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THE RELATION BETWEEN SPEED OF VISUAL PERCEPTUAL PROCESSING
AND INTELLIGENCE IN NORMAL POPULATIONS

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Ph.D. 1986
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THE RELATION BETWEEN SPEED OF VISUAL PERCEPTUAL PROCESSING AND INTELLIGENCE IN NORMAL POPULATIONS

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

DOCTOR OF PHILOSOPHY

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April 1986
The Relation Between Speed of Visual Perceptual Processing and Intelligence in Normal Populations

Abstract

The idea that there is an association between speed of visual perceptual processing and general intelligence is intuitively appealing, but success in establishing the relationship empirically has been only partially successful. Although it has been shown that retardates and normals differ in the speed with which they can perform simple tasks requiring rapid visual perceptual processing, when the same tasks are used to assess processing speed in normal populations individual differences in processing speed are not related to scores on measures of intelligence. Researchers interested in the correlates of reading ability, however, have had consistent success in establishing a relationship between levels of reading ability and individual differences in speed of visual perceptual processing in normal populations when the perceptual processing tasks involved locating or identifying letters in briefly presented multi-element arrays. This suggests that although the tasks used by intelligence and reading researchers are superficially similar,
the processing demands of the tasks differ.

As intelligence and reading ability are substantially correlated in normal populations, it was hypothesized that the consistently reported correlation between reading ability and speed of visual perceptual processing is mediated by the relation between reading ability and intelligence. This study examined the relationship between performance on tasks requiring subjects to either locate or identify targets in briefly presented arrays and Raven's Standard Progressive Matrices scores and scores on the Nelson Denny Reading Comprehension and Speed Test in a group of typical high school students. Accuracy of performance on tasks which required subjects to report the location or identity of uncued targets in arrays correlated with Raven's scores but not with reading ability scores. This supports the hypothesis that correlations between reading ability and visual perceptual processing speed are mediated by individual differences in general intelligence. More importantly, performance as assessed by two measures which have been shown to suffer decrements when attentional load is increased accounted for significant proportions of variance in Raven's scores.
<table>
<thead>
<tr>
<th>Table of Contents</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Ch. 1. Reading Ability and Visual Perceptual Processing</td>
<td>4</td>
</tr>
<tr>
<td>Ch. 2. Speed of Visual Perceptual Processing and Measures of Intelligence</td>
<td>16</td>
</tr>
<tr>
<td>Ch. 3. Summary of the Literature Review and Conclusions</td>
<td>31</td>
</tr>
<tr>
<td>Ch. 4. Visual Perceptual Processing and Feature-Integration Theory</td>
<td>34</td>
</tr>
<tr>
<td>Method</td>
<td>48</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>59</td>
</tr>
<tr>
<td>Conclusions, Significance, and Implication</td>
<td>83</td>
</tr>
<tr>
<td>Appendix A. Means and Standard Deviations of Ability Test Scores by Sex.</td>
<td>90</td>
</tr>
<tr>
<td>Appendix B. Correlations Among Computerized Tasks and Paper and Pencil Measures.</td>
<td>91</td>
</tr>
<tr>
<td>Bibliography</td>
<td>92</td>
</tr>
</tbody>
</table>
List of Tables

Table 1. Means and Standard Deviations of the Nelson Denny Reading Test (Speed), the Nelson Denny Reading Test (Comprehension), and Raven's Standard Progressive Matrices Test. 59

Table 2. Correlations Among the Nelson Denny Reading Test (Speed), the Nelson Denny Reading Test (Comprehension), and Raven's Standard Progressive Matrices Test. 60

Table 3. Means and Standard Deviations of the Percent Correct Responses on the Computerized Mason Tasks and the Location Only Identification Task. 62

Table 4. Means and Standard Deviations of the Hit and False Alarm Rates for the Treisman Tasks. 63

Table 5. Correlations of the Computerized Mason Tasks and the Location Only Identification Task with the Nelson Denny Reading Test (Speed), the Nelson Denny Reading Test (Comprehension), and Raven's Standard Progressive Matrices. 71

Table 6. Correlations Between Hit and False Alarm Rates on the Treisman Tasks and the Nelson Denny Reading Test (Speed), the Nelson Denny Reading Test (Comprehension), and Raven's Standard Progressive Matrices. 73

Table 7. Correlations of the Location Only Identification Tasks and the Letter Location Identification Tasks with Hit and False Alarm Rates for the Treisman Conjunction and Similarity Tasks. 77
The Relation Between Individual Differences in Visual Perceptual Processing and Intelligence in Normal Populations

Introduction

Since Wilhelm Wundt established the first experimental psychology laboratory at the University of Leipzig in the late nineteenth century, psychologists interested in individual differences in intelligence have attempted to explain at least some of the difference in mental ability between individuals in terms of speed of perceptual processing. The idea that individual differences in performance on tasks which assess sensory threshold or speed of perceptual processing might be related to differences in the ability to perform the complex cognitive tasks which define intelligent behavior is intuitively appealing; however, early attempts by Galton and others to establish such a relationship empirically failed (MacIntosh, 1981). With the development of more pragmatic ways to assess intelligence, for example, Binet's intelligence test, investigators more or less abandoned this line of research.

Recently, researchers interested in both mental
retardation and reading disabilities have begun looking at this relationship again and several researchers have reported finding a positive relationship between performance on various tasks intended to assess perceptual processing ability and performance on both intelligence and reading tests (Badcock & Lovegrove, 1981; Brand, 1981; Clifton-Everest, 1976; Gilbert, 1959; Goyen & Lyle, 1973; Guummerman & Roberts, 1972; Irwin, 1984; Jackson & McClelland, 1975, 1979; Lyle & Goyen, 1968, 1975; Mason, 1980; Nettlebeck & Lally, 1976, 1977, 1979; Pennington & Luszcz, 1975; Spitz & Thor, 1968; Stanley, 1975; Thor, 1970; Vernon, 1983; Welsandt & Meyer, 1974; Welsandt, Zupnick, & Meyer, 1975). These studies provide considerable evidence of a correlation between individual differences in speed of perceptual processing and measures of intelligence or intelligent behavior such as reading. The evidence, however, is inconclusive concerning whether speed of visual perceptual processing and intelligence are correlated in populations of normal intelligence.

The basic measure of speed of visual perceptual processing used by researchers interested in reading ability and in the correlates of intelligence has been accuracy of response to stimuli which are presented very briefly, followed by a backward mask. A backward
mask is a stimulus which is presented to terminate the target stimulus to prevent subjects from continuing to process the stimulus material. Performance on these tasks has generally been accepted as a measure of the speed of sensory registration and processing of visual stimuli (Gilbert, 1959; Liss & Haith, 1970; Santee & Egeth, 1982; Welsandt et al., 1975; Wickens, 1974).

Although the focus of this dissertation is the relationship between visual-perceptual-processing speed and intelligence in normal populations, the extensive literature relating speed of visual perceptual processing to reading ability will be reviewed first as this research was chronologically earlier, is more extensive, and reports more orderly and convincing evidence that speed of visual perceptual processing is correlated with ability as reflected by intelligent behavior such as reading. This is followed by a review of the smaller, more narrowly focused body of literature which examines the relationship between speed of visual perceptual processing and intelligence, particularly in populations including retardates.
Chapter One

Reading Ability and Visual Perceptual Processing

Reading researchers have known for almost a century that fast readers make fewer eye fixations during reading than slow readers, but that the length of a single fixation is about the same regardless of reading ability. In an effort to determine how fast readers can read as well or better than slow readers with fewer fixations of the material, Gilbert (1959) studied the performance of sixty-four university students on a series of tasks in which stimuli were very briefly presented and then masked. In determining what tasks to include in his study, Gilbert reviewed the extensive literature which reported no differences between good and poor readers or fast and slow readers in accuracy of reporting briefly presented stimuli and concluded that unless a backward mask is used it is impossible to measure speed of perceptual processing.

To assess perceptual speed, Gilbert presented phrases of from one to five familiar simple words for durations of 82 to 250 ms, then masked them with strings of unrelated letters. Subjects were asked to recall as much of the material (letters, words, phrases) as possible. One
unmasked condition was also included, in which stimuli were exposed for 82 ms. The 16 fastest readers of the group reported significantly more letters, words, and entire phrases than the 16 slowest subjects. Moreover, the difference between the two groups increased as the exposure duration of the masked conditions was decreased.

Fast readers reported about 96% of the words when no backward mask was used whereas slow readers reported 83% of the words in that condition. By comparison, when a backward mask was used at the same exposure duration (82 ms), fast readers were still able to report 79% of the words but slow readers could then report only 40%. The fact that slow readers are penalized more than fast readers by the backward mask at short exposure durations indicates that slow readers process visual information less efficiently than fast readers.

Correlations between the percentage of words reported and reading ability in the entire group were significant at the four briefest exposure durations whereas the correlation of reading ability with percentage of words presented in the unmasked condition was not. Thus, when all readers have sufficient time to process visual stimuli, their ability to recall what they have seen does not appear related to their reading level.
A series of studies by Lyle and Goyen (1968, 1975; Goyen & Lyle, 1973) used a brief exposure paradigm to investigate differences in the visual perceptual processing abilities of retarded and adequate readers. The subjects in these studies were all primary school children of normal intelligence.

In the first of these studies (Lyle & Goyen, 1968), the researchers tested 20 second and 20 third graders, of which half were retarded readers and the other half were reading at grade level. The authors wanted to determine whether either age or reading ability correlated with efficiency at recognizing briefly presented stimuli.

In this study, multichoice response cards presented at the end of each brief exposure served as masks. Three stimulus types were used: confusable letters, simple line forms, and two dimensional line drawings. Stimuli were exposed for 100 ms. Adequate readers identified more stimuli than retarded readers and third graders outperformed second graders. Moreover, the difference between retarded and adequate readers was greater in the younger group. Further analyses, however, indicated that whereas the difference between poor and adequate readers for the two sets of drawing stimuli decreased with age, this was not true for confusable letters. The
largest difference between retarded and adequate readers occurred when confusable letters were the stimuli and for this condition there was no age by reading ability interaction. This means that whereas retarded readers improve in their ability to recognize shapes relative to their normal peers as they get older, they do not demonstrate a comparable improvement in their ability to identify confusable letters.

In a subsequent study the same investigators (Goyen & Lyle, 1973) used a similar task with seven year old adequate and retarded readers. The stimuli were complex geometric shapes that represented the outlines of words in lower case letters. Stimuli were exposed for 500 ms then terminated by the presentation of a second form card. The required response was to indicate whether the two forms were identical. Adequate readers again outperformed retarded readers on this visual perceptual task.

Lyle and Goyen (1975) tested 36 adequate and 36 retarded 6.5 to 7.5 year old children for visual perceptual differences using the same geometric forms described above. Exposure durations were 10 ms, 1 second and 5 seconds. As in the 1968 study, a multichoice response card was presented to terminate the exposure of the target stimulus. Adequate readers were significantly better than retarded readers at
recognizing the stimulus at both the 10 ms and 1 second exposure durations, but the performance of the two groups did not differ when the exposure duration was 5 seconds.

