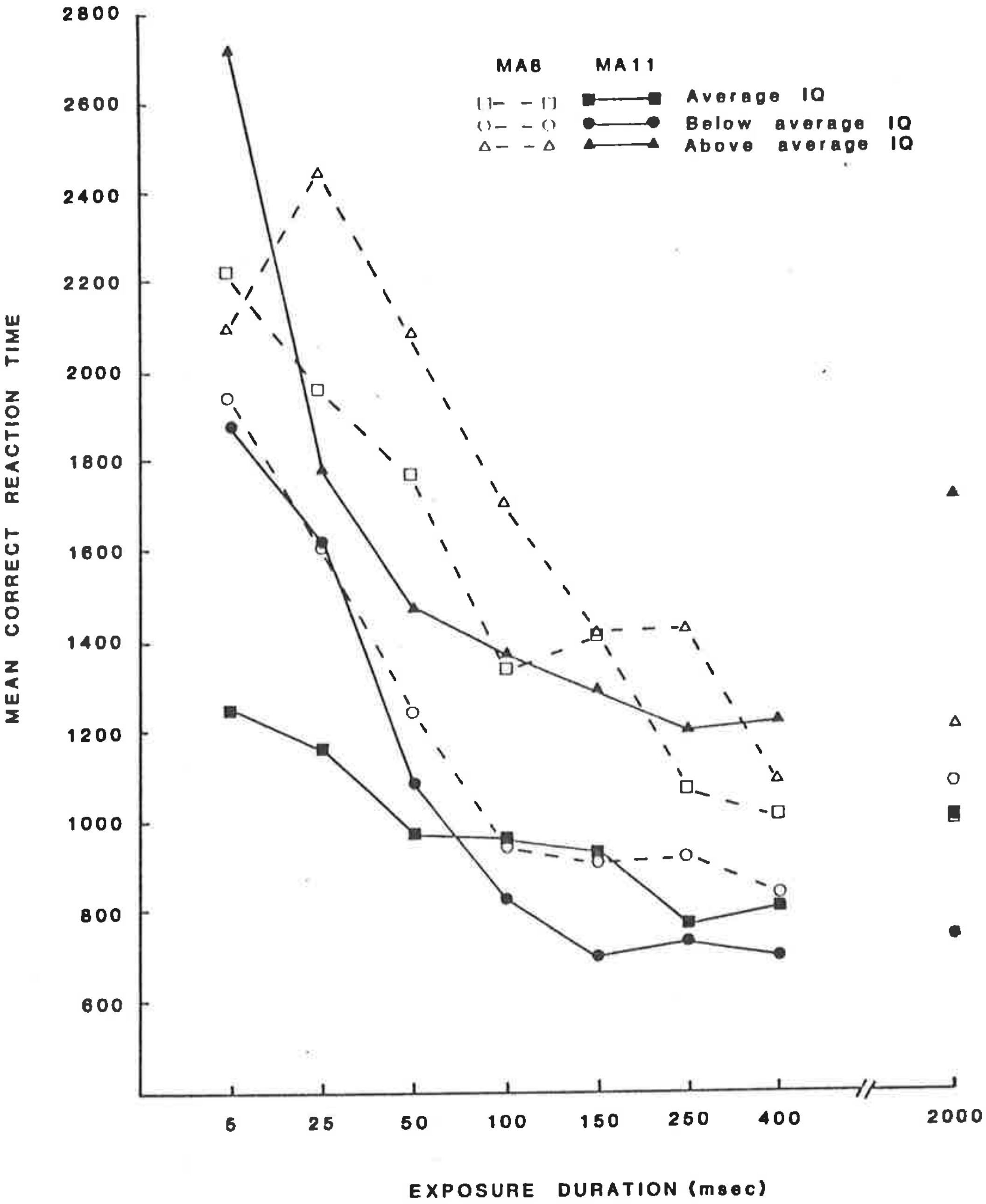

FIGURE 6.3. Mean Correct Reaction Time across Target Duration, in groups distinguished by MA and IQ.

(ii) The IT - IQ Relationship

The hypothesis, that IT should correlate more highly with measures of fluid intelligence (i.e. Raven's Coloured Progressive Matrices) in lower MA subjects than in higher MA subjects, was tested by a series of correlations. The results, described in Table 6.4, did not support the hypothesis, all of the coefficients failing to reach significance.

TABLE 6.4. Pearson correlations (r) between IT and measures of Intelligence (Raven's Coloured Progressive Matrices; Perceptual IQ from the Primary Mental Abilities Test, and Speed of Information Processing from the British Ability Scale), in groups distinguished by MA.

GROUP MA	Test	r	
8	Raven CPM IQ	.16	(n=23)[a]
	Processing Speed (BAS)	-.30	(n=15)[b]
	Perceptual IQ (PMA)	-.13	(n=23)
11	Raven CPM IQ	.16	(n=24)
	Processing Speed (BAS)	.02	(n=24)
	Perceptual IQ (PMA)	-.13	(n=16)[c]

a. Deletion of subject from MA 8, above average IQ who was unable to complete IT task.

b. Deletion of youngest group, MA 8, above average IQ who could not do Processing Speed task and one subject from MA 8, below average IQ who was also unable to complete the task.

c. Deletion of oldest group, MA 11, below average IQ, due to unavailability of norms for PMA in this age group.

Analysis of the RT - IQ relationship indicated that mean correct latency related more strongly to measures of fluid intelligence that did IT. Overall RT was derived from mean correct discrimination latency over the eight target durations and correlated with estimates of IQ both within MAs and over all subjects; (the latter correlation was included since MA did not produce a significant effect in the analysis of variance of RT data). The results indicated a small positive correlation between the Raven IQ and RT, substantiating the analysis of variance results. Negative correlations between RT and Speed of Information Processing (BAS) indicated that children with shorter RTs processed information more quickly than children with longer RTs. Lastly, within the MA 11 groups, shorter RTs were associated with higher Perceptual IQs as measured by the Perceptual Speed Test from the Primary Mental Abilities Test.

TABLE 6.5. Pearson correlations (r) between RT and Measures of Intelligence (Raven's Coloured Progressive Matrices, Perceptual IQ from the Primary Mental Abilities Test, and Speed of Information Processing from the British Ability Scale), in groups distinguished by MA.

GROUP MA	Test	r	
8	Raven CPM IQ	.24	(n=23)
	Processing Speed (BAS)	-.54*	(n=15)
	Perceptual IQ (PMA)	.05	(n=23)
11	Raven CPM IQ	.33	(n=24)
	Processing Speed(BAS)	-.48*	(n=24)
	Perceptual IQ (PMA)	-.55*	(n=16)
TOTAL	Raven CPM IQ	.25	(n=47)
	Processing Speed(BAS)	-.51**	(n=39)
	Perceptual IQ (PMA)	-.21	(n=39)

* p < .05 (two-tailed)
** p < .001 (two-tailed)

In summary, the results from this study indicated that IT related to MA rather than to IQ in groups composed primarily of nonretarded children and adults. RT, on the other hand, distinguished participants on the basis of IQ rather than MA, with subjects having the fastest RTs also having the lowest IQs.

(iii) The IT - Conceptual Tempo Relationship

Estimates of impulsivity and efficiency in conceptual tempo were calculated for each subject using the method described by Salkind and Wright (1977). From distributions for all participants, Z scores for Mean Latency and Total Errors were calculated for each subject (n = 47; 1 subject, aged 6 years 2 months with an IQ = 135+, was deleted from the standardization because his mean latency was approximately 10 times that of any other subject in the group). Impulsivity and efficiency were calculated by applying formulae 6.1 and 6.2 as presented in Section 1 (iii) (p. 162). As previously described, while impulsivity was evidenced by a high positive score on the impulsivity - reflectivity dimension, efficiency was represented by a high negative score on the second conceptual style dimenson.

Kagan and Messer (1975) have argued that a correlation between total errors and latency of the magnitude of .5 to .6 is necessary before it can be assumed that individuals with longer latencies are actively reflecting over alternative hypotheses. The results described in Table 6.6 indicate that this pre-requisite was met in the present study. Furthermore, efficiency and impulsivity failed to correlate at all (r = .00), confirming the orthogonality of these variables.

Separate analyses of variance were performed using both the Total Errors and Mean Latency data from the MFF test as dependent variables, as well as using the derived Impulsivity and Efficiency scores. In all analyses MA (8 or 11) and IQ (Above average, Average and Below average) were included as between-subject variables. Table 6.7 lists the mean of each of the dependent variables by group.

TABLE 6.6. Pearson Correlations (r) between Total Errors and Mean Latency in the MFF test in groups distinguished by MA and IQ.

GROUP MA	IQ	$\underline{r}$	
11	Above average	-.63*	
	Average	-.71*	
	Below average	-.70*	
8	Above average	-.40	
	Average	-.65*	
	Below average	-.46[a]	-.64[b]*
Total		-.47[a]**	-.38[b]**

a. Correlation excluding 1 anomalous subject; (refer to Section 3 (iii), p. 176).

b. Correlation including the anomalous subject.

* $p < .05$ (one-tailed)

** $p < .01$ (one-tailed)

TABLE 6.7. Mean Impulsivity, Efficiency, Total Errors and Latency (sec.) to first response in MA 8 and 11 subjects distinguished by IQ.

GROUP		Dependent Variable			
MA	IQ	Mean Impulsivity[a]	Mean Efficiency[b]	Mean Latency	Mean Total Error
11	Above Average	.029	-.270	13.0	9.6
	Average	-.379	-.811	12.6	6.6
	Below average	-1.319	.154	19.1[c]	6.8[c]
8	Above average	1.614	1.100	12.3	19.0
	Average	-.521	.426	17.3	10.1
	Below average	.778	-.435	9.9	11.5

a. Positive score is impulsive; Negative score is reflective.
b. Positive score is inefficient; Negative score is efficient.
c. Mean with deletion of 1 anomalous subject, with a Mean Latency of 139.5 sec and Total errors of 0; (refer to Section 3 (iii), p. 177).

The analysis of variance results showed that Total Errors on the MFF task distinguished subjects of different MAs (F (1,41) = 14.93, p < .01) and IQs (F (2,41) = 5.81, p < .01), with lower MA subjects producing a greater number of errors and, paradoxically, higher IQ subjects also exhibiting a higher error rate; (refer to Appendix 6.4 for the summary table). The same analysis of Mean Latency data showed no significant main effect (MA: F(1,41) = .87; and IQ : F(2,41) = .56), but a significant interaction between these variables (F(2,41) = 4.77, p < .05), with the longest latency exhibited by the below average IQ group of the MA 11 cohort, and the fastest latency by the below average IQ group of the MA 8 cohort. (The summary table for this analysis is included in Appendix 6.5.) Thus, this result suggests considerable confounding of the CA - mean latency relationship by the variables of MA and IQ. Analyses of variance performed on the Impulsivity and Efficiency data indicated that children of MA 8 were significantly more impulsive in response style than children of MA 11 (F (1,41) = 6.93, p < .05), while the IQ main effect just failed to reach significance (F (2,41) = 3.06, p = .058; Refer to Appendix 6.6). Similarly, the Efficiency analysis showed that performance, once again, varied between MA groups with MA 11 subjects more efficient than MA 8 children (F (1,41) = 6.75, p < .05), while IQ did not produce a significant result (F (2,41) = 2.08, p > .05; Appendix 6.7). A significant interaction effect (F (2,41) = 6.28, p < .01) reflected the fact that the Efficiency - IQ relationship varied between MAs. In the MA 8 group, greatest efficiency was associated with the below average IQ subjects (i.e. those with a chronological age of 11) while in the MA 11 group greatest efficiency was exhibited by the average IQ group (i.e. the children with a chronological age of 11).

In summary, it can be seen that no simple relationship was evidenced between MA or IQ and any of the dependent variables. There was some suggestion that both Efficiency and Impulsivity related to cognitive development (i.e. MA). The significant effects in the above analyses appeared to arise primarily out of the error data from the MFF test, with latency failing to distinguish groups. The ambiguity associated with some of the results may be due to the confounding of a CA - Impulsivity/Efficiency relationship with the variables MA and IQ.

The relationship between IT and Impulsivity and Efficiency was subsequently examined in a series of correlations. The hypothesis that IT might be associated with greater impulsivity in response style received only limited support. In the MA 8 group, particularly among the young subjects (CA < 6), increasing impulsivity appeared to be associated with longer ITs. In the oldest MA 8 group (i.e. those with a chronological age of 11), and in the MA 11 group, the relationship did not appear to hold and, if anything, higher ITs were associated with decreasing impulsivity; (refer to Table 6.8).

TABLE 6.8. Pearson correlations (r) between IT and measures of Impulsitivy and Efficiency in groups distinguished by MA and IQ.

