The Relations Among
Speed of Information Processing,
Intelligence, and Strategy Use

by

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for the degree of Master of Arts,
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Abstract
This thesis examines the relation between IQ and inspection time (IT; the minimum time required to reliably identify a highly evident feature of a stimulus) among university students. Experiment 1 introduces a same/different letter discrimination task conducted with the IT procedure. The letter IT task was found to successfully eliminate the use of systematic strategies, such as apparent movement and flash cues; in the past, such strategies have made the IT-IQ correlation difficult to interpret. Results of Experiment 2 indicate that when tested over five consecutive days, the letter IT task is as reliable as the typical 2-line procedure. Experiments 3 and 4 begin examining the extent to which higher order cognitive processes affect performance on the letter IT task. Results of these experiments further support the view that cognitive factors such as attention continue to be at least partly responsible for IT performance, suggesting that the IT task is more cognitively complex than previously believed.
For Douglas Bors,

You are not just a supervisor, but a friend. Over the last four years you have provided me with an endless amount of knowledge, support, and encouragement. You have helped me grow as a researcher, and as an individual. I will be forever thankful.

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This thesis begins with a brief introduction of the history of research examining the relation between speed of information processing and intelligence. Next, I will review the literature on the association between inspection time (IT), a paradigm typically used to measure speed of information processing, and intelligence. I will then discuss one of the potential limitations of the IT task, namely the reported use of response strategies, and propose an alternative IT task that seeks to eliminate this confound. Finally, I will explore the extent to which higher order cognitive processes influence performance on the new IT task, and the theoretical implications that this may have for the interpretation of the relation between IT and speed of information processing.

**History of Mental Speed and Intelligence**

Interest in a possible association between mental speed and intelligence (IQ) has been prevalent since the early days of psychology. The first attempt to correlate intelligence with performance on simple tests, many of which were thought to have little, if any, cognitive content, was pioneered by Galton (Galton, 1883; cited in Deary, 1986). Galton strongly believed
in the genetic determination of intelligence, and thus proposed that intelligence should be measured by means of simple biological tests, such as reaction time (RT).

The problematic nature of equating observed biological or psychological differences with genotypic differences has been a common feature of the nature-nurture debate. Because this debate is not central to my thesis, the issue will not be addressed in great detail. Simply stated, Galton's viewpoint that biological differences must arise from genetic differences was a faulty assumption. In her review of the effects of enrichment on the anatomy of the brain, Diamond (1988) cited evidence that the environment can produce neurological differences, such as those differences found with respect to learning rates. Nevertheless, Galton's faulty reasoning does not discredit the notion that an association between intelligence and biological measures may exist.

Early attempts to demonstrate an association between IQ and simple biological measures--including Galton's (1883)--were not successful. For example, Wissler (1901) conducted an influential study that found no significant relation between IQ and RT, work that was often cited as disproving Galton's hypothesis. Eysenck (1986), however, critically examined Wissler's study and argued that "Galton's proposal was rejected on the basis of a study so weak methodologically that no conclusions can in fact be drawn from it" (p. 603). For instance, he noted that the number of RT
trials used to establish an average for each person was surprisingly small, typically around 3 to 5, and that the range of ability was so small that the discovery of any kind of significant correlation was unlikely. Nevertheless, Galton's work—which sought to base intellectual attainment in simple perceptual-motor indices—was not deemed successful, and for most of this century the psychometric approach—which focuses on complex higher level cognitive skills, such as problem solving, memorizing, etc.—has dominated research on intelligence (Bors, MacLeod, & Forrin, 1993).

In recent years, there has been a revived interest in the Galtonian approach, with the view that differences in IQ may be largely dependent on mental speed (Eysenck, 1986). Although hypotheses about the specific mechanism involved may differ, according to this viewpoint, mental speed is deemed to be controlled by a fixed biological property of the nervous system that is uninfluenced by cognitive activity. Evidence commonly used to support this view stems from research on IQ and RT. For example, using a sample of 39 schoolgirls who had been given the Raven's Standard Progressive Matrices, Jensen and Munro (1979) found correlations of -.39 with total RT and -.31 with variance. In his review of the RT-IQ literature, Jensen (1979) reported that RT accounts for 10% to 40% of the variance in IQ; strong RT-IQ relations presumably reflect the greater mental speed of higher-ability subjects.
Mental Speed and Inspection Time

Inspection time (IT) has been another popular paradigm used to investigate the relation between individual differences in mental speed and individual differences in intelligence. In contrast to the RT paradigm, IT is not based on response latencies, but on accuracy rate as a function of the length of time a test stimulus is presented (Chaiken & Young, 1993). Theoretically, IT is assumed to be the minimum time required by an individual to make a single observation from sensory input and, therefore, is taken to be a basic element limiting the rate of information processing (Vickers, Nettelbeck, & Wilson, 1972). Operationally, IT is the briefest target stimulus duration associated with the required accuracy rate (usually 95% or 97.5%) when the discrimination required is very easy (Vickers et al., 1972).