This again demonstrates that good readers are able to process visual stimuli faster than poor readers. The fact that retarded readers were not worse than adequate readers at recognizing the shapes when exposure duration was 5 seconds rules out the possibility that the shapes may have been simply harder for retarded readers to remember or recall.

The results of this series of studies indicate that retarded readers are characterized by slowness of input or processing of visual information or by poorer ability to analyze distinctive features of stimuli or their interrelationships (Lyle & Goyen, 1975). Retarded readers clearly take longer to process visual stimuli than adequate readers for a variety of stimuli including complex geometric shapes and confusable letters.

A study by Jackson and McClelland (1975) also offers support for the hypothesis that faster readers encode more information during a single brief exposure than average readers. Their subjects were 12 university students, six fast and six average readers. These
investigators hoped to discover why fast readers can report more words after seeing a briefly exposed phrase than average readers, as reported by Gilbert (1959). Jackson and Mcclelland hypothesized that the difference between faster and slower readers might be due to the superiority of faster readers in (a) the temporal resolution of the visual system, (b) extracting information from the peripheral visual areas, (c) apprehending units from the information available after brief exposures, (d) the use of the knowledge of linguistic structure to form a representation of the contents of the briefly exposed phrase, or (e) some combination of these factors.

Reading ability was assessed by a reading test that evaluated reading speed and comprehension. In the perceptual processing task all stimuli were presented for 200 ms, with the exception of a single letter threshold determination task. Forward and backward masks were used in all tasks.

Single-letter-identification threshold was determined to assess the temporal resolution of the visual system. No difference was found between the two groups on this measure.

To assess whether fast readers can extract more information from the peripheral visual area than slower readers, pairs of letters
separated by increasing numbers of spaces were presented and subjects were asked to name the letters and indicate their positions. Again, there was no difference in the two groups' ability to perform.

To determine if fast readers are able to apprehend more units from the information available after a brief exposure, strings of eight letters were presented. Fast readers were able to report significantly more letters than average readers.

To discover whether fast readers use a superior knowledge of linguistic structure on the sensory information available after a brief exposure to form a representation of the stimulus, a forced choice task similar to the one devised by Reichel (1968) was used. In this task subjects saw a briefly exposed sentence such as "Sally wore a plaid scarf" and were asked to indicate in a multiple choice test such as "Sally wore a plaid/plain scarf" which word they had seen. Jackson and McClelland hypothesized that if faster readers actually process the information in the stimulus phrase faster than average readers they should perform better on this task, but if they normally perform better because they use their superior knowledge of linguistic structure to make better "guesses," then they would not be able to outperform average readers on this task. In fact, they did substantially outperform
the average readers indicating that they actually processed more of the information in the display than the average readers.

Jackson and McClelland concluded from these findings that faster readers do not have superior sensory processing capabilities since their single-letter-threshold was the same as the group of average readers and they did not outperform the average readers on the separated letter task. Rather, they are more efficient processors of the contents of the sensory store. This results in their being able to encode more elements and/or integrate these elements into an organized conceptual representation more efficiently.

A later study by Jackson and McClelland (1979) also included a measure of single-letter-identification threshold and a separated letter task. In this experiment, however, the letters were embedded in arrays of "&s". Although thresholds for these tasks were longer than those in the 1975 study, there was again no significant difference in the thresholds of fast and average readers. This means that the difference in the reading ability of fast and average readers is not due to the greater susceptibility of average readers to lateral masking effects.

The results of this pair of studies support the position that differences in reading speed are related to some general speed of
processing visual information beyond the sensory level and not to processes of retinal stimulation (quality or size of the iconic store).

Mason (1980) used the Nelson-Denny Reading Test to select sixteen highly skilled (90-99th percentile) readers and sixteen less skilled readers (11-40th percentile) from a group of college students who had all been above average performers in high school. Using the non-confusable letters B, C, M, and T, she measured accuracy of report after brief exposure of a single letter with a backward mask. In a second condition, the letters were embedded in a four element array in which the distractors were $\$s$. In this condition, subjects were asked to say where in the array the letter had appeared. There was no difference between highly skilled and less skilled readers in reporting the name in the single-letter-presentation condition; however, highly skilled readers were much more accurate at reporting the location of a letter in an array of letter-like distractors.

In a second experiment, accuracy of report for briefly-presented stimuli was assessed for single letters embedded in an array of $\$s$. In one condition, an arrow which appeared with the premask for 500 ms cued the subject to the location of the letter. In another condition, no precue was used. When the location precue was present, the two
groups were indistinguishable in their ability to identify the letter. When no location cue was used, however, highly skilled readers substantially outperformed less skilled readers. This difference led Mason to conclude that although both groups were equally proficient at encoding item information (in this case presumably the unique characteristic which defined each of the non-confusable letters B, C, M, and T), highly skilled readers were superior at encoding location information. This conclusion would have been more convincing if Mason had included a task in which only the encoding of location information was required. The results of Mason's study do not rule out the possibility that both groups encoded item and location information equally well but that the highly skilled readers were simply faster at encoding both item and location information when there were four stimuli to be processed as compared to one, at scanning locations, at combining item and location information, or at some combination of these.

Given the findings reported above, it is clear that in a variety of populations and for a variety of tasks, speed of visual perceptual processing is related to reading ability. In our society, the ability to read rapidly and accurately is a crucial aspect of intelligent behavior
(Cooper & Regan, 1982). Although reading ability and intelligence are not synonymous, in the general population, better readers have higher mean intelligence scores than poorer readers (Matarazzo, 1972). On this basis, it seems reasonable to hypothesize that if a measure of intelligence were included as a covariate in studies which assess the correlation between speed of visual perceptual processing and reading ability, a significant portion of the variance common to reading ability and speed of perceptual processing might be accounted for by the relationship between speed of perceptual processing and intelligence.

Why then did early researchers fail to establish a relationship between speed of perceptual processing and intelligence? Jensen (1979) argued that methodological and measurement problems prevented earlier researchers from demonstrating the relationship. Recent researchers, however, have not been hampered by the same limitations yet they have had very mixed success in establishing the relationship. Indeed, two recent reviews of the evidence (Irwin, 1984; Nettlebeck & Kirby, 1983) concluded that if the relationship exists, it is not substantial enough to be very useful. It is hard to reconcile these conclusions and the findings of reading researchers. A review of the research aimed at uncovering the association between speed of visual
perceptual processing and intelligence measures reveals some
differences in methodology which may help explain this apparent
paradox, and it is these differences that this review next addresses.
Chapter Two

Speed of Visual Perceptual Processing and Measures of Intelligence

Summarizing the evidence to this point, studies of reading ability provide consistent evidence of a positive correlation between individual differences in the speed with which letters, words, and shapes can be processed and individual differences in reading ability. Results of studies conducted to determine if individual differences in speed of visual perceptual processing are related to individual differences in measures of intelligence are, however, much less consistent. Researchers have reported correlations between scores on a variety of intelligence tests and measures of perceptual speed ranging from virtually zero (Vernon, 1983) to -0.92 (Nettlebeck & Lally, 1976). Many of the studies in which substantial correlations are reported are open to methodological criticisms (Irwin, 1984) and the majority of those which appear methodologically sound have failed to find a correlation in normal populations.

The focus of such research has been narrow, with most of the early work aimed at identifying differences between retarded and normal subjects in the ability to process briefly presented visual
stimuli with backward masks. Spitz and Thor (1968), for example, found a significant difference in the identification thresholds of normals and retardates for single letters when they were asked to report whether the briefly presented letter was an O or a D. Welsandt and Meyer (1974) employed a larger stimulus set (EHKX) and their subjects included normal and retarded adolescents and younger children. They found that normal adolescents were significantly better than retarded adolescents but that 9-10 year old normals were no better than adolescent retardates. They concluded that both age and intelligence are related to efficient processing of the iconic store when retardates and normals are included. Both Welsandt and Meyer and Spitz and Thor, however, describe a study by Pollock in which 7-10 year old normal children were tested with similar simple stimuli. In that group of normal children, no correlation between intelligence test scores and letter identification threshold was found.

Pennington and Luszcz (1975) compared college students and mildly retarded young adults and found that in adult samples including retardates and normals there is a relationship between ability to process rapidly presented visual stimuli and measures of intelligence. Retardates consistently reported fewer letters from
briefly presented arrays than normal subjects, regardless of array size or exposure duration.

Taken as a whole, these and other similar studies indicate that even at the earliest and most basic levels of visual perceptual processing there are differences between retardates and normals. Whether there is a correlation between speed of visual perceptual processing and intelligence in normal populations is less clear.

Nettlebeck (1973) failed to find a correlation between exposure threshold for a simple discrimination task and measures of intelligence in a group of university undergraduates. The procedure he used, which was developed by Vickers, Nettlebeck, and Willson (1972), has since been used extensively and modified by researchers interested in the correlates of intelligence. The task assesses the exposure duration needed by individuals to achieve 97.5% accuracy when making a line length discrimination. This exposure duration, labeled "Inspection Time" or IT, is thought to provide "an estimate of the rate at which some hypothetical sampling mechanism conveys information from preliminary storage to subsequent processing" (Nettlebeck & Kirby, 1983, p. 41).

The stimulus in this task consists of a figure with two vertical
limbs 24 and 34 mm long, a difference in lengths which subtends a visual angle of 1.6 degrees. Although accuracy is stressed, subjects are asked to indicate as rapidly as possible which limb is shorter. A trial begins with a spot of light appearing in the area where the difference will be seen. The stimulus is briefly presented and immediately masked for five seconds by a figure identical to the stimulus except that both limbs are 44 mm long. Exposure durations are varied randomly from 10 to 130 seconds in 10 ms increments. Using this procedure on a group of university students, Vickers et al. determined that the Inspection Time for most normal college students ranged from 70 to 130 msec with a mean of 100 ms.

Nettlebeck and Lally (1976) used this paradigm to test the idea that individual differences in intellectual ability might be partly attributable to speed of mental input or perceptual processing. They chose ten male subjects from a vocational rehabilitation center whose WAIS Full Scale intelligence measures ranged from 47 to 119. Subjects' Inspection Times were assessed on two different days; test-retest reliability was .96.

The Spearman Rank Order correlation coefficient between scores on the WAIS Performance Scale (PIQ) and IT was -.92 for day
one and -.89 for day two, and similarly high between IT and all of the subtests which make up the WAIS Performance Scale. No correlations were reported with WAIS Full Scale or WAIS Verbal Scale intelligence measures. Subjects with lower PIQs needed substantially longer exposure times to reach the 97.5% accuracy level than those with higher PIQs. Nettlebeck and Lally cautioned that these correlations probably overestimate the correlations in the general population due to the size and characteristics of the experimental sample.