GROUP		Correlations between IT and	
MA	IQ	Impulsivity	Efficiency
11	Above average	-.09	-.04
	Average	-.34	.41
	Below average	-.83**	.60
8	Above average	.88**[a]	.70[a]
	Average	.48	.21
	Below average	-.47	.17
11	All subjects	-.29	.21
8	All subjects	.45*[a]	.43*[a]
Total		.23[a]	.42[a]*

a. Deletion of 2 anomalous subjects; 1 unable to complete the IT task, and 1 with anomalous MFF test performance.

* $p < .05$ (one-tailed)
** $p < .01$ (one-tailed)

Efficiency showed a more consistent relationship with IT across MA than Impulsivity. In all groups apart from the youngest MA 11 group, decreasing ITs were associated with increasing efficiency (i.e. decreasing inefficiency) in the MFF task.

The RT - Impulsivity relationship was also examined in a series of correlations. RT, estimated as mean correct latency across durations in the IT task, related most consistently to efficiency in response style, with increasing efficiency associated with decreasing RT. The strength of the relationship varied across both MA and IQ, as indicated in Table 6.9. The RT - Impulsivity relationship over all subjects while less consistent, suggested a slight positive association between Impulsivity and RT, with more impulsive subjects by contrast tending to have longer RTs in the IT task.

TABLE 6.9. Pearson correlations (*r*) between Mean Correct RT across Durations and Measures of Impulsivity and Efficiency in groups distinguished by MA and IQ.

GROUP		Correlations	
MA	IQ	Impulsivity	Efficiency [a]
11	Above average	.37	.11
	Average	.40	.07
	Below average	-.84**	.75*
8	Above average	.79[a]	.47[a]
	Average	-.04	.44
	Below average	-.29	.18
11	All subjects	.12	.27
8	All subjects	.41[a]	.55*[a]
Total		.31*	.46***

a. *Positive* score is *inefficient*, *negative* score is *efficient* (refer to Section 1 (iii), p. 162).

b. Deletion of 2 anomalous subjects; one unable to complete the IT task, and one with anomalous MFF test performance.

* $p < .05$ (two-tailed)
** $p < .01$ (two-tailed)
*** $p < .001$ (two-tailed)

In summary, the hypothesized IT - Impulsivity relationship was evidenced only in children aged 8 or under. At older chronological ages, the relationship was no longer significant. It is therefore possible that the developmental IT trend evidenced in the studies reported in earlier chapters may reflect, in part, the differential contribution of conceptual tempo to ITs across ages. In addition, efficiency in processing appeared to relate to both the overall speed of the information processing mechanism (i.e. RT) and input processing speed specifically (i.e. IT) across a wide range of ages.

4. Conclusions

The attempt to relate developmental IT differences to both IQ and conceptual tempo has indicated that the relationship between these variables is complex. While IT successfully distinguished subjects with an MA of 8 from those with an MA of 11, it failed within levels of MA to distinguish subjects differing in IQ. Although contrary to the hypothesis formulated, this result does not necessarily contradict past studies in which a strong IT - IQ association has been noted. The severe logistical and practical constraints operating upon the selection of subjects for the present experiment resulted in limits being placed upon the IQs of the subjects in the below average groups. Consequently, although the means for these two groups were such as to place them in a borderline range, this was well above the widely accepted upper boundary of 70-75 for mental retardation (Grossman, 1983). As a consequence, correlations between IT and IQ may have been considerably attenuated and it is possible that including a retarded group would have resulted in the attainment of a significant IQ main effect and thus, MA deviation. However, the results do suggest that when the sample is restricted primarily to nonretarded participants, it is the level of cognitive development (i.e. MA) that distinguishes IT. Furthermore, within the same restricted IQ range, RT within the IT task does differentiate between groups of different IQ levels, with higher IQ subjects responding more slowly to the discrimination task. This difference may reflect the greater cautiousness of higher IQ subjects or, alternatively, indicate the slower response organization of children who were chronologically younger than their MA cohorts. The confounding of IQ with CA in this study makes conclusions on these issues problematic.

The IT - Impulsivity relationship is similarly confounded by the overlap of CA and IQ variables. The data suggest that while impulsivity is associated with higher ITs in children with a CA of 8 or less (and an IQ average, or below), when CA is greater than 8 this association is not found and if anything, the reverse relationship holds. In other words, in the MA 11 cohort, and the MA 8, CA 11 group, increasing IT appears to be associated with increasing reflectivity. Thus, the IT - Impulsivity relationship appears to change with development, and while the longer ITs of 8-year old children may be due, in part, to a more impulsive response style which results in a greater number of errors on the IT task, the shorter ITs of the 11-year-olds do not reflect more considered responding.

A more consistent relationship over age is reflected in the efficiency data. In all groups except one, increasing efficiency in the MFF task (i.e. decreasing mean latency, and decreasing total errors) was associated with a decrease in IT. The significant MA effect in both the efficiency and IT analyses of variance suggests that this result may reflect a factor of general cognitive maturation which influences performance on both of these tasks, as well as many others.

In conclusion it can be stated that no simple relationship exists between IT and either fluid intelligence or conceptual tempo. All relationships appear to vary with both MA and CA.

CHAPTER 7

CONCLUSION

The development of processing speed: The nature of the developmental function and its relationship to processing and general ability variables.

1. Summary of Experimental Results

The experiments described in the previous chapters of this thesis have illustrated an ontogenetic progression from a slow speed for processing visual input to increasingly faster processing between the ages of about 7 and 11 years, but with less pronounced change thereafter. In addition, these experiments have confirmed the reliable and robust nature of this developmental trend, suggesting that age differences represent maturational change in the efficiency of the central processing mechanism. Among the variables found to influence performance on the inspection time (IT) task used to investigate speed of processing can be included intra-individual variability and, to a lesser degree, registration efficiency. Developmental differences have also been shown to interact with a number of general ability variables, including mental age (MA), indicating that at least in nonretarded populations, decreasing IT is associated with increasing cognitive maturity.

Experiment 1 examined the issue of target-mask interaction, and more particularly, possible developmental differences in locus. In groups consisting of 8 and 11-year-old children and adults, performance accuracy in a dichoptic presentation condition, in which any interaction of target and mark had to occur centrally, did not differ significantly from binocular performance. Furthermore, performance in all three groups more closely approximated the "additive" rule (Equation 2.2, Chapter 2, p. 38) than the "multiplicative" rule (Equation 2.1, Chapter 2, p. 38). Thus, both direct and indirect assessment of the locus of the target - mask interaction indicated that in the binocular IT task the arrival of the masking figure interrupts processing of the target centrally in subjects aged between 8 and 20 years. Lastly, a significant difference in critical SOA between the 8-year-old subjects and the two older groups pointed to the possibility of a developmental difference in central input processing speed.

In the second experiment (2.1 and 2.2) the suggested developmental trend of Experiment 1 was verified by both cross-sectional and longitudinal analyses. Although a certain amount of difficulty was encountered when attempting to obtain reliable estimates of IT from children as young as 6 to 7 years, the data from the other groups in any case sufficed to illustrate a developmental function in which processing speed increased between 8 and 11 years. Beyond this point significant decreases were not observed, suggesting a tendency towards asymptotic performance somewhere around the commencement of adolescence.

The longitudinal verification of the cross-sectional trend indicated that these developmental differences were not an artifact of cohort variables arising out of differences in life-histories. The developmental trend was, at least in part, associated with increasing chronological age (CA) and not with increases in task-specific knowledge alone. This finding was established by the comparison of longitudinal and control data, which indicated that test - retest improvement over a period of 2 weeks was significantly less than the improvement in performance of children of a similar age observed after a period of 1 year. However, the existence of a practice effect did indicate that performance on the IT task was sensitive to both task - knowledge and practice, with extended time on task providing the opportunity for the development of more efficient processing strategies.

Experiment 2 also examined the validity and reliability of the IT estimation procedure. While reliability was shown to be high over a period of both 2 weeks and 1 year, with the Pearson's correlation coefficients generally in the order of .7 to .8, reliability did vary with both age and time between remeasurement. Validation data, while more contentious, indicated that performance on the IT task correlated weakly with speed on another input processing scale (the Speed of Information Processing subscale from the British Ability scale), particularly in young children (Experiment 2.1 and 6). Attempts, in these same experiments to relate IT to intelligence, were illustrative of a significant IT - MA association whereby children with a lower MA processed input more slowly.

In Experiment 3 task comparability across a range of ages was assessed together with the influence of methodological considerations, fatigue and attention on age-based performance variation. Results indicated that the IT task provided a robust measure of processing speed that was relatively reliable and not markedly influenced by the procedural manipulations introduced. The introduction of frequent rest pauses did not alter the performance of either 8 or 11-year-old children, and both groups exhibited consistently high levels of attention throughout. In addition, comparison of performance accuracy at both the upper and lower limits of the task (i.e. perfect and chance performance) indicated that the task was appropriate for comparisons across age.

Experiment 4 analysed the contribution of intra-individual variability to IT performance differences. The hypothesis tested was that more variable intra-individual performance in 8 compared with 11-year-old children, arising out of factors like fatigue, motivation, attention and systemic noise, might inflate group performance differences. This hypothesis was only partially supported by the results. Analyses showed that accuracy differences between these two age groups in session 1 were associated with greater variability in the performance of the 8-year-olds. However, when variability was assessed over the two sessions combined, intra-individual variability no longer distinguished the performance of the two groups, although accuracy differences were still observed. Thus, while differences in factors which produce intra-individual variability on the IT task may account in part for observed differences in accuracy of performance, processing speed differences appear to arise out of other factors as well.

Experiment 5 attempted to distinguish the influence of age differences on the efficiency of registration from age differences in rate of input processing. Results from Experiment 1, in which a significant ISI effect had been observed, suggested that differences in processing speed might arise because of the less efficient registration of stimuli by younger children. However, the results of Experiment 5 provided only limited support for this hypothesis. While both the main effect for ISI and the Group x ISI interaction failed to reach significance, there was a suggestion of a trend towards greater performance disruption in the younger children. In addition, data from Experiment 5 indicated that manipulation of the "bits" of information to be processed failed to disadvantage 8-year-old children more than 11-year-olds (i.e. resulted in a nonsignificant Choice x Group interaction), suggesting that group performance differences were not due primarily to differences in the rate at which an input is processed from registration into a central store. It therefore appeared that some further factor, not successfully identified in Experiments 3, 4, or 5, was needed to account for age differences in the efficiency of the processing system.

In the final study, Experiment 6, an attempt was made to relate developmental differences in the IT task to general ability variables, specifically, IQ and conceptual tempo. On the basis of the theoretical and experimental work of Furneaux (1960), White (1982), Spitz (1982) and Brand (1981; Brand & Deary, 1982), the following hypotheses were formulated: IT should correlate significantly with estimates of fluid intelligence; the correlation should increase with decreasing MA; IT should exhibit a significant MA deviation, with below and above average IQ children performing significantly differently to average IQ controls; and lastly, that a longer IT should be associated with greater impulsivity in response style. Results provided only limited support for the above hypotheses, reflecting a significant difference in the IT performance of subjects of MA 8 and 11, and a small association between IT and conceptual tempo in children aged 8 and under. A consistently significant effect for MA in all analyses of variance suggested that efficiency, impulsivity and IT all related to a general factor of maturation.

In sum, the results of the experiments of this thesis provide evidence on three basic issues; firstly, the validity and reliability of IT as a measure of central input processing efficiency in samples distinguished by age and IQ; secondly, the nature of the developmental function which relates IT to age; and thirdly, the possible association between IT and intelligence and between IT and conceptual tempo.

2. The Validity and Reliability of the IT Measure

Attempts were made in Experiments 1, 2 and 3 to establish the validity of the IT measure as an index of central input processing speed in a developmental context. While Nettelbeck (in press) has discussed the issue of validity in relation to retarded and nonretarded adults, with experimental results establishing the comparable locus of target-mask interaction in these populations (Nettelbeck, Hirons & Wilson, 1984), the results that he cites are not generalizable to samples composed of children. In a developmental study validation takes on special significance since conclusions about age-based differences in performance can only be made when the task has been shown to measure a comparable behavioural domain across age groups. Thus, if the validity of the IT measure was not established at a variety of ages, it would be possible to argue that any performance differences observed arose as a consequence of age-based variation in aspects of the task other than those defining IT.

Data from the first three experiments suggested that the IT task was suitable for developmental comparisons. Results obtained in Experiment 1 verified the central locus of the target-mask interaction across ages directly and indirectly. While a significant ISI effect indicated that in each age group (8, 11 and adults) introduction of an ISI into a constant SOA adversely affected discrimination accuracy, results still approximated the additive function (Chapter 2, Equation 2.2, p. 38) more closely than the multiplicative rule (Chapter 2, Equation 2.1, p. 38). Furthermore, greatest departure from the additive function was found to occur in the dichoptic presentation condition where target-mask interaction was, by definition, central, thereby mitigating against the possibility that the small departure from additivity was indicative of a locus difference between conditions. Data from Experiment 5 were consistent with the notion of a central locus for masking in children aged 8 and 11, as indicated by nonsignificant effects for both ISI and the Group x ISI interaction. When interpreted in conjunction with Experiment 1, this result attests to the comparable locus of target-mask interaction in children aged 8 and 11 years.