Inspection time was initially conceptualized as predominately measuring the rate of perceptual encoding, excluding mental components beyond the decision stage that are responsible for the execution of a response (Nettelbeck, Robson, Walwyn, Downing, & Jones, 1986). More recently, however, IT has been interpreted as representing a research strategy aimed at isolating a more general dimension of information processing in the brain (mental speed) thought to be fixed and relatively free
of influence from higher-order cognitive activities (Brand & Deary, 1982). Although some authors have suspected that IT may reflect additional factors, it is generally hypothesized that the speed of the brain limits both performance on the IT task and higher-order perceptual and cognitive abilities (e.g., Kranzler & Jensen, 1989).

The Typical Inspection Time Procedure

The 2-line task proposed by Vickers et al. (1972) has typically been used to measure IT in the study of the association between IT and intelligence. This method consists of a presenting a target stimulus with two vertical lines of markedly different lengths, located side by side, and connected at the top by a single horizontal line (see Figures 1a and 1b). The task of the subject is to indicate the side on which the longer of the two vertical lines occurred. The longer line appears on the left side or the right side of the stimulus with equal probability. The offset of the stimulus is immediately followed by the onset of a masking figure closely resembling the target (see Figure 1c). The backward-masking procedure is used to limit the time that the stimulus is visible and to prevent afterimages, which could enable the subject to extract further sensory information from the stimulus after it has disappeared (MacKenzie & Cummings, 1986; Sperling, 1960).
(a) A typical inspection time (IT) task stimulus, illustrating a "right" trial.  (b) A typical IT task stimulus, illustrating a "left" trial.  (c) A typical backward mask for the IT task (Adapted from Nettelbeck, 1987, p. 305).

In all IT studies, stimulus exposure duration is varied by one of two procedures: the method of constant stimuli or the method of limits. The method of constant stimuli includes a fixed number of trials at each of several predetermined target exposure durations selected from within a wide range which includes the expected level of IT (Nettelbeck, 1987). Stimulus exposure duration typically ranges in 20 msec steps between 20 and 180 msec, and is varied randomly from trial to trial (Vickers & Smith, 1986). The subjects percentage of correct responses is plotted against stimulus exposure duration, and the IT index is taken as the exposure duration corresponding to the point on the curve at which some predetermined level of accuracy is achieved (Vickers & Smith, 1986). Under the method of limits, testing begins at a long exposure duration and succeeding exposures are
lengthened or reduced as required, each change being determined by the accuracy of the response (Nettelbeck, 1987). The method of limits is typically achieved by the use of the Parameter Estimation by Sequential Testing algorithm (PEST; Taylor & Creelman, 1967). PEST is a psychophysical method which adjusts to the best performance of the subject, minimizing trials at redundant durations (i.e., where performance is either 100% accurate or at chance level; Egan, 1994). Trials begin at some initial exposure duration, with subsequent trials being shortened for a series of correct responses but lengthened for errors (Evans & Nettelbeck, 1993). In his review of the IT research, Nettelbeck (1987) concluded that estimates of IT derived from the method of constant stimuli are very similar to those derived using PEST.

**Evidence for an IT-IQ Association**

Nettelbeck and Lally (1976) were the first to speculate about the relation between IT and intelligence, reporting a correlation of −.92 between IT and Performance IQ on the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1955). Six years later, Brand and Deary (1982) calculated a median IT-IQ correlation of −.80 from five of the nine studies they reviewed. MacKintosh (1981), however, questioned the conclusions of these early studies, noting that the number of subjects was often quite
small and that several included mental retardates together with subjects of high ability. Inclusion of the retarded subjects may have contributed disproportionately to the correlations as it is difficult to find any psychological task on which retarded subjects do not perform poorly. For example, only 10 subjects whose Full Scale IQ ranged from 47 to 119 participated in the study by Nettelbeck and Lally (1976). Similarly, Vernon (1986) has warned that when a small sample size is accompanied by an excessive range on one or both of the variables, a spuriously large correlation will almost certainly appear.