Lally and Nettlebeck (1977) subsequently extended this research to a larger group. Subjects were forty-eight 17-24 year old men: sixteen each of below average (WAIS PIQs of 57-81), average (PIQs of 90-115), and above average (PIQs of 116-130) ability. In addition to assessing ITs by the procedure described above, they also assessed rate of information processing using a series of choice reaction time tasks with 2, 4, 6, and 8 choices. They defined rate of information processing (R) as the reciprocal of the slope of the regression line where reaction time is regressed on bits of information in choice reaction time tasks. The correlation between R and IT, which are both hypothesized to assess speed of information processing, was -.63.
IT correlated with WAIS PIQ -.80 in the whole sample and - .45 in the below average sample, but did not correlate significantly with PIQ in the average and above average groups. R correlated with WAIS PIQ .74 in the whole sample and .59 in the below average group. As with IT, R did not correlate significantly with PIQ in the other two groups.

The average and above average groups did not differ significantly in mean IT (approximately 100 msec in both groups) or R (approximately 5.65 bits/second in both groups), but both of these groups differed significantly from the below average group on both IT and R (207 msec and 3.7 bits/second respectively in the below average group). These data provide strong evidence that persons with below average WAIS PIQs need more time to accumulate and process incoming information than persons of average or high WAIS PIQs. Speed of perceptual processing as measured by simple tasks such as those employed in the assessment of IT and R does not appear to be related to intelligence as measured by WAIS PIQ in populations of average or above average ability.

In a subsequent study, Nettiebeck and Lally (1979) included children as well as retarded and normal adults. Subjects were
twenty-eight 7-10 year old normally intelligent school children, ten
17-23 year old university students, and ten 17-23 year old retarded
males with WAIS PIQs of 51-77. In the children's group IT did not
change as a function of age and in fact differed very little from that of
normal adults. Mean IT for children was 141 msec and for normal
adults 130 msec. The retarded adults differed from both other groups
with a mean IT of 256 msec. Although Nettlebeck and Lally (1979)
found that IT discriminated between normal and retarded subjects,
Nettlebeck, Cheshire and Lally (1979) found no significant correlation
between IT and PIQ within a group of mildly retarded and below
average (PIQs 60-95) subjects from a vocational rehabilitation center.

The series of studies done by Nettlebeck and Lally and their
colleagues at the University of Adelaide provides strong evidence that
there are important differences between subjects of normal intelligence
and retardates in perceptual processing speed. Further, it provides
evidence that individual differences in perceptual processing speed as
measured by this simple discrimination task are related to intellectual
ability in groups of below average intelligence but not in groups of
average or above average intelligence. These conclusions are generally
consistent with other research, although Jensen (1982) mentions finding
a correlation of -.31 between IT and Ravens Progressive Matrices Test scores in a group of university students who scored in the upper 25th percentile on national Raven's norms.

A series of studies conducted by Brand (1981) and his students at the Universities of Edinburgh and Dublin investigated the relationship of IT and intelligence using the general IT procedure developed by Vickers et al. with some modifications. They also used measures of intelligence other than WAIS PIQs.

In the first of these studies, IT was assessed for thirteen 16-26 year-olds who had Cattell Culture Fair Test or Stanford-Binet Intelligence Test scores of 44 to 133, essentially replicating Nettlebeck and Lally's (1976) design in a younger group. Brand reports a correlation of -.88 between IT and intelligence test scores in the whole group. When subjects were divided into upper and lower halves based on Cattell and Stanford-Binet test scores, the correlation between IT and intelligence in the lower group (intelligence test scores ranging from 69-97) was -.98! In the upper group, a correlation of -.41 was found, which was not statistically significant. According to Brand, the correlations in the two groups differed significantly which supports the hypothesis that IT is related to intelligence only in populations where
intelligence is below average, and that within that group lower intelligence is associated with slower perceptual processing.

When the IT stimulus was modified to have three and four limbs, correlations between IT and Cattell or Stanford-Binet scores fell to -.78 and -.66 (three and four limbs respectively). This led Brand to conclude that the advantage of subjects with greater intelligence on Inspection Time tasks is in perceptual or attentional processes rather than in processes such as decision making or multiple comparison.

In a second study, twelve four-year olds were tested with a modified IT procedure which involved different colors in the two limbs of the IT stimulus. These children had approximate Raven's scores of 95-123. IT's were assessed over a period of several days and ranged from 200-600 msec, substantially longer than those of the seven-year olds tested by Nettlebeck and Lally (1979). In these four-year olds, IT and Raven's scores correlated -.78 and the correlations between IT and Raven's did not differ in the upper and lower halves of the group. These results indicate that IT is related to mental ability (mental age), but it appears that once a certain proficiency is achieved, IT no longer differentiates between levels of ability. A study by Liss and Haith (1970) supports this view.
In the Liss and Haith study, subjects were eight four-to-five-year olds, eight nine-to-ten-year olds, and eight adults. Duration thresholds were assessed for a simple task (determining if a bar is horizontal or vertical) and a more complex task (determining where in a 3 X 3 matrix a single bar of a different orientation appears). Stimuli were presented for 20 msec with varying interstimulus intervals before onset of the backward mask. Recognition threshold was defined as the time from stimulus onset to post-mask at which subjects achieved 60% accuracy. Thresholds for the simple task were 41, 28, and 17 ms for the four-to-five-year olds, the nine-to-ten-year olds, and the adults, respectively.

Thresholds for the complex task were 89, 28, and 18 ms in the same order. The complex task was not more difficult for the older groups, but was considerably more difficult for the younger children. Compared to an unmasked condition, younger children were also penalized more by a backward mask. As in the prior study reported by Brand, the Liss and Haith results suggest that speed of perceptual processing for simple discrimination tasks is associated with mental age at lower levels of intellectual functioning but that once a certain level of proficiency is reached, speed of visual perceptual processing for simple
discrimination tasks no longer discriminates among levels of intellectual functioning.

A third study reported by Brand assessed exposure durations needed for recognition of briefly presented five letter animal names. Subjects were eighteen normally intelligent eleven- and twelve-year olds. When recognition thresholds and verbal intelligence scores were ranked and the ranks compared, the correlation was .54. When upper and lower halves were examined, the correlation between recognition threshold and verbal intelligence was .81 in the lower group. In the upper ability half, the correlation between IT and Raven's ranks was .31 which was not significant. When recognition thresholds for pictures were assessed, no significant correlation was found between picture recognition threshold and a either a measure of spatial ability (Thurstone's Primary Mental Abilities Test) or verbal intelligence scores.

Thus, word recognition thresholds but not picture recognition thresholds correlated with measures of verbal intelligence in this sample of normally intelligent older children. As earlier studies have revealed that recognition threshold for single letters is not correlated with intelligence test scores in normal populations, it appears that word
recognition involves perceptual processing abilities which are not
tapped by simple stimuli including single letters, simple line drawings,
and the IT stimulus, but which are related to ability measures in groups
of normal intellectual ability.

In a final study reported by Brand, the relationships between IT
as measured by the original Vickers et al. procedure and spatial ability
(Minnesota Paper Form Boards), intelligence (Cattell Culture Fair Test),
and Vocabulary (Mill Hill Vocabulary Test) were assessed for ten
16-to-24-year olds whose Cattell scores ranged from 85-122. The
correlation between IT and Cattell scores was .61 (reported as .61,
probably -.61) which was not significant. In a group composed of the
five subjects with the lowest Cattell scores (85-105), however, the
correlation was -.98. Spatial ability and IT did not correlate
significantly (r=.11), but vocabulary correlated with IT .88 (again,
probably -.88).

The series of studies reported by Brand provides evidence of a
relationship between speed of perceptual processing and intellectual
ability in normal populations. Unfortunately, the data were generated
from small and often unusually heterogeneous samples.

More recently, Nettlebeck (1982) assessed IT in a group of 45
university students by requiring subjects to determine whether a light
in any one of eight locations immediately adjacent to a vertical line
(four on either side) had appeared on the left or right of the line. He
reported a correlation of -.34 between this IT and a test of verbal
reasoning and a correlation of -.20 (not significant) between IT and
scores on Raven's Advanced Progressive Matrices Test.

Using the light procedure described in the previous paragraph
Nettlebeck and Kirby (1983) subsequently assessed IT for 182 adult
subjects, either university students, apprentices in a trades course, or
employees at a training center for the handicapped. This visual IT
measure correlated -.48 with intelligence as assessed by Raven's
Advanced Progressive Matrices Test (university students), the Standard
Progressive Matrices (apprentices), and WAIS Full Scale scores
(handicapped) in the entire sample of 182, and -.50 in a normally
distributed reduced sample of 91 subjects. The correlation fell to -.31
when only the 141 apprentices and university students were included,
to a non-significant -.20 when only university students n=59) were
examined, and to -.22 in the apprentice sample (n=82). Vernon (1983)
also reported no significant correlations between IT as assessed by the
original Vickers et al. procedure and either WAIS or Raven's scores in
two groups of 50 and 40 university students.

Rate of information processing was assessed by Nettlebeck (1983) using the slope of reaction time regressed on number of bits of information in choice reaction time tasks; however, the procedure was modified from that used earlier by Nettlebeck and Lally (1977) to correspond to reaction time measures defined by Jenson and Munro (1979) as decision time (DT) and movement time (MT). Slope DT (calculated from the time subjects needed to apprehend the target stimulus, decide where it appeared, and release the home button for 2, 4, 6, and 8 choice RT tasks) showed a pattern of correlations with intelligence test scores similar to that described above for IT. In the normally distributed and reduced sample DTs for the 2, 4, and 8 choice tasks correlated -.68, -.66, and -.73, respectively, with intelligence test scores. In a reduced sample which excluded subjects with intelligence test scores below 85, however, the correlations dropped to -.23, -.18, and -.24 between DTs on the 2, 4, and 8 choice tasks and intelligence test scores. No correlation is reported between IT and Slope DT, both of which Nettlebeck considers to be measures of the "rate of some kind of information processing" (Nettlebeck, 1983, p. 49).

Irwin (1984) found a correlation of -.34 between visual
inspection time scores and Raven's scores in a group of 50 normally intelligent eleven to thirteen year olds. The correlation between his IT and Mill Hill Vocabulary scores was not significant, however. Irwin's inspection time stimuli were the letters "o" and a "u umlaut" which was identical to the "o" except that its top "contained a gap to represent the diacritical mark" (Irwin, 1984, p. 53). The two stimuli were presented side by side on each trial and subjects were required to decide on which side the "o" appeared.