Experiment 3 examined the possibility that developmental IT trend observed in Experiment 2 (2.1 and 2.2) might be an artifact of an experimental method which differentially disadvantaged younger children (i.e. the parameter estimation PEST procedure). This hypothesis was formulated primarily in response to the discrepancy between the developmental results reported by Nettelbeck and Lally (1979) and those found in Experiments 1 and 2 and in the experiments of Wilson (1980) and Brand (1981). In Nettelbeck and Lally's (1979) experiment, IT did not differ significantly between children aged 7, 8, 9, and 10 years and adults when estimates were obtained using a method of constant stimulus differences (MCSD). By contrast, the first two experiments of this thesis reported a significant difference in estimates of IT obtained using the PEST method. Results from Experiment 3, which compared ITs derived using the MCSD and PEST methods, indicated that the developmental results of Experiments 1 and 2 were not an artifact of the method of estimation. In addition, data from Experiment 3 indicated that young children were not significantly more disadvantaged than were older children by a testing session consisting of approximately 100 trials in succession, with the introduction of regular rest pauses not significantly altering the results of either group.

Experiment 3 also examined the comparable difficulty of the IT task for children aged 8 and 11 years. Assessment of group differences at both the upper and lower limits of performance indicated that masking was equally effective across age groups, both 8 and 11-year-old children exhibiting chance accuracy at a very short duration (5 ms), and near perfect performance at a long duration (2000 ms) where the effectiveness of the mask was nullified. Thus, the IT task was validated as a procedure capable of measuring developmental differences in central processing speed by successfully discriminating among individuals over all portions of the age spectrum.

Attempts to verify IT as a measure of processing speed across ages by convergent validation produced ambiguous results. The correlation of IT with speed of information processing, as measured by the BAS subscale, undertaken in Experiments 2.1 and 6, produced highest coefficients in the youngest group of children in Experiment 2.1 (Grades 4 and 5) with the coefficients decreasing to nonsignificance subsequently (Chapter 2, Table 3.5, p. 71). Similar results in Experiment 6 (Chapter 6, Table 6.4, p. 175) indicated that speed of processing in the youngest groups was associated with decreasing IT. This finding does not necessarily invalidate IT as a measure of input processing speed in older groups but may instead reflect the changing contribution of various processing factors to performance on the BAS (and possibly IT), across ages. Thus, where at younger ages, performance on the Speed subscale may be primarily a function of the speed at which the numbers can be input into the processing system, at older ages, performance may increasingly be influenced by other variables, including response selection and organization. Certainly, in Experiment 6 RT correlated far more highly and consistently with the speed of information processing sub-test than did IT (Chapter 6, Table 6.5, p. 176). This result is not surprising given that both RT and the BAS subtest provide estimates of the speed of the human information processing system in total (i.e. from stimulus input to response output), as opposed to input processing speed specifically. Further attempts at validation of the IT measure requires the identification and isolation of convergent measures of those variables which define speed of input processing alone.

An integral issue in the assessment of the validity of a developmental scale is the degree to which it reliably distinguishes the performance of individuals within a group. Brand and Deary (1982) and Nettelbeck (in press) have shown the IT task to exhibit fairly high reliability in populations of adult subjects, including mildly retarded persons, and this result was confirmed in the experiments reported in this thesis. Despite the fact that children tend to exhibit considerably more performance variability than adults in all tasks, whether they be conventional intelligence tests or RT tasks, correlations indicating a remarkably high degree of performance consistency, particularly in children aged 10 or older, were obtained in a number of experiments reported here (Chapter 2, Table 2.2, p. 52; Chapter 3, Tables 3.11, 3.13, p.90, 92; Chapter 4, Table 4.2, p. 121). Even correlations obtained after a period of 2 years between sessions were of the order of .7. Only among the very youngest children of Experiment 2.2 and 3 was the level of reliability unacceptable. Thus IT appears to provide an index of performance which is illustrative of consistent individual differences, even in children.

In summary, the results of this thesis indicate that IT provides both a valid and reliable estimate of central processing efficiency over a wide range of ages. While some difficulty is associated with obtaining a reliable estimate from very young children (i.e. those aged 6 to 7 years or younger), after the age of about 8 years individual differences emerge that are remarkably consistent. Further refinement of the task is necessary so that estimates can reliably be obtained from very young children[1] thereby covering all ages. However, it is quite feasible that there are individual differences in central input processing which emerge at very young ages, possibly at birth, and which are maintained throughout life.

3. The Developmental IT function

Considerable consistency in the developmental results is evidenced across the experiments reported in this thesis (refer to Table 7.1). In all studies in which IT estimates have been obtained, a significant difference has been found between children aged 7 to 8 years and those aged 11, with nonsignificant differences between this latter group and adults. Thus, there is evidence of a developmental function that reflects a decrease in input

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[1] Attempts have been made in Edinburgh to refine the IT task for use with very young children. (Personal communication, Brand, December, 1981).

processing speed in the first decade of life, with decreasing change in the second. This result is consistent not only across studies, but also across procedures, providing support for many of the results obtained in the backward masking studies as described in Chapter 1 and summarized in Table 7.2.

TABLE 7.1. Mean IT estimates (ms), with n in parentheses, in groups aged between 7 and 20 years.

Grade	Experiment					
	1[a]	2.1[a]	2.2[a]	3[b]	6[c]	Grand Mean
2		434(10)	291(10)			363 (20)
3	229(10)	250(10)		252(10)	411(8)	244 (30)[d]
4		235(10)				235 (10)
5		216(10)				216 (10)
6		190(10)				190 (10)
7	133(10)	132(10)	167(10)	141(10)	329(8)	143 (40)[d]
8		162(10)				162 (10)
Adult	126(10)	115(10)	109(10)			117 (30)

a. Estimates obtained using the Parameter estimation by sequential testing (PEST) procedure.
b. Estimates obtained using the method of constant stimulus differences (MCSD) procedure.
c. Estimates obtained using the MCSD or PEST procedure.
d. Mean excludes estimates obtained in Experiment 6, in which commands as to the speed and accuracy of responding were omitted.

TABLE 7.2. Developmental backward masking studies involving single item arrays, listing significant differences between groups in critical SOA.

Study	Age (in years)	Significant Differences in critical SOA
Arnett & DiLollo (1979)	7,9,11 & 13	Significant age effect
Bosco (1972)	7,10,12	7 > 10; 0 > 12
Ferreira (1978)		
Exp. 1	5,8, Adult	5 > 8 and Adults
Exp. 2	5,8, Adult	5 > Adult
Exp. 3	8, Adult	8 > Adult
Gummerman & Gray (1972)	8,10,12, Adult	8, 10 > 12, Adult
Liss and Haith (1970)	5,10, Adult	5 > 10
Miller (1972)	8,12,20	8 > 12; 12 > Adult
Novik (1974)		
Exp. 2	6,11, Adult	6 > 11; 11 > Adult
Pollack (1965)	7,8,9,10	7 > 10
Spitz and Thor (1968)	9,15	9 > 15
Welsandt & Meyer (1974)	7-10, 12-16	7-10 > 12-16
Welsandt et al. (1973)	5,10,17,22	5 > 10; 10 > 17 and 22

The issue of the existence or otherwise of an asymptote in IT performance at the age of approximately 11-12 years is not clearly answered by the experiments of this thesis. While there is a consistent finding of a nonsignificant difference between 11-year-olds and adults in all of the experiments reported, the means do suggest a small improvement in processing speed after the commencement of adolescence. Backward masking studies in which young adult college students have been included have tended to support this interpretation on some occasions, as may be seen from Table 7.2; (Miller, 1972; Welsandt et al., 1973), but have found nonsignificant differences between adolescents and adults on others (Ferreira, 1978; Gummerman & Gray, 1972). Undoubtedly, any improvement in speed beyond adolescence is considerably smaller in magnitude than that found for the earlier years.

Viewing the results of the developmental IT experiments reported in this thesis in combination with other IT research and backward masking studies, the developmental function can be extended from infancy through to senescence. Hosie (1979, cited by Brand (1981) and Brand and Deary, 1982) found IT estimates in a sample of 4-year-olds to range from 200 to 600 ms, consistent with the very long processing estimates obtained in the Grade 2 sample of Experiment 2.1. A study by Lasky and Spiro (1980) attempted to assess the processing speed of infants aged 5 months, using a backward masking procedure in which a visual pattern of 100 ms duration was followed after an ISI of 0, 250, 500 or 2000 ms by a mask of 100 ms duration. Stimulus recognition accuracy was assessed by recording the infant's visual preference for the familiar stimulus or for a novel stimulus of comparable complexity. Infants were divided between ISI conditions with results showing that only the babies in the 2000 ms condition fixated the novel stimulus significantly longer than the familiar. In view of the major procedural difficulties involved when working with such young infants, this result may be less reliable than others discussed here. Nevertheless, Lasky and Spiro's results could possibly be interpreted as reflecting a processing speed in babies considerably slower than that of any other age group.

Results at the other end of the age spectrum also support a decrease in processing speed with the progression from middle to old age. An unpublished study of IT and ageing, reported in Nettelbeck (in press) suggests that ITs of the elderly (mean age, 78, mean IT using the lights task = 174 ms) are significantly greater than those of nonretarded adults in their twenties.

Similar results using the backward masking paradigm provide additional support for an upturn in the developmental function in later life, more particularly at the age of approximately 60 years (Walsh, 1976; Walsh, 1979). Figure 7.1 provides a representation of the entire developmental function from infancy to the age of 75 years on the basis of data obtained in the experiments in this thesis and other developmental backward masking studies. The function is hypothetical in nature beyond the age of 20 years and prior to the age of 6 years, indicating a decrease in IT from birth to approximately 11 years followed by asymptotic levels of performance until approximately 60 years at which time speed decreases once more.

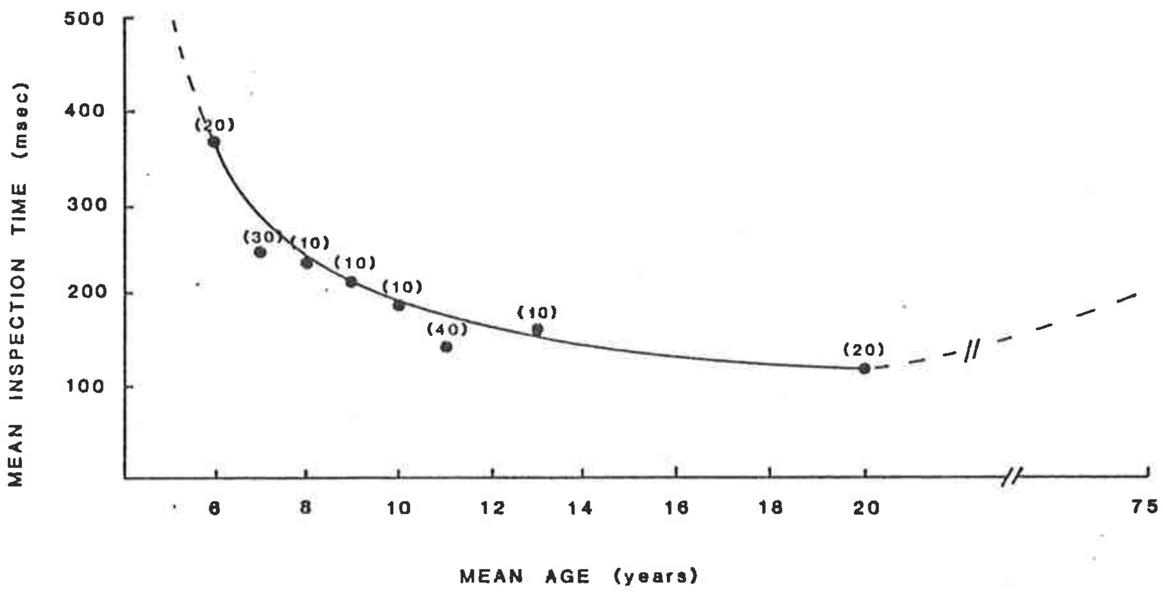

FIGURE 7.1. Developmental function mapping the relationship between mean IT and CA with hypothetical extension of the curve beyond 20 years and before 6 years.

Attempts were made in Experiments 4 and 5 to specify the source of the developmental performance differences evidenced in children within specific components of the processing mechanism, specifically, the executive control, registration and input processing levels. Results were ambiguous, suggesting that a significant part of the age-based accuracy difference was due to factors which influence intra-individual variability (i.e. attention, motivation, fatigue and systemic noise), with possibly some less significant influence arising from age differences in registration efficiency. Most surprisingly, input processing rate itself, that is the speed at which a peripherally registered target is input into the central processing mechanism, appeared not to distinguish the performance of 8-year-olds from 11-year-olds. It therefore appeared that a fourth factor, not successfully identified by the experimental manipulations of Experiments 4 or 5, may have accounted for the additional differences in accuracy not explained by the factors of intra-individual variability or registration. This fourth factor was shown to be independent of stimulus complexity, with age differences maintained over both a 2 and 4-choice discrimination. It was hypothesized that this factor may represent a general change in the efficiency of the central processing mechanism associated with maturation.