Both Nettlebeck and Kirby (1983) and Irwin (1984) conclude that the relationship between intelligence and typical measures of IT is weak in normal populations (although Nettlebeck and Kirby estimate that about 25% of the variance in intelligence in normal populations can be explained by a combination of rate of perceptual processing measures!). Brand's studies, while methodologically questionable, report a stronger relationship in normal populations when different stimuli are used to assess IT. Although the data do not provide unequivocal evidence that a relationship between speed of visual perceptual processing and intelligence exists, the data suggest that there are tasks for which speed of visual perceptual processing is related to intelligence in normal adult populations.
Chapter Three

Summary of the Literature Review and Conclusions

Based on the available research, what can be concluded about the relationship between individual differences in speed of visual perceptual processing and individual differences in intellectual functioning? Consistent findings of a correlation between reading ability and speed of visual perceptual processing provide evidence that individual differences in the speed with which visual stimuli are perceived are positively correlated with individual differences in performance on intellectually demanding tasks such as reading. While reading ability and intelligence are not synonymous, reading test scores and intelligence test scores are substantially correlated in the general population. The Wechsler intelligence tests for children (WISC) and adults (WAIS), like most widely used intelligence tests, include a Vocabulary Subtest which is the best single subtest at predicting both Verbal and Full Scales IQs (Matarazzo, 1972). Tests of reading ability also assess vocabulary knowledge, either directly or indirectly, as part of the reading ability score. As vocabulary knowledge is an important part of both intelligence tests and reading ability tests, these two ability
measures clearly overlap. Thus, it is not unlikely that perceptual processing skills are correlated with reading ability because both are correlated with intelligence.

Studies which compare retardates to normals provide convincing evidence that there are substantial differences in the perceptual processing rates of these two groups. In normal adult populations, however, the data suggest that speed of visual perceptual processing as assessed by simple discrimination tasks such as the Vickers et al. (1972) Inspection Time (IT) task or single letter threshold is not related to intelligence. The perceptual processing demanded by such tasks appears to be too simple to discriminate between levels of intelligence in normal populations. With very few exceptions (i.e. Jenson, 1982; Lally and Nettlebeck, 1977, as reanalysed by Nettlebeck & Kirby, 1983) studies which report correlations between speed of perceptual processing and intelligence test scores used tasks with more complex perceptual processing requirements than the IT task to assess speed of perceptual processing. Similarly, single letter threshold does not correlate with reading ability but performance on a variety of other tasks involving more complex visual stimuli does. In general, these other tasks involve the rapid processing of multiple stimuli, usually
letters.

What are good readers and more intelligent people able to do more efficiently when performing such tasks? The feature-integration theory of attention proposed by Treisman and Gelade (1980) provides a framework within which to systematically examine this question.
Chapter Four

Visual Perceptual Processing and Feature-Integration Theory

Feature-integration Theory (Treisman & Gelade, 1980) assumes that there are a number of functionally independent perceptual subsystems which are sensitive to different dimensions of visual stimuli such as color, orientation, spatial location, etc. Particular values on these dimensions are the features of a stimulus.

According to feature-integration theory, feature encoding comes first in perceptual processing. It proceeds automatically and in parallel and there are no capacity limitations except physiological ones. Encoded features are spatially free floating and can be identified independently of other features of a stimulus, including location. Thus we can detect "redness" as a feature without necessarily knowing where it appears or to which specific stimulus item it belongs.

Although feature encoding occurs in parallel and is effortless, the conjoining of the separately encoded features of a stimulus into a unitary representation requires focusing attention on the relevant location in the display and proceeds serially across locations. This requires both time and effort.
Thus feature-integration theory proposes that the perception of a target stimulus in a visual display can require different degrees of effort or attention. Detection or identification difficulty depends upon how distinctive the target's identifying features are and whether it can be defined in terms of a single unique feature or must be defined in terms of a conjunction of features which it shares with other items in the display. Thus the detection of single features (or targets defined by single features) should take place in parallel and require little effort; the detection of stimuli defined by conjunctions of features which the target shares with other items in the display, on the other hand, requires attention to be focused serially on restricted areas within the display in order for features to be conjoined and registered in consciousness as a unitary percept. A further level of difficulty in the perceptual processing of a stimulus arises when the separately encoded features of non-target items are interchangeable, giving rise to the possibility that features which have been separately encoded might be erroneously conjoined so that the subject perceives a target which was not present - an "illusory conjunction." According to Treisman and Gelade, such "illusory conjunctions" can only be perceived within contextual constraints so a blue sun is never seen in a yellow sky. It is
also improbable that an experienced reader would erroneously conjoin
the slanted line from a Z with the curved portion of a J to perceive a
strange non-letter when reading text. It is possible, however, that even
a practiced reader might combine a P with the tail from a Q to form an
"illusory R." Treisman and Gelade stress that unattended features will
also be conjoined within contextual constraints but that features in
unattended areas can not cross over to conjoin with features in the
attended area. To avoid "illusory conjunctions," then, attention must be
focused narrowly enough that no interchangeable features are present
within a single fixation area. In some instances, this might mean
focusing serially on each item in the display.

Feature-integration theory therefore defines levels of perceptual
processing demand which have nothing to do with the discriminability
of the stimulus features. These levels of processing demand depend
upon whether attention must be focused for identification, and if so,
how narrowly.

Following feature-integration theory, typical visual perceptual
speed tasks can be arranged in the following hierarchy based on the
time and effort demands they make on the perceiver:

1. detecting or identifying a stimulus defined by a single
feature in an array in which the target is not confusable
with the distractors (knowing whether an X was present in
an array of Os).

2. saying where in an array a stimulus defined by a single
feature appeared (knowing the exact location of an X
appearing among Os).

3. detecting or identifying a target defined by a single
feature when target and distractors are confusable
(knowing whether an R appeared in an array of Ps and Bs).

4. detecting, identifying, or saying the location of a target
defined by a conjunction of features where features of
distractors are interchangeable such that an "illusory
target" may be perceived (knowing whether or where an R
appeared in an array of Ps and Qs).

According to feature-integration theory, increasing the number of items
in the display should not increase the processing demands of tasks at
levels one and two since features are detected in parallel and guide the
focusing of attention which is required to conjoin location to other
features as required by tasks at level two. For tasks at levels three and
four, however, increasing the display size will necessitate more fixations
of attention, or location scanning, thus increasing time and effort
demands on the subject.

If the tasks researchers interested in the correlates of intelligence
have used to assess speed of perceptual processing are considered in
terms of the demand levels hypothesized by feature-integration theory,
it is apparent that in general they require only that a non-confusable
feature be identified or located (for example the Vickers et al. IT task)
and no correlation is found between speed of processing as measured
by these tasks and intelligence test scores in normal adult populations.
When correct responding requires additional processing, significant
though not exceptionally large correlations between efficiency on these
tasks and intelligence test scores are reported (e.g. Brand, 1981; Irwin,
1984). Similarly, performance on tasks which require processing
beyond simple feature detection are consistently found to be related to
differences in reading ability even in normal populations, whereas those
which make few demands (i.e. single letter threshold for a small set of
non-confusable letters) do not discriminate among levels of reading
ability.

To summarize, the typical tasks used by intelligence researchers
to assess individual differences in speed of perceptual processing have
not assessed individual differences in detecting targets in arrays where targets and distractors have confusable features or targets which share interchangeable features with distractors allowing for the perception of "illusory conjunctions". These tasks have instead assessed individual differences in single feature encoding efficiency which appears to have a curvilinear relationship to intelligence—once this skill is developed to a basic level of proficiency, individual differences in this ability are not correlated with scores on intelligence tests.

One additional consideration which is not directly addressed by Treisman and Gelade, is the fact that in every multi-item visual display all stimuli are "confusable" on one dimension—location. Differences in location in a linear array are not particularly discriminable; in fact, asking subjects to say where in such an array one letter appeared, even if the letter is defined by a unique feature, might be compared to a task requiring subjects to name the color of a target stimulus in which all elements in a linear array are shades of red, ranging from light pink through bright scarlet. Whereas the colors of stimuli which are far apart would be easily discriminable, the colors of those near each other would be very confusable. It is possible therefore, that for location identification tasks, increasing the density of items in an array may
indeed place more demands on subjects even when they are simply asked to name the location of a target defined by a unique feature. An "illusory conjunction" between the distinctive feature of the target and the location of a nearby distractor could occur causing the subject to erroneously perceive the target to be in that location. Avoiding this would require focusing attention which takes both time and effort.

A study by Butler (1981) provides evidence to support the hypothesis that performance on letter location identification tasks like the one used by Mason (1980) requires subjects to conjoin item and location features rather than simply to encode location information. Butler presented subjects with 3 X 3 matrices of letters and used the backward mask to indicate which letter to report. In some conditions subjects were given location precues which indicated where in the display the target letter would appear. Butler found, as has Mason, that providing location precues greatly enhanced performance; mislocation, but not intrusion, errors were greatly reduced. Mislocation errors occur when a letter from another location is reported as being in the target location. This kind of error can be thought of as a kind of "illusory conjunction" in which the location of one letter is conjoined to the features of another letter. To reduce the likelihood of this happening,
attention must be more narrowly focused. A location precue allows subjects to focus attention on a specific location without danger of missing the target during the brief exposure duration.

Treisman and Gelade propose that some stimuli may not be identified automatically, as only features are automatically encoded. In feature-integration theory all features are automatically encoded. If spatial location is a feature of the stimulus, feature-integration theory would predict that it would be encoded concurrently with all other features. In order to know the location of a target, even one defined by a single unshared feature, attention would have to be narrowed enough that the location feature and the identifying feature(s) of the target could be correctly conjoined. In the case of a target defined by a conjunction of features which it shares with other elements in the display, identification or detection of the target depends upon the correct conjoining of the features of that target, which also requires focusing attention. When attention is directed to the relevant location, all features of the stimulus, including its location, become known. This means that subjects should know the location of any conjunction target they can identify, which Butler's analyses supported.

In contrast to Treisman and Gelade, Butler proposes that all
stimuli (not just features) are automatically encoded, but that they cannot be reported until their location is known, which requires focusing attention in a process he calls localization. Localizing a stimulus implies narrowing attention to a relevant location.

Both Treisman and Butler predict that when targets are conjunctions, identification means that the location of the target will be known. Treisman and Gelade showed, however, that targets which are defined by single features may be identified even when their location is not known. Thus, all of Butler's findings can be predicted by feature-integration theory, but not all of Treisman and Gelade's findings can be explained in terms of Butler's localization theory. This difference supports the prediction of feature-integration theory that features rather than stimuli are automatically encoded and that spatial location may or may not be correctly conjoined to the other features of a stimulus. Further, it appears that the differences in performance which arise as a function of location pre-cueing are related to the possibility of "illusory conjunctions" which result in mislocation errors. When "illusory conjunctions" are possible, attention has to be narrowed to a smaller area, but narrowing attention may prevent a target feature from being correctly conjoined to its location if it is located in the
unattended area. Thus, location precueing allows the subject to narrow attention to the relevant location so that all the features of the target, including its location, are correctly conjoined.

Data recently collected by Kleiss and Lane (1986) support the hypothesis that detecting Rs in briefly presented arrays of Ps and Qs makes different perceptual processing demands than detecting Rs in Ps and Bs as hypothesized by feature-integration theory. Earlier research (Duncan, 1980; Shiffrin & Gardner, 1972), based on a simultaneous/ successive presentation paradigm, has suggested that all stimuli are processed in parallel without capacity limitations, even stimuli that permit the possibility of conjunction errors.

Kleiss and Lane employed the simultaneous/successive presentation paradigm with the Treisman and Gelade similarity (RPB) and conjunction (RPQ) stimuli to test the generalizability of Shiffrin and Gardner's and Duncan's conclusions and to identify the locus of capacity limitations in the processing of visual arrays. In the simultaneous presentation condition, four stimuli are presented at once whereas in the successive presentation condition pairs of stimuli are presented sequentially. Subjects have the same amount of time to process each stimulus element, but the number of stimuli which must be processed
at one time is doubled in the simultaneous presentation condition, thus
doubling the divided attention load. Kleiss and Lane found that when
divided attention load was increased for the Treisman and Gelade
similarity (RPB) and conjunction (RPQ) tasks, performance as assessed
by the number of correct detections in the RPB condition and the
number of false alarms or false positives in the RPQ condition was
significantly poorer. Performance as assessed by the number of correct
identifications in the RPQ condition and the number of false alarms in
the RPB condition, however, did not change significantly as a function of
divided attention load. Changes in divided attention load did not affect
performance on the similarity (RPB) and conjunction (RPQ) tasks in the
same way, indicating that different skills are being assessed by
performance on these tasks. Kleiss and Lane concluded that the fact
that the number of correct detections in the similarity (RPB) condition
decreased when divided attention loads were increased indicates that
there was "at least one other source of capacity limitation which may be
unrelated to feature integration" (Kleiss & Lane, 1986, p. 36) in the
processing of letter stimuli.

No research has directly tested the hypothesis that individual
differences in the ability to identify stimuli in confusible arrays or in
arrays where there is a possibility of perceiving "illusory conjunctions" are related to individual differences in reading ability or intelligence, but the types of tasks which have been found to correlate with reading test scores and measures of intelligence suggest the possibility. Mason's (1980) data indicate that knowing the location of a letter in an array may represent one aspect of feature conjoining which is particularly important to reading ability. Irwin (1984) found that when accuracy of response at reporting the location of one of two highly confusable stimuli was used to assess "inspection time", this visual IT measure did correlate with Raven's Standard Progressive Matrices scores in college students. In addition, the ability to report briefly presented words and phrases has been found to correlate with both reading ability and intelligence (e.g. Brand, 1981; Gilbert, 1959; Jackson & McClelland, 1975).

In terms of feature-integration theory, reporting briefly seen words or phrases requires subjects to both identify conjunctions and to detect features when the features of the elements are confusable. Letters have many common features, some which are interchangeable allowing for the possibility of "illusory conjunctions," so some form of serial focusing of attention on locations in the array may be required to
"localize" letters, allowing words to be identified. The efficiency with which attention can be focused will determine the number of words which can be identified in a very brief exposure. Greater efficiency may mean focusing attention on more locations in a given time period or being able to attend to a larger area without making conjunction errors, or both. The data reviewed in this paper indicate that both intelligence and reading ability are related to ability to report words after short exposure durations. Since knowledge of language could provide contextual constraints which would limit the number of possible "illusory conjunctions" in printed text, good readers might be expected to be more efficient perceptual processors in this task as they would not need to focus their attention as narrowly as readers who have less knowledge of letter position restriations, letter combination probabilities, and redundancy, for example. They may also simply be able to attend to more locations during a brief exposure period.

The concepts of feature-integration theory offer a framework within which to test the hypothesis that the apparently inconsistent findings reported by reading researchers and researchers interested in the correlates of intelligence are due to differences in the processing demands of the tasks they employed. Feature-integration theory also
suggests tasks which would allow the processing demands of different speed-of-perceptual-processing tasks to be systematically examined.

The present investigation tested the hypothesis that the speed-of-visual-perceptual-processing tasks used by intelligence researchers and reading researchers, although superficially similar, differed in their visual-perceptual-processing demands and that the apparent fundamental difference in findings could be explained within the framework of feature-integration theory. This study further tested the hypothesis that the consistently reported correlation between reading ability and performance on speed-of-perceptual-processing tasks was mediated by the correlation of intelligence and reading ability and that individual differences in performance on those tasks which have been found to correlate with individual differences in reading ability would also correlate with individual differences in intelligence. In addition, in an effort to specify the processing demands of typical speed-of-visual-perceptual-processing tasks, correlations between individual differences in performance on Mason's four tasks and individual differences in performance on three tasks hypothesized to make specific processing demands were examined.
METHOD

Design

To assess the relationship between intelligence, reading ability, and speed of visual perceptual processing in normal populations, performance by a group of typical high school students on seven measures of speed of perceptual processing was assessed and the correlations between performance on these tasks and paper and pencil measures of general intelligence and reading ability were examined. In addition, in order to explicate the processing demands of the speed-of-perceptual-processing tasks, performance on four tasks hypothesized to assess ability to encode item identity and item location information (the Mason tasks) was compared to performance on a task hypothesized to require encoding only location information (LOC) and to performance on tasks hypothesized to require either (1) the encoding of feature information when features of stimulus elements are confusable or (2) the integration of features when "illusory conjunctions" are possible (the Treisman and Gelade tasks). Regression analyses were used to determine the extent to which individual differences in speed-of-perceptual-processing task performance explained the variance of reading comprehension after the effect of intelligence was
partialled out of the speed of perceptual processing scores.

Subjects

Subjects were 78 high school students ranging in age from 14 to 18. They were recruited from Houston public and private high schools in the vicinity of Rice University. All participants were paid $10. Data from three female subjects who were not native English speakers were dropped reducing the total to 75, of which 39 were female and 36 male.

Tasks

Computerized Tasks

Common procedure. For all seven computerized tasks a common procedure was followed. The subjects sat immediately behind a shoulder high bar which was 1 meter from the video screen. The task was explained to the subjects who were then allowed to ask questions. To begin a trial, subjects were instructed by a message on the video screen to "Press button to present trial". When they pressed the button a fixation point (+) appeared for 300 ms in the center of the display area. This was immediately followed by the pre-mask, the test array, and the post mask. All elements in the array were pre- and
post-masked by an X superimposed on a $. Pre-mask duration was 83 ms and post-mask duration was 50 ms. After each trial the appropriate question for the task was presented on the screen along with all the possible answers. Subjects operated the computer mouse on a lap board and used the mouse-driven cursor to indicate the correct answer. If subjects did not know the answer, instructions called for guessing. All tasks were self-paced. After subjects responded to each trial, they were asked to press the button when they were ready to begin the next trial.

The Mason tasks. These four tasks were computer adaptations of the tasks used by Mason (1980). The targets were the non-confusable letters B, C, M, and T and the distractors were $. Figure 1 depicts the four target letters, the distractor element, and the pre- and post-mask element. The order in which the target stimuli were presented was randomly generated for each subject as was location in the four element array tasks, with the constraint that each target letter appeared an equal number of times in each location and for two durations: 16.7 ms and 33 ms. The durations were chosen after pilot testing and represent the shortest and next shortest presentation times possible on the Macintosh. Presentation times must be in multiples of 16.7 ms which is
Figure 1. Target letters for the Mason tasks and distractors and mask elements for all tasks.

the refreshing time for the screen. At the third lowest presentation time (50 ms), some subjects showed near perfect performance on some of the tasks during pilot testing. For this reason only the two shortest presentation times were chosen. Performance was substantially above the chance level (25% correct) at these times during pilot testing.
The single element display subtended .29 degrees of visual angle horizontally and .39 degrees of visual angle vertically. The four element arrays subtended 2 degrees of visual angle horizontally.

Unique aspects of the four Mason tasks are described below:

1. Mason single letter identification (SLI) task: (32 practice trials: 32 test trials). In this task, a B, C, M, or T was presented and subjects were asked to identify it.

2. Mason location dependent letter identification (LDL) task: (12 practice trials: 64 test trials). In this task an array of four elements was presented. Three of the elements were $s$ and the fourth was either a B, C, M, or T. Subjects again responded by indicating which letter had appeared.

3. Location independent letter identification (LIL) task: (12 practice trials: 64 test trials). In this task the pre-mask cued the location at which the letter would appear. Directly below and pointing toward the element in the pre-mask where the target letter would be presented was a black arrow. This location precue was separated from the mask and target element by a gap which subtended a visual angle of .16 degrees. The location precue arrow itself subtended
.23 degrees of visual angle vertically and .15 degrees of visual angle horizontally. The duration of the premask was increased in this task to 375 ms to correspond more closely to conditions in the Mason task. The cue remained in place during the presentation of the letter and during the post-mask. Subjects again responded by indicating what letter had appeared among three $s$.

4. Mason letter location identification (LL1) task: (12 practice trials: 64 test trials) In this task, presentation was identical to the location dependent letter identification task (2 above) except that subjects responded by indicating the location in the array at which the letter appeared. They did not have to name the letter.

**Location Only Identification Task (LOC):** (12 practice trials: 16 test trials)

In order to include a condition in which subjects had only to encode location information without having first to identify which element in an array was a letter, a task was developed which presented an array with six possible elements, one of which was an empty space. Subjects
were informed that the empty space would never occur in either of
the end positions. Subjects responded by indicating where the empty
space was located. No pre-mask was employed in this task since pilot
testing showed that visual persistence prevented subjects from
detecting the empty location.

The Treisman Tasks

These two tasks were computerized adaptations of the Treisman and
Gelade (1980) similarity and conjunction tasks discussed in the text.
In both tasks the test array had two rows of six letters but subjects
were informed that the target letter, R, would only appear in one of
the inner eight positions. Rs appeared on half of the trials and the
order of appearance and location of the R was randomly generated but
appeared an equal number of times in each location. Exposure
duration was 300 ms. Subjects' response was to indicate whether the
target letter, an R, had appeared. Pilot testing showed that subjects
were correct in their answers about 75% of the time at this exposure
duration. Figure 2 depicts the four stimuli used in the two
Treisman and Gelade tasks. Unique aspects of the two Treisman tasks
are described below:
1. Treisman conjunction (RPQ) task: (16 practice trials; 32 test trials). In this task the distractor elements in the arrays were Ps and Qs. The Qs on this task were constructed so that the "tail" on the Q is identical to the "tail" on the R.

2. Treisman similarity (RPB) task: same as the conjunction (RPQ) task except that the distractor letters in the arrays were Ps and Bs.

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Figure 2. Stimulus letters for the Treisman and Gelade similarity (RPB) and conjunction (RPQ) tasks.
Paper and Pencil Tests

The Nelson-Denny Reading Test (Comprehension and Speed of Reading) (Brown, Bennett, & Hanna, 1981). On this timed test subjects have 20 minutes to read the passages and answer the 36 accompanying questions. To get a measure of reading speed, subjects were instructed to begin reading the first passage when told to "start" and to go on reading until they were told to "mark" which would occur after one minute. At that time they were to write down the number beside the line they had been reading and then continue reading and answering questions until instructed to "stop". Thus there were two scores for this test- a speed of reading score based on the number beside the line (words per minute) and a comprehension score based on the number of questions correctly answered in 20 minutes.