Whether this nonspecific maturational change in the efficiency of the processing mechanism relates ultimately to developmental change in structure or function is a matter open to debate. The significant practice effect evidenced in Experiment 2.2, in which children aged 8 and 11 and adults all registered decreased estimates of IT when remeasured on the task after a period of 2 weeks, does indicate that IT estimates are dependent, at least in part, upon task-knowledge. Certainly, the existence of practice effects in young children indicates that performance can be improved. Thus, to the extent that the study fails to bring any group to asymptote, it can be argued that age IT differences are inflated. However, the failure in this study to find a significant Group x Session interaction also indicates that no one age group was significantly more disadvantaged by this lack of task experience and it would therefore seem unlikely that group differences arise from this factor alone. Further support for this interpretation is to be found in the comparison of improvement observed after a period of 1 year between measures, with the improvement observed in children of a comparable age after a period of 2 weeks. While it could be argued that at least part of the significant IT changes observed longitudinally arise out of time-on-task experience, the significantly greater improvement in performance observed after 1 year indicates that a factor, over and above practice, must account for the performance change associated with maturation. Furthermore, the significant Group x Session interaction found in Experiment 2.2 indicates that, while some improvement is exhibited by all age groups over a period of 2 weeks, the larger improvement associated with maturation is only observed in the younger subjects. Thus, the asymptotic nature of the developmental function ensures that while all children may show some performance improvement with practice, only the younger children will show significantly greater improvement with development due to the convergence of the older subjects upon maturational asymptote.

While it has been argued above that maturational changes in processing speed cannot be equated with increases in task-specific knowledge alone, the developmental improvement evidenced may arise out of changes in other cognitive factors which aid performance on the IT task. Among these factors can be included increasingly sophisticated cognitive strategies, associated with learning.

Studies which have attempted to estimate the effect of possible differences in the strategies controlling processing on developmental differences have in general found them to be only partially successful as an explanation of group differences (Roth, 1983). Schwantes (1982), for example, used a tachistoscopic single report procedure to examine age differences in encoding of visual information, hypothesizing that developmental differences may be due to less efficient use of the left-to-right scanning operation among younger children. To test this hypothesis he compared children aged approximately 8 years with college students aged 20 on report accuracy for a probed letter from a six-letter non-word array presented for 150 ms. Onset of the probe, a red light indicator, occurred either 50 or 450 ms after the offset of the target array. Which of these delays occurred was randomized in one condition while in the second condition a blocked delay presentation was used whereby the first half of the session consisted of the long delay trials, followed in the second half by the shorter delay. The theory behind this design was as follows: in a very short cue delay condition processing is directed on the basis of spatial location to the information still available, while in a sufficiently delayed cue condition a left-to-right scanning operation can be employed to process the array. Further, when the delay durations are randomized, use of a scanning strategy will supposedly be reduced because delay duration cannot be predicted beforehand. Results of this experiment indicated that while there were age differences in the use of the systematic left-to-right scanning strategy, these differences were not sufficient to account for age differences in encoding since significant age differences in performance were still evidenced in the randomized delay condition.

Other attempts to define strategies which might account for age differences in the efficiency of encoding and input processing have been similarly unsuccessful. Scanning strategies and eye movements have, in particular, attracted considerable attention. Ferreira (1978), who examined the influence of developmental differences in eye fixation on backward masking performance, found that while younger children exhibited significantly more instances of deviant eye-movements, these were not sufficient to explain recognition accuracy differences, since performance differences were still observed when appropriate fixation occurred.

One study has attempted to examine the possibility that IT differences may arise out of differences in the efficient use of a specific cognitive strategy, namely, the discrimination of apparent movement. Nettelbeck (1982) has stated that in virtually all of his studies, "some subjects have been able to make use of other sources of information than the briefly exposed stimulus figures, such as subtle post masking cues associated with apparent movement" (page 307). Results from an experiment by Mackenzie and Bingham (1984) are consistent with the suggestion that use of this strategy does assist performance on the IT task. Data from their study indicated that adult subjects who spontaneously adopted the apparent movement strategy had significantly shorter ITs than subjects who did not. However, attempts to train the latter group in the use of this strategy proved unsuccessful, the ITs of these subjects not improving after introduction to this cognitive strategy. A number of interpretations can be placed upon this outcome. Mackenzie and Bingham (1984) speculate that their result may reflect a qualitative difference between groups in the nature of some "specific ability". The same results could, however, also be interpreted as suggesting that only subjects not using the strategy were actually performing the IT task as it was designed, and therefore only in this group could performance differences be interpreted as reflecting differences in processing speed. It is therefore possible that differences in mean IT performance between groups distinguished by age reflect between-group differences in the proportion of strategy users to non-users, presumably with a larger percentage of the latter to be found at younger ages. Certainly, the possible influence of the perception of apparent movement on estimates of IT and on individual differences in this task warrants further investigation.

The results described above are illustrative of the difficulties involved in the isolation of the specific cognitive strategies which account for both group and individual differences in performance on input processing and encoding tasks. Ultimately, any attempt to prove that cognitive strategies are not involved in the developmental IT differences of Experiments 1, 2 and 3 is impracticable. While successive studies may prove that a specific strategy does not account for all performance variance, it can always be logically argued that such a finding reflects a failure on the part of the experimenter to identify the crucial strategies which account for performance differences. Even if some pre-eminent strategic factor were to be isolated, it would still be arguable that its voluntary emergence in a developmental context was structurally dependent (cf. Piaget & Inhelder, 1969). Thus, one is limited to concluding that the existence of a developmental function relating processing speed to CA indicates that IT is subject to maturational influences which may reflect increasingly sophisticated cognitive functioning, or an increasingly efficient information processing mechanism, or both. No more specific exploration distinguishing the contribution of functional from structural influences is possible.

4. The Relationship of IT to Intelligence and Conceptual Tempo

The attempt to relate developmental IT performance to differences in IQ, MA and conceptual tempo produced ambiguous results. While the data from both Experiments 2.1 and 6 provided some evidence of an IT-MA association, as predicted by Brand and Deary (1982), within MAs no significant IQ-IT association was reported. This finding is therefore in contrast to both the IT work summarised by Nettelbeck (in press), and the work described by Brand and Deary (1982), both reviews documenting a consistent and significant IT-IQ association.

The outcome of Experiment 6, however, while contrary to the general finding of some IT-IQ association, is not unreconcilable with the theory of intelligence proposed by Brand (Brand, 1981; Brand & Deary, 1982). According to this model IT provides an estimate of information processing which, in turn, reflects some fundamental intellectual potential, analagous in part to fluid intelligence as defined by Cattell (1971). Individuals who are capable from birth of processing input from the environment more efficiently will have the ability to both "sustain differential abilities in fluid intelligence" (Brand & Deary, 1982, p. 141) and to develop higher levels of crystallized intelligence as measured by conventional IQ tests. By contrast, those individuals whose processing speed is severely constrained, for whatever reason, will be disadvantaged from birth and consequently, not have the potential to develop a high IQ. In such cases, no subsequent training will provide those people with the opportunity to "catch up". The high IT-IQ correlation is therefore a reflection of individual differences in the potential for intelligence.

Failure of the correlation coefficients of Experiment 6 to reach significance is illustrative of the sensitiveness of the IT-IQ association to restriction in the IQ range of the constituent sample. While such a restriction has been shown to have a considerable influence on the strength of the association in adult populations (Chapter 6, Section 1(i), pp. 154-157) its influence in samples restricted to nonretarded children would appear to be even greater. Hulme and Turnbull (1983), for example, in the first of two experiments, tested 65 children aged between 6 and 7 years on the IT task and on a short form of the WISC-R which provided an estimate of both verbal IQ (VIQ) and performance IQ (PIQ). Pearson correlations performed on the data indicated a nonsignificant relationship between IT and both Full Scale IQ (-.2) and VIQ (-.08) in children whose full scale IQs ranged from 86 to 125. A small, but significant correlation was obtained between IT and the PIQ subscale (-.28), predicting just 8% of the variance. In a second experiment in which the same IT task was administered to a sample restricted to 8 mentally retarded adults with PIQs ranging from 41 to 86, a correlation of -.71 was obtained. Thus these results, together with those of Experiment 6 suggest a severe curtailment of the IT-IQ associations when the experimental sample is restricted to a population of nonretarded children.

Two factors may contribute to the decrease in the IT-IQ association. Firstly, developmental differences in the reliability of both IQ and IT measures have been found. Anastasi (1968) reported that the test-retest reliability for the WISC and Stanford-Binet varied considerably across age and IQ level, with greatest unreliability being found in the sub-test reliabilities of 7½ year old children. Similar attempts to assess the test-retest coefficients of the IT measure have certainly found some unreliability in the performance of adults with a mean correlation of -.8 cited by Brand and Deary (1982) and somewhat lower correlations of -.65 (nonretarded adults) and -.71 (retarded adults) reported by Nettelbeck (in press). Results from Experiment 2.2 suggest that the test-retest reliability of young children (i.e. 6 to 7 years) is even lower; refer to Tables 3.11, p. 90 and 3.13 p, 92. Thus, given increasing unreliability in estimates of both IT and IQ with decreasing CA, a decrease in correlation is to be expected. Secondly, the strength of the association between IT and IQ in both young children and adults may be diminished in part by the less than perfect association between intellectual potential, as measured by IT, and achievement as measured by IQ, arising out of factors such as motivation and opportunity. In other words, assessing the strength of the association between processing speed and intellectual potential by correlating IT and IQ may provide an inadequate measure of the strength of the relationship, given the fact that there may be a considerable mismatch between potential (IT) and achievement (IQ), particularly in young children whose performance is subject to greater influence from extraneous factors.

Results from the studies of Hulme and Turnbull (1982) and Experiment 6 suggest a modification to Brand's model that would accommodate the weakening of the correlation in a sample restricted to nonretarded persons. Hulme and Turnbull (1983) have suggested that "the speed of certain operations may be a limiting factor [on IQ] up to a point, but beyond this increases in this speed have very little effect on intellectual performance." (p. 369). In other words, rather than propose a model of intelligence in which IQ at all levels is directly dependent upon the speed at which information is processed, it would appear more appropriate to suggest that there is a critical level of processing speed that is necessary for normalcy, but not sufficient for high IQ (cf. Jensen, 1979). Such a proposition would successfully explain the dependence of the size of the IT-IQ correlation upon the IQ range of the constituent sample while still allowing for a considerable and critical speed component in intelligence. This model would go some way in explaining the results of Experiment 6, particularly if the model is extended to incorporate processing speed as an index of MA development in normal children (a finding hypothesized by Brand & Deary, 1982, p. 142).

Thus, the IT measure appears to provide a two-fold estimate of intellectual performance. With a sample composed of nonretarded and borderline IQ children, processing speed reliably distinguishes children of different MA, mapping cognitive development. However, when the sample is broadened to include those with an IQ defined as mildly retarded or below, the IQ-IT association becomes stronger, reflecting the critical nature of the relationship between normalcy and processing speed.

An alternative explanation for the change in correlation of IT and IQ in nonretarded samples across ages can be derived from the changing pattern of relationship between IT and dimensions of conceptual tempo. The fact that impulsivity in response style was associated with longer ITs primarily in children under the age of 8, with, if anything, a reversal in the direction of association after this age, indicates that the pattern of the association between IT and conceptual tempo varies developmentally. Two explanations for this finding are possible. Firstly, the impulsivity in response style exhibited at younger ages may account for the slower IT of this same group, on the assumption that impulsivity in response selection would increase error rate. As developmental maturation decreases impulsivity, response style may play an increasingly negligible part in the IT task, with processing speed increasingly influenced by other factors. Alternatively, a longer IT and less efficiency in input processing may produce greater response errors on the MFF test, as well as slower latencies, while at later ages increasing speed of processing may be associated with efficiency rather than impulsivity in response style. In other words, the correlations produced in the analyses of Experiment 6 provide no indication as to the direction of causality. Indeed, causality may not be evidenced at all, with the correlation coefficients simply reflecting the relationship of all dependent measures to some intervening developmental variable. The consistently significant main effect for MA found in the analyses of variance of IT, impulsivity and efficiency data provides some additional support for this alternate hypothesis by indicating that performance on all three tasks varied significantly between MA 8 and MA 11.

There are consequently severe limitations on the conclusions which might be drawn about IT and conceptual tempo. While there is some suggestion of a changing pattern of association between conceptual tempo and IT across ages, the confounding of MA, IQ and CA makes interpretation of this relationship difficult. However, despite this difficulty there appears to be a general association between maturation, as measured by MA, and IT, impulsivity, and efficiency. Whether the conceptual tempo variables can be causally related to age differences in IT performance requires additional verification.