Raven's Standard Progressive Matrices Test (Raven, Court, & Raven, 1977). This test of general intelligence is composed of five sets of 12 non-numerical and non-verbal "problems". Each set and item within each set is progressively more difficult. The items consist of 3 X 3 matrices of patterns or figures which change systematically both
horizontally and vertically. To solve the problems the person being tested must pick one of either six or eight choices which completes the matrix if placed in the empty lower right hand corner. Test takers may work as long as they like and the only stipulation is that they not return to earlier items after having completed later ones. Most subjects spent about 25 minutes on this test although some finished considerably sooner and a few took as long as 45 minutes. Scores on this test represent the number of correctly completed matrices.

**Apparatus**

The computerized tasks were all controlled by an Apple Macintosh computer. The main program was written in Microsoft Basic and a machine language program was used to present the stimuli. Four computers were available for concurrent testing. They were installed in separate experimental booths, the backs of which opened into a common area. This allowed the subjects to be instructed in groups but to perform the computerized tasks independently.

**Procedure**

Subjects were tested in groups of up to four. They first completed the
seven computerized tasks in the order listed above with a short break inserted after the first three. Both sets of computerized tasks required about 45 minutes. Next, following another short break, they moved to a room equipped with desks and tables for taking the paper and pencil tests. Here they were administered the Reading Speed and Comprehension Section of the Nelson-Denny reading test followed by Raven’s Standard Progressive Matrices test.
Results and Discussion

Basic Data, Paper and Pencil Tests

Table 1 presents the means and standard deviations of the Nelson Denny Reading Test (Speed), the Nelson Denny Reading Test (Comprehension), and Raven's Standard Progressive Matrices Test.

Table 1
Means and Standard Deviations of the Nelson Denny Reading Test (Speed), the Nelson Denny Reading Test (Comprehension), and Raven's Standard Progressive Matrices Test.

<table>
<thead>
<tr>
<th></th>
<th>Reading Speed</th>
<th>Reading Comprehension</th>
<th>Raven's Matrices</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEAN</td>
<td>305.4</td>
<td>27.0</td>
<td>50.4</td>
</tr>
<tr>
<td>SD (n=75)</td>
<td>118.2</td>
<td>5.0</td>
<td>7.6</td>
</tr>
</tbody>
</table>

There were no significant sex differences on either the paper and pencil or computerized task scores. Appendix A presents the means and standard deviations for the ability test scores by sex.

Age correlated significantly with reading comprehension ($r = .38, p < .001$) and with Raven's scores ($r = .41, p < .001$), but did not correlate significantly with reading speed ($r = -.16, p = .13$). The similar correlations of age with reading comprehension and with Raven's scores indicate that the skills underlying both these tests develop at about the same rate.
Table 2 presents the intercorrelations of the three paper and pencil tests.

Table 2
Correlations Among the Nelson Denny Reading Test (Speed), the Nelson Denny Reading Test (Comprehension), and Raven's Standard Progressive Matrices Test.

<table>
<thead>
<tr>
<th></th>
<th>Reading Speed</th>
<th>Reading Comprehension</th>
<th>Raven's Matrices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading Speed</td>
<td>1.00</td>
<td>.52</td>
<td>.32</td>
</tr>
<tr>
<td>Reading Comprehension</td>
<td>.52</td>
<td>1.00</td>
<td>.61</td>
</tr>
<tr>
<td>Ravens</td>
<td>.32</td>
<td>.61</td>
<td>1.00</td>
</tr>
</tbody>
</table>

n=75; all correlations p<.004.

There were significant correlations among the three measures of ability, the largest being between Raven's scores and reading comprehension scores. Reading speed correlated highly with reading comprehension but less substantially with Raven's scores.

When reading comprehension was regressed on age, 14.5% (p<.01) of the variance in reading comprehension scores was explained. When Raven's scores were added to the equation, 39% of the variance in reading comprehension was explained. Thus, almost
25% (p<.01) of the variance in reading comprehension was explained by Raven's scores independently of age.

**Basic Data, Computerized Tasks**

**The Mason Tasks and the Location Only Identification Task**

Table 3 presents the means and standard deviations of the number of correct responses on each of the four computerized Mason tasks and the Location Only Identification Task.

In every case there was the expected substantial improvement in the number of correct responses at the longer exposure duration. There was a noticeable decrement in letter identification performance when the letter was embedded in a four element array as compared to the single element array (LDL vs. SLI) which probably resulted from having to determine which stimulus in the four element array was the target. That the decrement in performance in the four element array (when compared to single letter identification) was due to subjects having to decide which of the four elements was the target is borne out by the fact that when the target location was pre-cued (task LIL), letter identification performance improved to beyond the level seen in the single element letter identification task. The pattern
Table 3
Means and Standard Deviations of the Percent Correct Responses on the Computerized Mason Tasks and the Location Only Identification Task.

<table>
<thead>
<tr>
<th>TASK</th>
<th>SLI</th>
<th>LDL</th>
<th>LIL</th>
<th>LLI</th>
<th>LOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>DURATION</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>% Correct</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>40.6</td>
<td>63.5</td>
<td>32.6</td>
<td>50.0</td>
<td>45.2</td>
</tr>
<tr>
<td>SD</td>
<td>14.7</td>
<td>19.4</td>
<td>8.4</td>
<td>14.0</td>
<td>11.4</td>
</tr>
</tbody>
</table>


of performance on these four tasks is essentially the same as that reported by Mason (1980).

Indicating where an empty space in an array appeared (Location Only Identification - LOC), a task which does not require letter identification, appears to be a much easier task than identifying where in an array of elements a target defined by a unique feature appears. Subjects were much better at this task than at the Letter Location Identification (LLI) task at both durations. This suggests that "localizing" a target, even when it is defined by a single unique feature, involves additional processing beyond simply encoding location information.
Location Only Identification (LOC) was the only computerized task that correlated with age \( r=.27, p<.02 \) at Duration 1; \( r=.30, p<.01 \) at Duration 2. Older subjects were better than younger ones at locating an empty space in an array but not at locating a letter.

The Treisman Tasks

Mean hit and false alarm rates and standard deviations for the two Treisman tasks are shown in Table 4. In the RPQ Task, in which conjunction errors are possible, subjects had a lower hit rate \( (p<.01) \) and a higher false alarm rate \( (p<.01) \) than in the RPB task, a result consistent with feature integration theory and the findings of Kleiss and Lane (1986). Both distractors in the RPB condition are similar to the target, whereas only one of the distractors is similar to the target.

<table>
<thead>
<tr>
<th></th>
<th>RPQ Task</th>
<th>RPB Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Hit Rate</td>
<td>.738</td>
<td>.800</td>
</tr>
<tr>
<td>SD</td>
<td>.117</td>
<td>.125</td>
</tr>
<tr>
<td>Mean False Alarm Rate</td>
<td>.425</td>
<td>.363</td>
</tr>
<tr>
<td>SD</td>
<td>.168</td>
<td>.181</td>
</tr>
</tbody>
</table>

RPQ Task: distractors Ps and Qs, Target R. RPB Task: distractors Ps and Bs, Target R. (n=75)
in the RPQ condition. Since similarity increases confusability, more
false alarms would be expected in the RPB than in the RPQ condition
condition on the basis of similarity. The fact that there were
significantly more false alarms in the RPQ condition supports Treisman
and Gelade's hypothesis that similarity of items is not the only source of
confusion in tasks of this type.

**Speed of Visual Perceptual Processing and Intellectual Ability**

The main purpose of this study was to determine whether there
is a relationship between speed of visual perceptual processing and
intelligence. Research conducted by researchers interested in the
correlates of intelligence suggests that more intelligent people are not
generally more efficient than less intelligent people at the perceptual
processing of information in briefly presented visual displays.
However, there is some evidence that this depends upon the kind of
perceptual processing demanded by the task. The question to be
addressed, then, is whether the different tasks used to assess speed of
visual perceptual processing, although superficially similar, are actually
assessing different perceptual processing skills.

A related goal of this research was to determine whether the well
established correlation between tasks assessing
speed-of-visual-perceptual processing and reading ability is actually attributable to the correlation between intelligence to reading ability. Reading researchers appear to have entirely ignored the possibility that individual differences in intelligence might mediate the relationship between reading ability and various measures of speed of perceptual processing.

Intelligence researchers, on the other hand, have limited themselves almost exclusively to individual differences in speed of processing for tasks which do not discriminate between levels of intellectual ability in normal populations. Their efforts have been focused on establishing the relationship between individual differences in intelligence and speed in accomplishing the most elementary levels of perceptual processing when retardates and normals are compared.

The present investigation attempted to integrate the findings of these two bodies of research by first assessing the relationship between Raven's intelligence scores and reading ability in normal individuals. Performance on speed-of-perceptual-processing tasks was also assessed and the relationship between performance on those tasks and individual differences in Raven's scores and reading ability scores was
examined. Regression analyses were employed to determine the
relative importance of processing speed to intelligence and to reading
ability after the effect of intelligence was partialled out of the speed of
processing task scores. In addition, performance on four of the
speed-of-perceptual processing tasks typical of those used by reading
researchers was compared to performance on three tasks hypothesized
to require different specific processing skills. The interrelationships
among these measures of performance were then examined to
determine what skills were tapped by the various speed-of-perceptual
processing tasks.

Reading, Intelligence, and the Mason Computerized Tasks.

Table 5 presents the correlations of the computerized Mason tasks and
the Location Only Identification task with the three ability measures.
The correlations among all of the computerized tasks and the
paper-and-pencil measures are given in Appendix B.

Performance on all four of the measures which required subjects
to report locations (Letter Location Identification and Location Only
Identification, durations 1 and 2) correlated significantly with Raven’s.
These findings show a consistent relationship between general intelligence and the ability to identify the location of a target.

Performance on the Location Dependent Letter Identification task at the shorter duration correlated significantly ($r=.29$, $p<.01$) with Raven's scores but not with reading ability. Individual differences in accuracy on this task do not appear to be related to the ability to encode location information as they were not correlated with individual differences on LOC performance. Performance on LDL does appear to be related to individual differences in the ability to identify targets defined by a single feature–performance on LDL correlated with performance on every Mason letter identification task with the exception of SLI at the longer duration. That aspect of ability assessed by LDL at the short duration which is related to intelligence, however, appears to be not the ability to encode feature information, but the ability to determine which element in a multi-element array is the target. Both of the Mason tasks which required subjects to decide which element was the target before responding (LDL and LL1) correlated with reading ability in Mason's study and correlate with Raven's in the present study. Performance on SLI and L1L, which do not require subjects to determine which element in the array is the target before
responding, did not correlate with reading in Mason's study or with Raven's in this study.