5. Conclusions

Attempts in the experiments reported in this thesis to map the developmental course of input processing speed have indicated that maturation is associated with increasing efficiency in input processing. This ontogenetic decrease in IT is both robust and reliable and is not an artifact of an experimental design which differentially disadvantages young children. Although task-specific experience significantly affected the performance accuracy of both children and adults, longitudinal change is such as to indicate a general contribution from maturation, over and above practice. Whether this change reflects developmental differences in the structure or function of the information processing system is a matter open to conjecture. There is some slight suggestion that part of the explanation for the developmental trend may reside in difficulties of registration in young children, and factors which produce greater intra-individual variability in this same group (eg. attentional fluctuations, motivation, fatigue and systemic noise). However, there also appears to be some additional influence from a factor not clearly identified which dictates the efficiency of the input processing mechanism. This overriding efficiency variable may account not only for age differences in IT but also for the documented association between CA and speed as measured by a variety of processing paradigms (Chapter 1). In other words, the general relationship between RT in an information processing task and CA and MA, may be a reflection of an association between maturation and efficiency of the processing system.

LIST OF APPENDICES

APPENDIX

Key to abbreviations used in analysis of variance tables:

Df	Degrees of Freedom
SS	Sum of Squares
SS%	Sum of squares as a percentage of corrected SS of input data
MS	Mean Square
VR	F ratio

Significance levels are reported only when significant at the .05 (*) level or the .01 (**) level. Analyses of variance involving repeated measures were calculated using the Genstat V Statistical Packages Mark 4.01 - 4.03 (1977, 1978, 1979, 1980). In those analyses with missing data the program included estimated values in the final analysis. In these circumstances, degrees of freedom were reduced by the number of missing cases and listed in brackets beside the total df. Analyses of variance tables are reproduced in the same format as the output tables.

SS% values are independent of the scale of measurement of the variate analysed. Statistically, the entries are increments of squared multiple correlation. The grand total of the column of SS% is derived by addition and if there are missing values or covariates, the resulting non-orthogonality will produce a grand total not equal to 100. The discrepancy from 100 gives a useful measure of the effects of any such non-orthogonality.

Appendix 2.1: Results of pilot study examining the effect on specified accuracy level in resultant PEST estimated IT.

Order of task completion	Critical Mean Target Duration			Derived IT		
	.75	.85	.90	.75	.85	.90
.75; .85; .90	36	36	50	103	68	74
.85; .90; .75	46	71	67	133	136	100
.90; .75; .85	29	39	52	83	74	77

<u>Analysis of Variance Table</u>:

Factors:

Order - .75; .85; .90 vs .85; .90; .75 vs .90; .75; .85

Level - level of accuracy: .75 or .85 or .90

Source of Variation	Df	SS	SS%	MS	VR
Order. Subject Stratum					
Order	2	18511.9	16.93	9255.9	1.559
Residual	12	71226.7	65.15	5935.6	12.031
TOTAL	14	89738.6	82.09	6409.9	12.993
Order. Subject, Level Stratum					
Level	2	3851.5	3.52	1925.8	3.904 *
Order. Level	4	3889.5	3.56	972.4	1.971
Residual	24	11840.1	10.83	493.3	
TOTAL	30	19581.1	17.91	652.7	
GRAND TOTAL	44	109319.7	100.00		

Appendix 2.2: Repeated measures analysis of variance examining the nature of masking across ages with planned comparisons. (Experiment 1)

Factors:
ISI (ISI = 0, ISI > 0)
Condition (Binocular, Dichoptic)
Order (Binocular/Dichoptic, Dichoptic/Binocular)
Group (Grade 3, Grade 7, Adults)

Planned Compsrisons:
REG1 (Grade 3 vs Grade 7 and Adults)
REG2 (Grade 7 vs Adults)

<u>Analysis of Variance Table</u>:

Source	Df	SS	SS%	MS	VR
Group.Order.Sub Stratum					
Group	2	76298.6	34.24	38149.3	9.942 **
REG1	1	76006.0	34.11	76006.0	19.808 **
REG2	1	292.6	0.13	292.6	0.076
Order	1	73.6	0.03	73.6	0.019
Group.Order	2	7129.7	3.20	3564.9	0.929
REG1.Dev	1	7117.7	3.19	7117.7	1.855
REG2.Dev	1	12.0	0.01	12.0	0.003
Residual	24	92091.0	41.33	3837.1	17.661
Total	29	175593.0	78.81	6054.9	27.869
Group.Order.Subject.ISI Stratum					
ISI	1	4538.7	2.04	4538.7	7.843 **
Group.ISI	2	3495.6	1.57	1747.8	3.020
REG1.Dev	1	3352.5	1.50	3352.5	5.793 *
REG2.Dev	1	143.1	0.06	143.1	0.247
Order.ISI	1	300.8	0.14	300.8	0.520
Group.Order.ISI	2	484.6	0.22	242.3	0.419
REG1.Dev.Dev	1	484.5	0.22	484.5	0.837
REG2.Dev.Dev	1	0.1	0.00	0.0	0.000
Residual	24	13888.2	6.23	578.7	2.663
Total	30	22708.0	10.19	756.9	3.484
Group.Order.Subject.Condition Stratum					
Condition	1	124.0	0.06	124.0	0.241
Group.Condition	2	1315.1	0.59	657.6	1.279
REG1.Dev	1	1192.6	0.54	1192.6	2.319
REG2.Dev	1	122.5	0.05	122.5	0.238
Order.Condition	1	1717.6	0.77	1717.6	3.340
Group.Order.Condition	2	1178.2	0.53	589.1	1.145
REG1.Dev.Dev	1	1157.2	0.52	1157.2	2.250
REG2.Dev.Dev	1	21.0	0.01	21.0	0.041
Residual	24	12343.0	5.54	514.3	2.367
Total	30	16678.0	7.49	555.9	2.559
Group.Order.Subject.ISI.Condition Stratum					
ISI.Condition	1	1540.8	0.69	1540.8	7.092 *
Group.ISI.Condition	2	635.0	0.29	317.5	1.461
REG1.Dev.Dev	1	630.5	0.28	630.5	2.902
REG2.Dev.Dev	1	4.5	0.00	4.5	0.021
Order.ISI.Condition	1	0.3	0.00	0.3	0.001
Residual	26	5648.8	2.54	217.3	
Total	30	7825.0	3.51	260.8	
Grand Total	119	222804.0	100.00		

Appendix 3.1: Oneway analysis of variance of Inspection Time by Grade (2, 3, 4, 5, 6, 7, 8, and adult). (Experiment 2.1)

Source	Df	SS	MS	VR
Between Groups	7	213014.7682	30430.6812	5.864 **
Within Groups	72	373607.1818	5188.9886	
Total	79	586621.9500		

Appendix 3.2: Oneway analysis of variance of Inspection Time by Grade with the exclusion of Grade 2. (Experiment 2.1)

Source	Df	SS	MS	VR
Between Groups	6	44487.4857	7414.5810	4.182 **
Within Groups	63	111691.1000	1772.8746	
Total	69	156178.5857		

Appendix 3.3: Repeated measures analysis of variance of IT in practice control sample. (Experiment 2.2)

Factors: Group (Grade 2, 7, and Adults)
Session (1 and 2)

Planned Comparisons: REG1 (Grade 2 vs Grade 7 and Adults)
REG2 (Grade 7 vs Adults)

Source	Df	SS	SS%	MS	VR
Group. Sub Stratum					
Group	2	80186.2	29.83	40093.1	6.307 **
Reg1	1	71834.1	26.72	71834.1	11.300 **
Reg2	1	8352.1	3.11	8352.1	1.314
Residual	27	171632.2	63.85	6356.7	13.348
Total	29	251818.5	93.68	8683.4	18.234
Group. Sun Sess. Stratum					
Sess	1	3067.4	1.14	3067.4	6.441 *
Grp. Sess	2	1053.3	0.39	526.7	1.106
Reg1.Dev	1	1009.2	0.38	1009.2	2.119
Reg2.Dev	1	44.1	0.02	44.1	0.093
Residual	27	12857.9	4.78	476.2	
Total	30	16978.5	6.32	566.0	
Grand Total	59	268797.0	100.0		

Appendix 3.4: Repeated measures analysis of variance of IT in longitudinal sample.
(Experiment 2.2)

Factors: Group (Grades 2/3, 3/4, 4/5, 5/6, 6/7, and Adults)
Session (1 vs 2)

Source	Df	SS	SS%	MS	VR
Group Sub Stratum					
Group	5	155479	20.43	31096	4.159 **
Residual	54	403786	53.06	7478	3.315
Total	59	559265	73.49	9479	4.203
Group Sub Sess. Stratum					
Sess	1	71963	9.46	71963	31.906 **
Grp. Sess	5	35359	4.65	7072	3.135 *
Residual	49(5)	110517	14.52	2255	
Total	55	217839	28.62	3961	
Grand Total	114	777103	102.11		

Appendix 3.5: Repeated measures analysis of variance comparing improvement in IT over 1 year with improvement over 2 weeks.
(Experiment 2.2)

Factors: Group (Grade 2, 7, and Adults)
Period (2 weeks vs 1 year)
Session (1 vs 2)

Planned Comparisons: REG1
REG2

Source	Df	SS	SS%	MS	VR
Group. Period. Sub Stratum					
Group	2	222032	25.02	111016	12.919 **
Reg1	1	209677	23.63	209677	24.401 **
Reg2	1	12355	1.39	12355	1.438
Period	1	2671	0.30	2671	0.311
Grp. Period	2	6548	0.74	3274	0.381
Reg1.Dev	1	6220	0.70	6220	0.724
Reg2.Dev	1	327	0.04	327	0.030
Residual	54	464018	52.30	8593	4.235
Total	59	695268	78.36	11784	5.808
Group. Period. Sub Sess Stratum					
Sess	1	38086	4.29	38086	18.772 **
Grp. Sess	2	22284	2.51	11142	5.492 **
Reg1.Dev	1	20060	2.26	20060	9.887 **
Reg2.Dev	1	2224	0.25	2224	1.096
Period Sess	1	13650	1.54	13650	6.728 **
Grp. Period Sess	2	10779	1.21	5389	2.656
Reg1.Dev	1	9352	1.05	9352	4.609*
Reg2.Dev	1	1427	0.16	1427	0.703
Residual	53(1)	107531	12.12	2029	
Total	59	192330	21.68	3260	
Grand Total	118	887598	100.04		

Appendix 3.6: Repeated measures analysis of variance examining change in IT performance over years 1981, 1982 and 1983.
(Experiment 2.2)

Factors: Group (Grades 2/3/4, 3/4/5, 4/5/6/, and 5/6/7)
Session (1981, 1982, 1983)

Due to the large amount of missing data (13 cases) a covariate analysis was performed on each missing case as opposed to the estimation method used in past analyses. Covariate did not produce a significant effect.

Source	Df	SS	SS%	MS	VR
Group Sub Stratum					
Group	3	77028	9.09	25676	2.793
Covariates	9	74284	8.77	8254	0.898
Residual	27	248213	29.30	9193	3.273
Total	39	399526	47.16	10244	3.648
Group Sub Sess Stratum					
Sess	2	137791	16.26	68896	24.532 **
Grp. Sess	6	39709	4.69	6618	2.357
Covariates	13	33247	3.92	2557	0.911
Residual	59	165694	19.56	2808	
Total	80	376442	44.43	4706	
Grand Total	119	775967	91.59		

Appendix 3.7: Repeated measures analyses of variance of IT in groups varying by age and cohort. (Experiment 2.2)

Factors: Age (Grade when IT was measured)
Cohort (Defined by year of entering school)

a. Grades 3 and 4. Entered school 1979 and 1980.

Source	Df	SS	SS%	MS	VR
Cohort Sub Stratum					
Cohort	1	4707	3.27	4707	0.731
Residual	18	115980	80.60	6443	4.596
Total	19	120688	83.87	6352	4.530
Cohort Sub Age Stratum					
Age	1	16808	11.68	16808	11.988 **
Cohort Age	1	40	0.03	40	0.028
Residual	16(2)	22433	15.59	1402	
Total	18	39281	27.30	2182	
Grand Total	37	159969	111.17		

b. Grades 4 and 5. Entered school 1978 and 1979.

Source	Df	SS	SS%	MS	VR
Cohort Sub Stratum					
Cohort	1	12962.3	12.47	12962.3	2.601
Residual	17(1)	84726.3	81.49	4983.9	8.987
Total	18	97688.6	93.96	5427.1	9.786
Cohort Sub Age Stratum					
Age	1	9341.4	8.98	9341.4	16.844 **
Cohort Age	1	2.0	0.00	2.0	0.004
Residual	15(3)	8318.6	8.00	554.6	
Total	17	17662.1	16.99	1038.9	
Grand Total	35	115350.6	110.94		

Appendix 3.7: Cont.

c. Grades 5 and 6. Entered school in 1977 and 1978.