In a study designed to determine the relative importance of a number of information processing components to performance on substitution tests, Laux and Lane (1985) found that individual differences in the time required to carry out an information processing component called "array search and match/no match decision" correlated substantially with Symbol Digit substitution test scores (r = .45, .40, and .48 in children, young, and older adults, respectively; p < .001), a non-verbal component of a number of intelligence tests. In carrying out the "array search and match/no match decision" component, subjects looked for one particular letter in a nine letter array, a task which appears to assess perceptual speed as conceptualized by both Guilford and Thurstone (Guilford, 1967). Since the task requirements of the LDL task are very similar to those of the "array search and match/no match decision" component, individual differences in performance on LDL may correlate with Raven's scores because more intelligent people are faster at completing tasks which assess perceptual speed.

Although the performance measures described above (LDL, LL1,
and LOC) correlated with Raven's scores, neither the computerized Mason Task (LDL and LLI) scores nor the Location Only Identification task (LOC) scores correlated significantly with the reading ability measures. This is not consistent with Mason's finding that scores on LLI (Letter Location Identification) and LDL (Location Dependent Letter Identification) were related to reading ability.

Mason's measure of reading ability included a vocabulary test, a measure which is known to be the single best predictor of Full Scale Intelligence scores (Matarazzo, 1972). There is a substantial correlation between reading ability and intelligence even when no direct measure of vocabulary is used in the assessment of either. In this study, for instance, the correlation between intelligence test scores and reading test scores was .61, although no vocabulary test was included in the assessment of reading ability. Mason's inclusion of vocabulary in the measure of reading assessment makes it very likely that the correlation between intelligence and reading ability was inflated, and that Mason's groups differed significantly in mean intelligence. Furthermore, the fact that Mason chose her groups to represent extremes in terms of reading ability resulted in greatly increased variability, making it more likely that a correlation between reading
ability and performance on the perceptual speed measures would be found. These methodological differences probably explain why she found a relationship between performance on tasks requiring subjects to find targets in four element arrays and reading ability which was not replicated in this more representative group of readers.

Although no correlation was found between Letter Location Identification (LLI) or Location Dependent Letter Identification (LDL) and reading ability in the present study, the pattern of correlations that was revealed between Raven's scores and those two tasks here corresponds to the pattern of correlations Mason reports between performance on LLI and LDL and Nelson Denny Reading scores. This offers further support for the hypothesis that Mason's correlations were mediated by the relationship between intelligence and performance on these two tasks.

Additional evidence that the correlations which have been reported between speed of perceptual processing and reading ability were mediated by the correlation between reading ability and intelligence was revealed by examining the semi-partial correlations of speed-of-perceptual-processing scores and reading comprehension scores. As reported earlier, when reading comprehension scores were
Table 5
Correlations Between the Computerized Mason Tasks and the Location Identification Only Task with the Nelson Denny Reading Test (Speed), the Nelson Denny Reading Test (Comprehension), and Raven's Standard Progressive Matrices

<table>
<thead>
<tr>
<th>Test/Task</th>
<th>Reading Speed</th>
<th>Reading Comprehension</th>
<th>Raven's Matrices</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLI Duration 1</td>
<td>.01</td>
<td>-.04</td>
<td>.08</td>
</tr>
<tr>
<td>SLI Duration 2</td>
<td>.04</td>
<td>-.06</td>
<td>.07</td>
</tr>
<tr>
<td>LDL duration 1</td>
<td>.00</td>
<td>.08</td>
<td>.29*</td>
</tr>
<tr>
<td>LDL Duration 2</td>
<td>.12</td>
<td>.10</td>
<td>.11</td>
</tr>
<tr>
<td>LIL Duration 1</td>
<td>-.05</td>
<td>.05</td>
<td>.05</td>
</tr>
<tr>
<td>LIL Duration 2</td>
<td>-.02</td>
<td>-.02</td>
<td>.08</td>
</tr>
<tr>
<td>LLI Duration 1</td>
<td>.04</td>
<td>.09</td>
<td>.27*</td>
</tr>
<tr>
<td>LLI Duration 2</td>
<td>.11</td>
<td>.21</td>
<td>.25*</td>
</tr>
<tr>
<td>LOC Duration 1</td>
<td>.05</td>
<td>.18</td>
<td>.31**</td>
</tr>
<tr>
<td>LOC Duration 2</td>
<td>-.08</td>
<td>.14</td>
<td>.25*</td>
</tr>
</tbody>
</table>


regressed on age and Raven's scores, 39% of the variance in reading
comprehension scores was accounted for. When all four LDL and LL1 task scores were subsequently entered into the regression equation simultaneously, there was an overall increase in the variance explained of less than 3%, which was not a significant proportion of the variance. Individual differences in performance on the speed-of-perceptual-processing tasks which Mason found to be related to reading ability and which she hypothesized to be assessing the ability to encode location information, did not explain a significant proportion of the variance in reading comprehension scores in this more representative group of students.

Reading, Intelligence, and the Treisman Tasks

Table 6 presents the correlations between the number of hits and false alarms on the two computerized Treisman tasks and the three ability measures.

Both the number of false alarms in the RPQ task and the number of hits in the RPB task correlated significantly with all three measures of ability while their counterparts did not. The correlation between RPQ hits and RPQ false alarms was not significant (r = -.03, p = .82), indicating that high false alarm rates were not due to the subject simply...
Table 6

Correlations Between Hit and False Alarm Rates on the Treisman Tasks and the Nelson Denny Reading Test (Speed), the Nelson Denny Reading Test (Comprehension), and Raven's Standard Progressive Matrices.

<table>
<thead>
<tr>
<th>Test</th>
<th>Reading Speed</th>
<th>Reading Comprehension</th>
<th>Raven's Matrices</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPQ Hits</td>
<td>.16</td>
<td>.10</td>
<td>.06</td>
</tr>
<tr>
<td>RPQ False Alarms</td>
<td>-.28**</td>
<td>-.34**</td>
<td>-.30**</td>
</tr>
<tr>
<td>RPB Hits</td>
<td>.24*</td>
<td>.30**</td>
<td>.28*</td>
</tr>
<tr>
<td>RPB False Alarms</td>
<td>-.04</td>
<td>.05</td>
<td>-.03</td>
</tr>
</tbody>
</table>

RPQ Task: Target R in Ps and Qs. RPB Task: Target R in Ps and Bs. n=75; *p<.05, **p<.01

deciding to say "yes" most of the time.

There was a correlation of .45 (p<.001) between false alarms in the RPQ task and false alarms in the RPB task showing that subjects adopted a consistent level of caution in responding to both tasks. The fact that false alarm score in the RPB task did not correlate with any of the ability measures and false alarm scores in the RPQ task did indicates that it was not the degree of caution which subjects adopted that was responsible for the correlation between RPQ False Alarms and ability. More intelligent subjects and better readers made fewer
false alarms in the RPQ condition than less able subjects but were just as likely to make false alarms in the RPB condition as less able subjects. This means that the ability that enables subjects to avoid "illusory conjunctions" in the RPQ condition is related to intelligence and reading ability whereas the ability to avoid false alarms in the RPB (similarity) condition is not.

These results are consistent with Treisman and Gelade's hypothesis that identifying targets defined by a single feature makes different processing demands than identifying targets which are defined by a conjunction of features, especially when features of distractors may give rise to "illusory targets." Performance on tasks which require the identification of conjunction targets is affected more by short exposure durations than performance on tasks where no conjunction errors are possible. This indicates that under conjunction conditions, identification takes more time than under similarity conditions.

Hit rate in the RPQ condition did not correlate strongly with hit rate in the RPB condition ($r=.25, p<.03$). Hits in the RPB condition, however, correlated with all three of the ability measures although hits in the RPQ condition did not. Whatever ability these two
measures have in common is not the ability which is related to intelligence and reading comprehension or speed.

Although both hit rate in the RPB condition and false alarm rate in the RPQ condition correlated with the three measures of ability, they did not correlate significantly with each other ($r=-.12, p=.31$) meaning that each correlates with ability for different reasons. Those subjects whose RPQ false alarm rate is low are not necessarily those who have high RPB hits, yet high Raven's scores and high reading test scores are associated with both fewer RPQ false alarms and more RPB hits.

It is not immediately clear why false alarm rate in the RPQ condition but not hit rate correlates with ability or why the reverse is true in the RPB condition. If it is assumed that the RPQ task makes greater attentional demands upon the subject as held by Treisman and Gelade's theory, then false alarms result when subjects are unable to focus attention narrowly enough and features from two different stimuli get misjoined forming "illusory targets." That this does indeed happen has been shown by both Treisman and Gelade (1980) and Kleiss and Lane (1986). If Treisman and Gelade are correct, subjects who report more false alarms are less efficient at focusing attention or
scanning serially. An alternative explanation may be that people of lower ability simply do not recognize the necessity for serial scanning or focusing attention in the RPQ condition and continue to try to process the entire array in parallel, thereby seeing more "illusory Rs."

Hits in the RPQ condition may also have been "illusory Rs" — subjects who made many false alarms were as likely to see an "illusory R" on a trial when there was an R present as on a trial when there was no R present. But whereas all of the Rs they saw when no R was present were false alarms, some hits occurred when the subject actually saw the target and others were "illusory Rs" but registered as hits causing the hit score to vary more or less randomly with relation to the false alarm score. Hit rate, therefore, does not predict ability to avoid false alarms.

The fact that performance on all four of the location identification tasks (LOC and LLI, durations 1 and 2) correlated negatively with the false alarm rate in the RPQ condition supports the conclusion that in order to avoid making conjunction errors in the RPQ task, subjects must serially scan locations. The relationship of the location task scores to the hit and false alarm rates of the RPQ and RPB Treisman tasks is complex and interesting. Table 7 presents the correlations between
LOC (Location Only Identification) task scores and LLI (Letter Location Identification) task scores and the hit and false alarm rates for the Treisman Conjunction and Similarity Tasks.

<table>
<thead>
<tr>
<th>Task</th>
<th>RPQ Hits</th>
<th>RPQ FAs</th>
<th>RPB Hits</th>
<th>RPB FAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOC Duration 1</td>
<td>.05</td>
<td>-.33**</td>
<td>.20</td>
<td>-.12</td>
</tr>
<tr>
<td>LOC Duration 2</td>
<td>.01</td>
<td>-.32**</td>
<td>.18</td>
<td>-.12</td>
</tr>
<tr>
<td>LLI Duration 1</td>
<td>.11</td>
<td>-.25*</td>
<td>.07</td>
<td>-.11</td>
</tr>
<tr>
<td>LLI Duration 2</td>
<td>.25*</td>
<td>-.47**</td>
<td>.22</td>
<td>-.45**</td>
</tr>
</tbody>
</table>

LOC Task: Location only identification task. LLI Task: Letter location identification task. Duration 1=16.33 ms. Duration 2=33 ms. n=75; * p<.05, ** p<.01

The ability to indicate where a target was located in a briefly presented array was clearly associated with the ability to avoid "illusory conjunctions" in the RPQ condition. Subjects who were unable to report the location of a target letter within an array of three $s$ or an empty space within an array of five $s$ perceived the most "illusory Rs." This supports Treisman and Gelade's hypothesis that under conjunction conditions, attention must be narrowly focused and locations serially
scanned to avoid seeing an illusory target, which takes time. The fact that performance on the four tasks that require subjects to report the locations of targets did not correlate with hit rate on the RPB task indicates that ability to identify locations does not help subjects detect the target in the similarity (RPB) condition.