Source	Df	SS	SS%	MS	VR
Cohort Sub Stratum					
Cohort	1	2691.9	4.27	2691.9	1.123
Residual	17(1)	40732.2	64.58	2396.0	4.947
Total	18	43424.1	68.85	2412.4	4.981
Cohort Sub Age Stratum					
Age	1	17407.7	27.60	17407.7	35.942 **
Cohort Age	1	1476.8	2.34	1476.8	3.049
Residual	15(3)	7264.9	11.52	484.3	
Total	17	26149	41.46	1538.2	
Grand Total	35	69573.4	110.31		

d. Grades 6 and 7. Entered school 1976 and 1977.

Source	Df	SS	SS%	MS	VR
Cohort Sub Stratum					
Cohort	1	2217.9	4.55	2217.9	1.027
Residual	16(2)	34563.1	70.92	2160.2	5.848
Total	17	36781.0	75.47	2163.6	5.857
Cohort Sub Age Stratum					
Age	1	7768.6	15.94	7768.6	21.032 **
Cohort Age	1	3010.2	6.18	3010.2	8.149 **
Residual	12(6)	4432.5	9.10	369.4	
Total	14	15211.3	31.21	1086.5	
Grand Total	31	51992.3	106.69		

Appendix 4.1: Repeated measures analysis of variance of IT measured using PEST and MCSD procedures in groups varying by age. (Experiment 3)

Factors: Method (MCSD, MCSD with pauses, PEST)
Grade (Grades 3 and 7)
Order (MCSD pause/MCSD no pause and MCSD no pause/MCSD pause)

Source	Df	SS	SS%	MS	VR
Grade.Order. Sub Stratum					
Grade	1	260305	24.30	260305	9.997 **
Order	1	9375	0.88	9375	0.360
Grade.Order	1	36507	3.41	36507	1.402
Residual	16	416632	38.89	26039	2.858
Total	19	722819	67.47	38043	4.175
Grade.Order.Sub. Method Stratum					
Method	2	27447	2.56	13723	1.506
Grade.Method	2	27813	2.60	13907	1.526
Order.Method	2	1647	0.15	824	0.090
Grade.Order. Method	2	0	0.00	0	0.000
Residual	32	291606	27.22	9113	
Total	40	348513	32.53	8713	
Grand Total	59	1071332	100.00		

Appendix 4.2: Repeated measures analysis of variance of IT measured using PEST and MCSD proceduces in groups varying by age, with the deletion of one anomalous measure.
(Experiment 3)

Source	Df	SS	SS%	MS	VR
Grade.Order.Sub Stratum					
Grade	1	193319	29.62	193319	11.106 **
Order	1	692	0.11	692	0.040
Grade.Order	1	14531	2.23	14531	0.835
Residual	16	278503	42.67	17486	4.074
Total	19	487046	74.62	25634	5.999
Grade.Order.Sub.Method Stratum					
Method	2	19603	3.00	9802	2.294
Grade.Method	2	4566	0.70	2283	0.534
Order.Method	2	10228	1.57	5114	1.197
Grade.Order. Method	2	9856	1.51	4928	1.153
Residual	31(1)	132465	20.30	4273	
Total	39	176718	27.08	4531	
Grand Total	58	663763	101.70		

Appendix 5.1: T-tests comparing accuracy at each duration between subjects with an MA of 8 and those with an MA of 11 years (2 tail probability).

a. Exposure duration : 5 ms

T = -.77; df = 46

b. Exposure duration : 25 ms

T = .40; df = 46

c. Exposure duration : 50 ms

T = -2.28; df = 46 *

d. Exposure duration : 100 ms

T = -2.72; df = 46 **

e. Exposure duration : 150 ms

T = -3.03; df = 46 **

f. Exposure duration : 250 ms

T = -2.20; df = 46 *

g. Exposure duration : 400 ms

T = -2.02; df = 46 *

h. Exposure duration : 2000 ms

T = -1.93; df = 46

Appendix 5.2: Individual estimates of Impulsivity and Efficiency derived from a within sample standardization.

Group (MA:IQ)	Impulsivity[a]	Efficiency[b]
11: Above average	- .69	- .71
	.43	-1.19
	2.24	.48
	- .01	- .75
	-2.76	.42
	.94	.20
	- .22	- .24
	.30	- .44
11: Average	- .25	-1.43
	1.29	- .47
	-3.50	.84
	- .24	- .84
	.50	-1.26
	.03	-1.43
	-1.05	- .63
	.19	-1.27
11: Below average	-2.46	.42
	-1.42	.02
	.08	- .22
	- .72	-1.32
	-2.42	1.34
	.53	- .35
	-3.77	1.43
	- .37	- .09
8: Above average	-2.24	2.10
	3.56	2.96
	3.57	1.37
	2.69	.65
	- .02	-1.06
	.23	- .37
	3.51	2.05
	-19.85	16.55
8: Average	- .73	- .03
	-1.95	1.81
	-1.08	.94
	.08	- .22
	.11	.39
	-1.40	.32
	-1.42	.02
	2.22	.18
8: Below average	1.14	- .32
	- .23	- .53
	.54	-1.94
	1.14	- .32
	2.51	- .11
	.77	- .27
	1.22	- .40
	- .87	.41

a Positive score - Impulsive; Negative score - Reflective

b Positive score - Inefficient; Negative score - Efficient

Appendix 5.3: Repeated measure analysis of variance of SD of sample by age and duration within sessions. (Experiment 4)

Factors: Grade (Grades 3 and 7)
Duration (100, 125 and 150 ms)
Session (1 and 2)

Source	Df	SS	SS%	MS	VR
Grade.Sub Stratum					
Grade	1	5.7760	7.48	5.7760	5.263 *
Residual	22	24.1465	31.26	1.0976	5.289
Total	23	29.9225	38.73	1.3010	6.269
Grade.Sub.Dur Stratum					
Dur	2	4.5884	5.94	2.2942	11.425 **
Grade.Dur	2	0.1183	0.15	0.0591	0.294
Residual	44	8.8353	11.44	0.2008	0.968
Total	48	13.5420	17.53	0.2821	1.360
Grade.Sub.Sess Stratum					
Sess	1	11.7649	15.23	11.7649	25.470 **
Grade.Sess	1	0.3422	0.44	0.3422	0.741
Residual	22	10.1622	13.15	0.4619	2.226
Total	24	22.2693	28.83	0.9279	4.472
Grade.Sub.Dur.Sess Stratum					
Dur.Sess	2	1.5205	1.97	0.7602	3.664 *
Grade.Dur.Sess	2	0.8654	1.12	0.4327	2.085
Residual	44	9.1305	11.82	0.2075	
Total	48	11.5164	14.91	0.2399	
Grand Total	143	77.2502	100.00		

Appendix 5.4: Repeated measures analysis of variance of SD of sample by age and duration across the 10 blocks of both sessions.
(Experiment 4)

Factors: Grade (Grades 3 and 7)
Duration (100, 125 and 150 ms)
Session (1 and 2)

Source	Df	SS	SS%	MS	VR
Grade.Sub Stratum					
Grade	1	3.8088	11.54	3.8088	3.786
Residual	22	22.1311	67.05	1.0060	9.296
Total	23	25.9399	78.59	1.1278	10.422
Grade.Sub.Dur Stratum					
Dur	2	2.2096	6.69	1.1048	10.209 **
Grade.Dur	2	0.0938	0.28	0.0469	0.433
Residual	44	4.7613	14.43	0.1082	
Total	48	7.0647	21.41	0.1472	
Grand Total	71	33.0045	100.00		

Appendix 5.5: Repeated measures analysis of variance of discrimination accuracy by age and duration within sessions and blocks. (Experiment 4)

Factors:
Grade (Grades 3 and 7)
Duration (100, 125 and 150 ms)
Session (1 and 2)
Blocks (1, 2, 3, 4 and 5)

Source	Df	SS	SS%	MS	VR
Grade.Sub Stratum					
Grade	1	125.8347	9.00	125.8347	7.241 *
Residual	22	382.3306	27.35	17.3787	24.764
Total	23	508.1653	36.35	22.0941	31.484
Grade.Sub.Dur Stratum					
Dur	2	18.5028	1.32	9.2514	16.384 **
Grade.Dur	2	1.7861	0.31	0.8931	1.582
Residual	44	24.8444	1.78	0.5646	0.805
Total	48	45.1333	3.23	0.9403	1.340
Grade.Sub.Sess Stratum					
Sess	1	127.5125	9.12	127.5125	22.903 **
Grade.Sess	1	14.1681	1.01	14.1681	2.545
Residual	22	122.4861	8.76	5.5676	7.934
Total	24	264.1667	18.90	11.0069	15.685
Grade.Sub.Block Stratum					
Block	4	29.6389	2.12	7.4097	4.929 **
Grade.Block	4	9.2000	0.66	2.3000	1.530
Residual	88	132.2944	9.46	1.5033	2.142
Total	96	171.1333	12.24	1.7826	2.540
Grade.Sub.Dur.Sess Stratum					
Dur.Sess	2	4.8083	0.34	2.4042	6.377 **
Grade.Dur.Sess	2	0.5361	0.04	0.2681	0.711
Residual	44	16.5889	1.19	0.3770	0.537
Total	48	21.9333	1.57	0.4569	0.651
Grade.Sub.Dur.Block Stratum					
Dur.Block	8	10.1361	0.73	1.2670	1.858
Grade.Dur.Block	8	4.7417	0.34	0.5927	0.869
Residual	176	119.9889	8.58	0.6818	0.971
Total	192	134.8667	9.65	0.7024	1.001
Grade.Sub.Sess.Block Stratum					
Sess.Block	4	24.8833	1.78	6.2208	6.719 **
Grade.Sess.Block	4	6.6444	0.48	1.6611	1.794
Residual	88	81.4722	5.83	0.9258	1.319
Total	96	113.0000	8.08	1.1771	1.677
Grade.Sub.Dur.Sess.Block Stratum					
Dur.Sess.Block	8	10.2750	0.74	1.2844	1.830
Residual	184	129.1250	9.24	0.7018	
Total	192	139.4000	9.97	0.7260	
Grand Total	719	1397.7986	100.00		

Appendix 5.6: Repeated measures analysis of variance of accuracy on a 2 and 4 choice task, with an ISI equal to or greater than 0, in groups of different ages.
(Experiment 5)

Factors: Group (Grades 3 and 7)
Choice (2 and 4)
ISI (Equal 0 and greater than 0)

Source	Df	SS	SS%	MS	VR
Group.Sub Stratum					
Group	1	588.613	19.90	588.613	7.456 *
Residual	18	1421.025	48.04	78.946	16.423
Total	19	2009.638	67.94	105.770	22.004
Group.Sub.Choice Stratum					
Choice	1	418.612	14.15	418.612	26.089 **
Group.Choice	1	25.313	0.86	25.313	1.578
Residual	18	288.825	9.76	16.046	3.338
Total	20	732.750	24.77	36.638	7.622
Group.Sub.ISI Stratum					
ISI	1	17.112	0.58	17.112	3.610
Group.ISI	1	15.312	0.52	15.312	3.230
Residual	18	85.325	2.88	4.740	0.986
Total	20	117.750	3.98	5.887	1.225
Group.Sub.Choice.ISI Stratum					
Choice ISI	1	2.112	0.07	2.112	0.439
Group.Choice.ISI	1	9.112	0.31	9.112	1.896
Residual	18	86.525	2.93	4.807	
Total	28	97.750	3.30	4.887	
Grand Total	79	2957.888	100.00		

Appendix 6.1: Repeated measures analysis of variance of discrimination accuracy across durations in groups distinguished by MA and IQ.
(Experiment 6)

Factors: MA (8 and 11)
IQ (Above average, Average, and Below average)
Duration (5, 25, 50, 100, 150, 250, 400 and 2000 ms)

Source	DF	SS	SS%	MS	VR
MA.IQ.Sub Stratum					
MA	1	105.361	1.53	105.361	10.481 **
IQ	2	30.630	0.44	15.315	1.523
MA.IQ	2	24.478	0.35	12.239	1.217
Residual	41(1)	412.170	5.97	10.053	2.648
Total	46	572.638	8.29	12.449	3.279
MA.IQ.Sub.Dur Stratum					
Dur	7	5156.081	74.65	736.583	194.038 **
MA.Dur	7	73.740	1.07	10.534	2.775
IQ.Dur	14	71.516	1.04	5.108	1.346
MA.IQ.Dur	14	71.964	1.04	5.140	1.354
Residual	287(7)	1089.474	15.77	3.796	
Total	329	6462.774	93.56	19.644	
Grand Total	375	7035.412	101.85		

Appendix 6.2: An analysis of variance of IT by MA and IQ.
(Experiment 6)

Source	Df	SS	MS	VR
Main Effects	3	236642.981	78880.994	2.428
MA	1	194979.297	194979.297	6.002 *
IQ	2	46921.081	23460.541	0.722
2-Way Interactions	2	22396.708	11198.354	0.345
MA.IQ	2	22396.708	11198.354	0.345
Explained	5	259039.688	51807.938	1.595
Residual	41	1331867.929	32404.584	
Total	46	1590907.617	34584.948	

Appendix 6.3: Repeated measures analysis of variance of RT across duration in groups distinguished by MA and IQ. (Experiment 6)

Factors: MA (8 and 11)
IQ (Above average, Average, Below average)
Duration (5, 25, 50, 100, 150, 250, 400, 2000 ms)

Source	Df	SS	SS%	MS	VR
MA.IQ.Sub Stratum					
MA	1	5551049	2.18	5551049	2.451
IQ	2	19844741	7.78	9922370	4.381 *
MA.IQ	2	2878900	1.13	1439450	0.636
Residual	41(1)	92854401	36.38	2264741	8.588
Total	46	121129091	47.46	2633241	9.986
MA.IQ.Sub.Dur Stratum					
Dur	7	49077068	19.23	7011010	26.587 **
MA.Dur	7	3159970	1.24	451424	1.712
IQ.Dur	14	2278744	0.89	162767	0.617
MA.IQ.Dur	14	6570088	2.57	469292	1.780
Residual	287(7)	75682752	29.65	263703	
Total	329	136768622	53.59		
Grand Total	375	257897713	101.05		

Appendix 6.4: An analysis of variance of total errors in the MFF task by MA and IQ. (Experiment 6)

Source	Df	SS	MS	VR
Main Effects	3	680.080	226.693	8.589 **
MA	1	394.091	394.091	14.931 **
IQ	2	306.794	153.397	5.812 **
2-Way Interactions	2	73.284	36.642	1.388
MA.IQ	2	73.284	36.642	1.388
Explained	5	753.364	150.673	5.709 **
Residual	41	1082.125	26.393	
Total	46	1835.489	39.902	

Appendix 6.5: An analysis of variance of mean latency in the MFF task by MA and IQ. (Experiment 6)

Source	Df	SS	MS	VR
Main Effects	3	80.939	26.980	0.648
MA	1	36.402	36.402	0.874
IQ	2	46.990	23.495	0.564
2-Way Interactions	2	398.003	199.002	4.777
MA:IQ	2	398.003	199.002	4.777
Explained	5	478.942	95.788	2.300
Residual	41	1707.866	41.655	
Total	46	2186.809	47.539	

Appendix 6.6: An analysis of variance of impulsivity by MA and IQ. (Experiment 6).

Source	Df	SS	MS	VR
Main Effects	3	29.351	9.784	4.220 *
MA	1	16.077	16.077	6.934 *
IQ	2	14.176	7.088	3.057
2-Way Interactions	2	10.967	5.484	2.365
MA:IQ	2	10.967	5.484	2.365
Explained	5	40.318	8.064	3.478 **
Residual	41	95.056	2.318	
Total	46	135.375	2.943	

Appendix 6.7: An analysis of variance of efficiency by MA and IQ. (Experiment 6)

Source	Df	SS	MS	VR
Main Effects	3	8.012	2.671	3.530 *
MA	1	5.109	5.109	6.753 *
IQ	2	3.144	1.572	2.078
2-Way Interactions	2	9.500	4.750	6.279 **
MA:IQ	2	9.500	4.750	6.279
Explained	5	17.513	3.503	4.630 **
Residual	41	31.018	0.757	
Total	46	48.531	1.055	

Appendix 7.0: Raw data for Experiments 1 to 6.

Experiment 1.

Subject No.	Age (Yrs-Mths)	Grade	Order[b]	SOA$_{.85}$			
				Binoc.	Dichopt.	Binoc.	Dichopt.
				ISI = 0		ISI > 0[a]	
001	8-1	3	B/D	117	69	129	60
002	8-0	3	"	119	151	145	140
003	8-4	3	"	58	59	65	115
004	8-1	3	"	154	125	165	183
005	8-5	3	"	84	76	95	99
006	8-0	3	D/B	51	66	58	78
007	8-6	3	"	72	150	87	194
008	8-9	3	"	169	152	136	195
009	7-8	3	"	160	137	226	225
010	8-2	3	"	114	86	128	191
011	11-7	7	B/D	71	58	107	136
012	11-11	7	"	150	101	95	99
013	12-6	7	"	37	45	69	55
014	12-4	7	"	85	62	77	85
015	11-7	7	"	70	42	41	28
016	11-5	7	D/B	76	54	116	101
017	11-2	7	"	25	35	28	40
018	12-2	7	"	53	58	60	63
019	12-3	7	"	91	91	120	100
020	11-8	7	"	57	76	33	34
021	24-2	Adult	B/D	79	72	56	63
022	19-4	Adult	"	78	86	87	100
023	17-3	Adult	"	89	58	76	63
024	19-0	Adult	"	54	38	42	46
025	17-6	Adult	"	68	79	92	95
026	19-11	Adult	D/B	104	79	77	87
027	19-4	Adult	"	81	83	76	77
028	18-6	Adult	"	43	50	54	58
029	19-4	Adult	"	24	38	27	36
030	24-5	Adult	"	54	57	74	71

[a] TS duration = 25 ms

[b] Binocular, Dichoptic; Dichoptic, Binocular

Experiment 2.1 and 2.2

					SOA$_{.85}$	
Subject No.	Age (Yrs-Mths)	Grade (Year 1)	Peabody IQ	Measure 1 1981	Measure 2 1982	Measure 3 1983
031	6-7	2	93	392	155	90
032	8-6	2	75	425	284	100
033	6-10	2	131	41	23	–
034	7-4	2	104	90	123	130
035	7-1	2	104	231	193	120
036	7-6	2	100	450	95	103
037	7-3	2	87	147	51	77
038	7-4	2	95	29	33	17
039	7-4	2	133	100	86	53
040	7-3	2	87	408	85	28
041	8-0	3	85	126	56	44
042	7-7	3	135	213	250	163
043	7-8	3	125	136	55	28
044	7-7	3	123	103	64	46
045	7-2	3	81	64	51	–
046	8-2	3	106	114	19	24
047	8-4	3	130	172	–	–
048	7-9	3	125	114	94	45
049	8-0	3	126	183	150	119
050	7-10	3	121	100	63	83
051	8-10	4	121	136	126	61
052	8-8	4	128	193	–	–
053	8-8	4	109	109	50	32
054	8-10	4	119	94	103	32
055	8-7	4	118	86	69	76
056	8-11	4	131	34	31	15
057	8-6	4	111	147	99	97
058	8-5	4	114	182	80	61
059	8-10	4	108	156	104	86
060	8-10	4	105	109	120	55
061	9-5	5	146	108	–	–
062	9-4	5	118	119	36	24
063	9-3	5	129	124	110	–
064	9-11	5	129	64	–	–
065	10-7	5	104	215	143	103
066	10-5	5	116	111	53	33
067	9-9	5	95	99	24	62
068	9-9	5	123	78	37	–
069	9-9	5	110	69	70	51
070	9-9	5	84	167	78	–
071	10-9	6	121	130	48	–
072	11-2	6	100	80	46	–
073	11-4	6	118	77	40	–
074	10-9	6	112	135	87	–
075	10-9	6	112	171	101	–
076	10-4	6	146	62	41	–
077	10-6	6	130	125	–	–
078	11-2	6	100	34	26	–
079	10-10	6	118	103	25	–
080	11-3	6	112	94	65	–
081	11-9	7	117	93	–	–
082	11-11	7	105	34	–	–
083	12-2	7	92	93	–	–
084	11-6	7	106	156	–	–
085	11-11	7	105	18	–	–
086	12-2	7	108	90	–	–

Experiment 2.1 and 2.2 cont.

				SOA$_{.85}$		
Subject No.	Age (Yrs-Mths)	Grade (Year 1)	Peabody IQ	Measure 1 1981	Measure 2 1982	Measure 3 1983
087	11-11	7	118	36	-	-
088	12-4	7	103	25	-	-
089	11-6	7	103	75	-	-
090	12-1	7	111	84	-	-
091	13-9	8	76	82	-	-
092	13-6	8	118	75	-	-
093	12-10	8	124	26	-	-
094	13-3	8	97	107	-	-
095	13-1	8	142	90	-	-
096	13-0	8	138	105	-	-
097	13-1	8	124	80	-	-
098	12-10	8	135	100	-	-
099	13-4	8	125	92	-	-
100	13-3	8	146	107	-	-
101	18-6	Adult	-	117	133	-
102	22-3	Adult	-	18	26	-
103	25-2	Adult	-	130	166	-
104	20-9	Adult	-	13	11	-
105	18-1	Adult	-	69	21	-
106	20-6	Adult	-	75	68	-
107	19-9	Adult	-	50	27	-
108	27-3	Adult	-	23	19	-
109	24-0	Adult	-	15	6	-
110	22-0	Adult	-	103	64	-
Control						
111	6-3	2	-	250	140	-
112	6-5	2	-	247	271	-
113	6-11	2	-	91	57	-
114	7-6	2	-	169	111	-
115	6-5	2	-	38	23	-
116	6-4	2	-	307	272	-
117	6-7	2	-	70	75	-
118	7-2	2	-	159	93	-
119	6-9	2	-	95	121	-
120	7-1	2	-	126	130	-
121	12-0	7	-	52	49	-
122	11-7	7	-	97	75	-
123	11-5	7	-	116	119	-
124	11-7	7	-	20	25	-
125	12-4	7	-	90	116	-
126	11-11	7	-	26	32	-
127	11-10	7	-	137	94	-
128	11-9	7	-	63	65	-
129	11-9	7	-	160	122	-
130	11-6	7	-	125	83	-
131	17-6	Adult	-	41	62	-
132	18-1	Adult	-	45	30	-
133	17-1	Adult	-	20	35	-
134	19-7	Adult	-	60	28	-
135	17-1	Adult	-	16	34	-
136	17-10	Adult	-	76	62	-
137	18-0	Adult	-	9	16	-
138	38-6	Adult	-	116	99	-
139	20-0	Adult	-	77	48	-
140	17-5	Adult	-	116	98	-

Experiment 3

				SOA$_{.975}$	
Subject No.	Age (Yrs-Mths)	Grade	PEST	MCSD (pauses)	MCSD (no pauses)
141	8-4	3	250	140	249
142	7-10	3	331	99	185
143	7-10	3	92	117	449
144	7-2	3	348	332	849
145	8-0	3	111	100	114
146	8-1	3	321	259	283
147	7-5	3	297	283	272
148	7-6	3	329	426	287
149	7-6	3	404	340	323
150	7-11	3	254	165	188
151	11-2	7	288	192	249
152	12-8	7	197	88	141
153	11-9	7	241	206	153
154	11-8	7	226	108	103
155	11-8	7	41	166	73
156	12-0	7	150	113	140
157	11-5	7	241	143	168
158	11-2	7	32	27	28
159	11-8	7	66	29	49
160	11-10	7	207	210	170

Experiment 4.

Subject No.	Age (Yrs-Mths)	Grade	Duration	Number Correct (out of 10)									
				Session 1 (Blocks 1-5)					Session 2 (Blocks 6-10)				
				1	2	3	4	5	6	7	8	9	10
161	8-0	3	100	10	6	5	6	6	6	7	10	8	10
			125	6	10	6	8	9	9	10	10	9	10
			150	7	8	8	9	8	8	10	9	10	9
162	7-11	3	100	10	10	9	10	10	10	10	10	10	10
			125	10	9	10	10	10	10	10	10	10	10
			150	10	10	10	9	10	10	10	10	10	9
163	8-2	3	100	9	9	10	9	7	9	10	10	9	10
			125	7	9	9	8	9	10	10	10	9	9
			150	9	10	10	10	10	10	10	10	9	10
164	7-11	3	100	8	10	10	10	9	10	10	8	10	10
			125	10	9	8	10	10	10	10	10	10	8
			150	8	9	10	10	9	10	10	10	9	10
165	8-2	3	100	4	6	9	9	9	9	8	9	8	10
			125	9	8	10	8	10	9	10	9	9	9
			150	9	9	5	9	10	9	10	8	9	9
166	7-8	3	100	6	8	8	7	9	10	9	9	8	10
			125	7	9	8	8	9	10	9	9	10	10
			150	10	4	8	5	9	10	10	9	10	10
167	7-8	3	100	8	10	10	10	9	10	10	10	10	10
			125	10	10	8	10	9	10	10	10	10	10
			150	10	10	10	10	10	10	10	10	10	10
168	8-0	3	100	8	9	9	8	10	10	10	10	10	9
			125	10	10	10	9	10	10	10	10	10	10
			150	9	10	9	9	10	10	9	10	10	9
169	7-9	3	100	4	4	4	7	9	10	8	8	9	8
			125	4	6	6	3	9	10	8	8	9	9
			150	5	6	6	5	8	10	10	10	9	10
170	8-4	3	100	10	5	6	5	7	10	8	6	8	10
			125	9	6	5	7	9	10	8	8	9	10
			150	7	9	8	5	9	10	9	7	10	10
171	8-5	3	100	1	6	6	4	7	5	9	8	7	10
			125	5	7	7	6	7	7	9	7	8	9
			150	3	7	6	5	7	6	10	8	10	6
172	7-7	3	100	8	9	10	10	10	9	10	10	10	9
			125	10	9	10	10	10	10	10	10	10	9
			150	10	10	10	10	10	10	9	10	9	10
173	11-6	7	100	8	10	10	10	9	10	10	10	10	10
			125	10	10	10	10	9	10	10	10	9	10
			150	10	10	10	10	10	10	10	10	10	10
174	11-5	7	100	8	9	10	10	8	10	10	10	8	10
			125	10	10	10	10	10	10	10	10	9	10
			150	8	9	10	10	9	9	9	10	9	10
175	11-0	7	100	4	10	10	10	10	10	10	10	10	10
			125	9	10	10	10	10	9	10	10	10	10
			150	7	10	10	10	10	10	10	10	10	10
176	11-11	7	100	8	9	8	10	10	10	10	10	10	10
			125	10	10	8	10	10	10	10	10	10	10
			150	10	10	10	9	10	10	10	10	10	10
177	11-11	7	100	3	10	9	9	10	9	10	10	10	10
			125	8	9	8	10	10	10	10	10	10	9
			150	7	7	10	9	8	10	10	10	10	10
178	11-7	7	100	8	10	10	9	10	10	10	9	10	10
			125	10	10	10	10	10	10	10	9	10	10
			150	8	9	10	9	9	10	10	10	10	10

Experiment 4 cont.