What RPB Hit Rate does measure is not clear. Individual differences in RPB Hit Rate do not correlate with scores on any of the computerized tasks except for a modest correlation with RPQ Hit Rate ($r=.25, p<.05$), but do correlate with Raven's and both reading ability scores. Whatever this task assesses that is related to intelligence and reading ability does not appear to be related to either speed of encoding item identity information or ability to encode location information.

There is an interesting parallel between the present findings of a correlation between RPQ False Alarms and RPB Hits and ability measures and findings reported by Kleiss and Lane (1986). These researchers compared detection performance for the Treisman and Gelade conjunction (RPQ) and similarity (RPB) tasks under successive and simultaneous presentation conditions and found significant differences in hit rate in the RPB condition and false alarm rate in the RPQ condition.
In the Kleiss and Lane study, performance as assessed by both the number of correct identifications (Hit Rate) in the RPB condition and the number of false positives (False Alarm rate) in the RPQ condition was poorer when divided attention load was increased. In the present study, individual differences in both of these proportions correlated with Raven’s scores and reading ability scores although they did not correlate with each other. Furthermore, Hit Rate in the RPQ condition and False Alarm rate in the RPB condition, performance measures which do not differ as a function of divided attention load, did not correlate with ability measures. This suggests that there are individual differences in divided attention capacity which are related to individual differences in general ability.

The data in the present study indicate that to a significant extent, False Alarm rate in the RPQ condition is related to ability to report location information. What Hit Rate in the RPB condition assesses remains unclear. As it does not correlate with RPQ False Alarms or any of the other computerized tasks, including LOC, it clearly measures some unique aspect of general intellectual functioning. Kleiss and Lane concluded that the RPB results obtained in their study indicated that there was a source of capacity limitation unrelated to feature
integration in the processing of letter stimuli. The results of the present study do not tell us what this is, but individual differences in performance on tasks which show this attentional effect were related to individual differences in performance on measures of intelligence and reading ability.

**Reading, Intelligence, and Location Encoding**

If the location of a stimulus is simply another feature like color or size, then the ability to report location information should not be distinct from the ability to report other feature information. If this were true, performance on tasks requiring the reporting of location information would be correlated with performance on tasks requiring the reporting of item identity information and performance on both location identification and item identification tasks would correlate with other measures such as Raven's scores. In this study, however, performance on the Location Only Identification (LOC) task did not correlate with performance on the Mason tasks hypothesized to assess ability to encode feature or item identity information (SLI, LIL). In addition, performance on the location only identification tasks (LOC) correlated with Raven's scores, but performance on tasks which required reporting item identity information did not. This suggests that
the processing demands of LOC were different from those of the item identification tasks.

As discussed earlier, however, locations of stimuli in arrays are easily confusable which may make the encoding of location information simply more difficult (time-consuming). If more intelligent subjects are faster processors of feature information, this might account for the fact that less intelligent subjects are penalized to a greater extent than more intelligent ones by processing time restrictions when the correct answer requires reporting a location, but are not penalized more by short exposure durations when required to report item identity information. Performance on the Location Only Identification task does not support the notion that the encoding of location information is more difficult- percent correct on LOC was as good as, or better than, percent correct on every Mason task. These data suggest that the location of a stimulus is not simply another dimension which can be encoded in parallel and without capacity limitations, and that performance on the Location Only Identification task (LOC) assesses different abilities than tasks requiring the encoding of feature information.

It is possible that the encoding of location information requires serial scanning and that performance on the LOC task would show a
decrement under increased divided attention loads. Individual differences on this apparently easy task are related to both RPQ False Alarms and to Raven's scores, but when Raven's is regressed on both RPQ False Alarms and LOC, LOC explains 5.5% (p<.05) of the variance in Raven's independently. This is difficult to explain as the processing hypothesized to be required in avoiding "illusory conjunctions" subsumes that required to encode a location. It is clear, however, that LOC measures something more than is measured by RPQ False Alarms.

Similarly, although both LOC and Raven's correlate with age, when Raven's is regressed on both age and LOC, LOC explains 4.6% (p<.05) of the variance independently. LOC does not correlate with Raven's simply because both are correlated with age.

That performance on LOC assesses some unique and important aspect of intellectual functioning is further supported by the fact that when Raven's is regressed on LDL (reporting the name of a letter in an array, the location of which is uncued), LLI (reporting the location of a letter in an array), and LOC, LOC accounts for 5.6% of the variance in Raven's beyond that accounted for by the other tasks. Mason was correct in concluding that the ability to encode location information is important to reading ability. What she failed to take into account,
however, is the mediating role of intelligence in this relationship.
CONCLUSIONS

Analyses of these data reveal that there is a relationship between speed-of-visual-perceptual processing and intelligence in normal individuals. More importantly, these analyses show that individual differences in the speed with which people process certain kinds of visual stimuli are related to individual differences in level of intellectual functioning as assessed by both speeded (reading comprehension) and non-speeded (Raven’s Standard Progressive Matrices) tests. The analyses also strongly suggest that the relationship between reading ability and measures of visual-perceptual-processing efficiency reported by Mason and others are due to the correlation between intelligence and reading ability, and not to reading ability per se.

Both RPQ False Alarms and RPB Hits predicted Raven’s scores and reading ability. The fact that performance on all four tasks requiring subjects to report location correlated similarly with both RPQ False Alarms and Raven’s scores suggests that the ability to encode location information underlies the correlation between RPQ False Alarms and intelligence.

RPB Hit rate, however, does not correlate with any of the other
computerized tasks except for a modest correlation with RPQ hits. The skill or ability assessed by RPB hit rate contributes to intelligence in a way unique from the other tasks. In the RPB task features of the target and distractors are highly confusable (although no conjunction errors are possible) and there are twelve elements in the array. When Treisman and Gelade compared performance on the RPB task for different array sizes, they found that detection performance on these tasks was not capacity free, and hypothesized that some form of non-serial search was required. An alternate explanation is that it simply takes longer to encode features when there are more of them (a larger array) even when they are encoded in parallel.

RPB Hit Rate and RPQ False Alarm rate are not correlated with each other, but both predict Raven's scores. The fact that they are not correlated indicates that they are not measuring individual differences in the same perceptual processing abilities; however, Kleiss and Lane (1986) have shown that when attentional loads increase, target detection performance as measured by both these proportions suffers. The two performance measures that are not negatively affected by increasing attentional demands, RPQ Hit Rate and RPB False Alarm Rate, do not correlate with ability measures. This suggests that individual
differences in divided attention capacity may be related to intelligence.

Significance and Implications

There is clearly a relationship between speed of visual perceptual processing and intelligence. When groups including retardates are tested, performance on tasks that require the identification of features discriminates between groups of retardates and those of average and above average intelligence. However, within groups of people of normal intelligence performance on these tasks is not related to ability. When multi-item arrays are employed in the measurement of speed of visual perceptual processing, individual differences in performance on a variety of tasks have been found to be related to individual differences in general intelligence.

Further research needs to be done on the development of the skills underlying individual differences in performance on the speed-of-visual-perceptual-processing tasks which correlate with intelligence. This understanding is necessary to determine whether performance on these tasks will be useful as an early predictor of learning disabilities such as reading impairment. Lovett (1984) has
defined two types of impaired readers: accuracy impaired and rate impaired. These two groups differed significantly in the way they performed on a battery of diagnostic reading tests. Lovett hypothesized that these impairments represent "inaccurate" and "dysfluent" decoding of textual material, respectively, and are related to encoding automaticity and speed of information processing. It would have been very useful to assess how such groups perform on the tasks which predicted Raven's scores and reading ability in this study.

Additional research also needs to be done to determine exactly what was being measured by the tasks that correlated significantly with Raven's scores in this study. Since performance on these tasks appears to measure a number of distinct processing abilities, they are potential diagnostic tools in the assessment of both reading ability and intelligence.

Individual differences in the degree to which people reported "illusory conjunctions" on the RPQ task, for instance, predicted 9% of the variance in general intelligence as measured by Raven's and almost 12% of the variance in reading comprehension scores. Given the "non-intellectual" nature of the RPQ task, determining exactly what is involved in the performance of this task would yield important
information about what basic abilities underlie intelligent behavior.

If performance on the RPB task involves some form of non-serial search as hypothesized by Treisman and Gelade, then individual differences in non-serial scanning rate may be related to intelligence. Still, neither the Treisman and Gelade data nor the Kleiss and Lane data rule out the possibility that individual differences in RPB Hit rate are related to individual differences in divided attention load capacity or to individual differences in recognizing what kind of processing produces optimal performance on these tasks. Since Hit Rate on the RPB task predicted 8% of the variance in general intelligence as measured by the Raven's and 9% of the variance in reading comprehension scores, individual differences in the skill or skills assessed by performance on this task have a substantial impact on the general level of intellectual functioning.

Performance on the Location Dependent Letter Identification task (LDL) at the briefer exposure, but not at the longer exposure, predicted 8% of the variance in Raven's scores but did not correlate significantly with reading ability. When subjects must search arrays and decide which element is the target, individual differences in the speed with which this can be accomplished are related to individual differences in
intelligence. The processing requirements of the LDL task match those which Guilford employed to describe measures of perceptual speed. Scores on tasks which assess perceptual speed typically correlate with intelligence test scores, which may explain the correlation between LDL performance and Raven's scores.

Each of these performance measures contributed uniquely to the variance in ability as measured by the Raven's. Scores on tests such as Raven's are used to make a number of important educational and vocational decisions. Knowing more precisely what is assessed by performance on the speed-of-visual-perceptual-processing tasks which correlated with Raven's would enable more valid and useful decisions to be made.
Appendix A

Means and Standard Deviations of Ability Tests by Sex

<table>
<thead>
<tr>
<th>Task</th>
<th>Males (n=36)</th>
<th>Females (n=39)</th>
</tr>
</thead>
<tbody>
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<td>Raven's Matrices</td>
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### Appendix B

**Correlations Among Computerized Tasks and Paper and Pencil Measures**

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A1=SLI D1; A2=SLI D2; B1=LDL D1; B2=LDL D2; C1=LIL D1; C2=LIL D2; D1=LOC D1; D2=LOC D2; E1=LIL D1; E2=LIL D2; Q1=RPQ Hits; Q2=RPQ False alarms; P1=RPB Hits; P2=RPB False alarms; R=Raven's; S=Reading speed; C=Reading comprehension. For $r > .22$, $p < .05$; for $r > .28$, $p < .01$. 
Bibliography