Subject No.	Age (Yrs-Mths)	Grade	Duration	Number Correct (out of 10)									
				Session 1 (Blocks 1-5)					Session 2 (Blocks 6-10)				
				1	2	3	4	5	6	7	8	9	10
179	11-11	7	100	9	10	9	10	9	10	10	10	10	10
			125	10	10	10	9	10	10	10	9	10	10
			150	10	10	10	10	10	10	10	10	10	10
180	12-9	7	100	5	7	6	10	8	10	10	9	10	10
			125	4	9	10	7	8	10	10	10	10	10
			150	6	9	9	7	9	10	10	9	10	10
181	12-0	7	100	7	10	9	10	10	10	10	10	10	10
			125	9	10	10	10	10	10	10	10	10	10
			150	10	8	10	10	10	10	10	10	10	10
182	11-9	7	100	9	9	10	10	9	10	10	9	10	9
			125	10	10	10	9	10	10	10	10	10	10
			150	10	10	10	10	10	10	10	10	10	9
183	12-5	7	100	9	10	10	10	10	10	10	10	10	10
			125	10	10	10	10	10	10	10	10	10	10
			150	10	10	9	10	10	10	10	10	10	10
184	12-1	7	100	9	10	10	9	10	10	10	10	10	10
			125	10	9	9	10	10	10	10	10	10	10
			150	10	10	10	10	10	10	10	10	10	10

Experiment 5.

Subject No.	Age (Yrs-Mths)	Grade	Number Correct (out of 40)			
			2 Choice		4 Choice	
			ISI=90	ISI=0	ISI=90	ISI=0
185	8-5	3	38	36	34	35
186	8-1	3	37	40	31	39
187	7-7	3	37	36	28	36
188	7-4	3	38	35	32	31
189	8-1	3	22	23	12	17
190	7-7	3	38	38	34	35
191	8-3	3	36	39	32	32
192	7-8	3	37	39	22	26
193	8-7	3	28	30	22	17
194	8-0	3	31	34	28	35
195	11-9	7	40	40	37	39
196	13-6	7	38	40	30	22
197	12-3	7	40	40	37	38
198	11-11	7	40	40	40	39
199	12-0	7	37	38	35	34
200	12-11	7	38	37	35	38
201	12-3	7	39	38	33	37
202	11-7	7	39	40	38	39
203	11-6	7	40	40	34	29
204	12-0	7	36	38	37	38

Experiment 6

Subj. No.	Age (Yr-Mth)	IQ	CA (Yr-Mth)	MFFT Mean Latency	Total Errors	BAS Score	PMA		Number of Correct Trials (out of 20) Duration								$IT_{.975}$	Mean Correct Reaction Time Duration							
							Score	PIQ	5	25	50	100	150	250	400	2000		5	25	50	100	150	250	400	2000
Group: MA 8: Above Average IQ																									
205	9-6	125	5-11	29	10	-	25	141	9	12	9	13	10	20	19	20	427	1194	1067	1336	741	897	816	794	774
206	8-9	120	5-9	12	31	-	18	116	11	8	12	12	15	17	16	19	709	5062	4856	4220	2558	2260	2793	1370	1938
207	8-9	120	6-1	6.5	26	-	22	121	13	8	9	11	9	15	12	16	-	1103	845	948	1283	1733	716	704	1164
208	8-0	118	5-3	7	21	-	18	127	13	13	11	11	17	17	18	20	603	2589	4416	2979	3353	2475	1671	1518	1454
209	10-0	125	6-8	10.5	7	-	25	125	8	7	9	12	13	18	20	20	354	953	1675	880	1538	916	1251	845	1077
210	9-0	131	5-10	12	10	-	13	117	12	8	8	15	12	20	18	17	460	1914	1376	1637	1135	1098	1282	1258	1030
211	10-0	135	5-3	9	28	-	16	121	10	6	10	11	8	13	17	20	783	1485	2514	2268	1457	1380	1342	1148	1432
212	10-6	135	6-2	139.5	0	-	28	146	7	10	11	17	20	20	19	18	260	1477	1187	1251	1157	935	798	721	724
Group: MA 8: Averge IQ																									
213	8-0	102	7-4	16.5	8	35	26	109	10	12	14	16	18	20	20	20	210	1616	1435	1618	846	890	712	627	816
214	8-0	100	8-0	27	10	0	18	91	6	7	10	9	15	14	17	19	604	1270	1953	2278	1996	2320	1684	1353	1266
215	7-6	100	7-6	21	10	10	20	99	10	13	15	19	20	20	20	20	117	2328	2189	1102	986	1012	917	839	811
216	8-6	102	8-0	13	10	0	24	103	9	12	14	13	15	20	20	20	288	1122	1176	629	1011	828	943	837	780
217	8-0	98	8-8	15	12	0	18	87	9	12	12	12	18	17	19	20	433	4223	2790	1307	2074	2553	1177	989	943
218	8-0	98	8-8	20	7	10	24	99	11	10	11	10	10	16	19	20	582	1932	2295	3206	1488	1589	1281	1202	1181
219	8-6	95	8-10	19	6	64	28	104	11	14	14	18	18	20	20	20	196	2871	2628	1979	937	882	808	714	715
220	7-6	95	8-4	7	18	0	28	91	9	15	11	14	16	16	16	19	857	2283	1154	1623	1296	1161	965	1476	1464
Group: MA 8; Below Average IQ																									
221	8-9	88	10-4	9	13	89	30	99	7	8	15	12	14	20	20	20	283	2285	1168	911	950	941	771	697	772
222	7-6	90	9-1	13	8	75	23	94	8	12	14	13	16	18	18	20	494	1971	1696	1411	1316	1174	1441	1039	1219
223	8-0	90	9-7	5.5	6	82	18	106	11	10	16	17	16	18	20	19	327	1142	1299	1407	1014	1068	1008	1021	1245
224	7-6	86	9-11	9	13	82	27	96	9	15	9	12	16	17	18	18	552	740	801	620	631	494	527	523	706
225	7-3	87	9-3	5	18	82	33	111	11	11	8	15	20	19	20	19	241	1753	1897	1551	1082	1094	1045	961	1344
226	8-0	70	11-11	10.5	12	-	21	77	11	13	8	10	17	18	17	20	591	1261	1934	1259	554	638	625	530	616
227	10-0	78	12-5	8.5	13	34	22	96	10	8	10	18	19	20	19	20	276	4567	2353	1192	779	644	659	657	653
228	7-0	86	9-1	18.5	9	10	13	99	9	8	10	13	13	20	18	17	435	1767	1709	1598	1215	1215	1274	1324	2088

Experiment 6 cont.

Subj. No.	Age (Yr-Mth)	IQ	CA (Yr-Mth)	MFFT Mean Latency	Total Errors	BAS Score	PMA Score	PMA PIQ	Number of Correct Trials (out of 20) Duration								IT$_{.975}$	Mean Correct Reaction Time Duration							
									5	25	50	100	150	250	400	2000		5	25	50	100	150	250	400	2000
Group: MA 11; Above Average IQ																									
229	12-0	128	8-1	14	6	35	29	112	13	10	11	13	10	18	17	20	719	1454	1025	815	897	1029	1146	956	811
230	11-0	122	8-1	8.5	8	10	32	115	12	10	15	16	20	20	20	19	167	1543	1252	1114	1002	919	869	966	843
231	11-0	122	7-10	8	19	0	19	93	8	9	13	12	17	19	20	19	285	2967	2565	3050	2344	2096	1807	2139	3386
232	11-0	122	8-0	11.5	8	10	37	121	12	10	16	17	19	19	20	20	233	4653	2436	1648	1831	1607	1761	1863	3812
233	12-0	128	8-0	25	3	35	23	101	7	16	13	13	20	19	20	20	243	2166	1226	1019	994	844	844	868	891
234	11-6	125	8-3	11.5	14	76	31	114	11	13	12	12	18	19	19	20	388	914	1104	722	674	707	653	580	655
235	12-0	125	8-4	14	9	35	27	104	10	13	13	12	18	19	20	20	296	6392	2833	1870	1808	1725	1113	931	1312
236	11-0	122	7-11	11.5	10	35	37	121	11	8	13	12	19	19	20	20	269	1645	1831	1546	1434	1407	1398	1369	1932
Group: MA 11; Average IQ																									
237	11-0	104	10-7	10	5	104	36	131	9	13	15	18	17	20	20	20	206	726	760	671	887	901	805	856	1005
238	10-6	107	9-9	8	13	104	32	132	10	9	13	19	18	20	18	20	361	1879	1943	1780	1249	1689	910	1104	1218
239	11-0	107	9-11	29	2	127	29	123	9	11	10	12	15	15	19	19	521	1357	1083	889	873	912	732	776	705
240	a	114	11-5	12	7	0	37	127	11	12	12	15	14	19	18	19	507	1099	901	833	768	697	671	595	604
241	a	114	10-9	8	8	104	36	131	8	14	18	20	20	20	20	20	68	1366	970	722	589	663	574	558	645
242	a	109	10-9	9	6	127	37	134	12	9	12	15	20	20	16	19	538	989	1604	812	1668	795	691	696	765
243	a	113	11-1	15.5	5	90	40	145	8	10	12	17	19	20	20	20	171	1016	982	794	700	700	673	681	723
244	a	110	10-3	9	7	116	25	118	9	4	9	15	17	19	20	20	257	1563	1047	1257	997	1072	1118	1196	2363
Group: MA 111 Below Average IQ																									
245	11-6	90	16-4	24	4	0	23	-	13	10	13	17	17	20	19	20	334	2992	1842	1757	1279	1251	1126	947	1048
246	11-6	90	20-5	19	6	164	32	-	14	9	12	14	18	20	20	20	248	1497	1036	1015	713	726	703	675	743
247	10-0	80	19-0	13	10	73	18	-	8	10	19	17	20	20	20	20	126	1293	501	437	442	432	439	490	554
248	9-6	78	19-0	12	4	73	39	-	12	9	15	17	18	19	20	19	252	1653	1373	658	560	562	570	650	685
249	11-0	88	19-0	27	7	0	14	-	8	8	8	20	15	19	20	20	258	3983	4390	661	1098	724	1211	870	867
250	12-0	92	17-1	11	11	0	34	-	9	9	10	17	20	19	20	20	209	848	868	873	818	654	616	709	722
251	10-6	85	17-0	32	3	73	27	-	11	10	10	18	20	17	17	19	533	1889	2258	2734	1210	759	729	779	833
252	11-0	88	20-2	15	9	127	19	-	9	9	18	16	19	20	19	20	281	825	691	544	513	490	444	469	455

[a] Selected using the Ravens Standard Progressive Matrices

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ERRATA

Page: 4	Line: 11	For "suppport" read "support"
6	8	For "Posner *et al.*, 1969" read "Posner, Boles, Eichelman and Taylor, 1969."
31	3	The word "be" was omitted. Sentence should read: "Thus, any developmental IT differences observed may reflect attentional variables and consideration will be given to this factor in subsequent chapters."
32	5	For "Nettelbeck, 1983" read "Nettelbeck, in press"
	7	For "Nettelbeck, 1984" read "Nettelbeck, in press"
60	Footnote (line 1)	Insert "(published 1982)". Footnote should read: "The British Ability Scale (published 1982), which is still in the process of being developed, consists of subtests . . . . "
68	Footnote (line 1)	For "MCSD" read "Method of Constant Stimulus Differences"
92	18	For "attentuation" read "attenuation"
190	25	The word "the" was omitted. The sentence should read: "Experiment 3 examined the possibility that the developmental IT trend observed in Experiment 2 . . ."
246		A reference was omitted. List should include: Hick, W. (1952) On the rate of gain of information. *Quarterly Journal of Experimental Psychology*, *4*, 11-26.