Two recent reviews of the IT research have estimated that the correlation between IT and IQ in the normal adult population is around −.5 (Kranzler & Jensen, 1989; Nettelbeck, 1987). Thus, a significant negative correlation between IT and IQ remains even after mental retardates are excluded from such research. Deary (1993) noted that the raw correlations obtained in many studies are more typically in the region of −.3, however, the correlation estimate of −.5 is obtained after IQ scores have been corrected for the attenuation due to a restriction in the range of ability that is found in many studies which tend to include only university students. Nevertheless, the correlation between IT and IQ still exceeds that typically found between RT and IQ. Deary and Stough (1996) reported that with respect to RT and IQ, there are few correlations with single indexes that reliably reach or exceed .2 to .3.
Bors, Stokes, Forrin, and Hodder (in press) tested the reliability of the IT measure by having subjects complete 300 trials of the typical 2-line IT task on each of three consecutive days. They found correlations among ITs of .76, .72, and .90 for Days 1 & 2, Days 1 & 3, and Days 2 & 3, respectively. Thus, the available evidence suggests that IT is quite reliable across days. The test-retest reliability of any measure of individual differences is important because it will limit the maximum correlation the measure can have with another variable. IT can be said to meet the criteria of reliability and, given the high test-retest stability, little correction need be made for the IT-IQ correlation.

**IT as a Culture Free Measure of IQ**

Inspection time has been praised as a potentially culture free measure of intelligence. This suggests a number of practical implications. The problem of cultural bias in mental testing was first acknowledged by Binet and Simon (1908; cited in Jensen, 1980) who developed the first practical test of intelligence which had been standardized on children of the Parisian working class and applied to groups of children of higher social status, whose test scores were higher, on average, than those of the working class children.

Today, differences in IQ between middle and working classes
and between blacks and whites in the United States are well established, but are frequently regarded as evidence of the bias inherent in mental tests (MacKintosh, 1981). MacKintosh (1981) has warned that there will always be the possibility that mental tests may discriminate unfairly against those whose background has made them less familiar with the material in question.

Understanding of Cattell's (1971) dual factor theory of intelligence will clarify the nature of the inherent bias in mental testing. Cattell (1971) argued that general intelligence (g) can be subdivided into two independent classes of abilities: (1) fluid abilities which are genetically determined, and (2) crystallized abilities which derive from education and experience. Accordingly, bias in mental testing stems largely from the fact that, in addition to fluid intelligence, standard IQ tests measure crystallized intelligence, which may result in lower test scores among those from lower socioeconomic backgrounds. On the other hand, Brand and Deary (1982) assert that IT is a test of fluid intelligence which is "transparently fair to people of varying socioeconomic, psychopathological, ethnic, national, and racial groups" (p. 146). The discovery of a correlate of IQ, such as IT, that is independent of past experience would be advantageous to both educational practice and the domain of intelligence research.

MacKenzie and Cummings (1986) were the first investigators to collect data to demonstrate the culture-fair status of IT.
They reasoned that participating in the IT task, which requires subjects to concentrate on an impoverished image and rapidly push buttons in response to it, is very similar to playing video games. Hence, they argued that if it could be shown that subjects who regularly play video games have faster ITs (but not higher IQs) than subjects who do not, then the IT task would be shown not to be a culture-fair measure of IQ. Their subjects consisted of 38 males, 19 of whom were video game players, and 19 of whom were non-players. When corrections were made for mean differences in age and IQ, the regular video game players did not have faster ITs than the non-players. Consequently, evidence was found that previous practice on a real life activity that is very similar to the IT task does not lead to faster performance on the IT task, thus indirectly supporting the idea that IT is something independent of previous experience.

In contrast, Nettelbeck, Evans, and Kirby (1982) and MacKenzie and Bingham (1985) reported improvements in the ITs of young adults across occasions. Similarly, Bors et al. (in press) found a significant linear decrease in IT across three consecutive days, concluding that there appear to be other processes, perhaps strategic in nature, related to performance on the IT task that become more efficient over time. Hence, these findings question the notion that IT is independent of previous experience. More compelling, Bors et al. (in press) found that practice attenuated the relation between IT and IQ.
The finding of an attenuation in the correlation between IT and IQ over time, together with the finding that IT improves with practice, has led sceptics to raise doubt about the mental speed hypothesis, suggesting instead that processes other than mental speed are responsible for the correlations that have been found between IT and IQ. It should be noted, however, that the theoretical implications of the attenuation in the correlation between IT and IQ over time, improved IT with practice, the mental speed hypothesis, and alternative hypotheses, are complex. Improvement in mean IT performance over time neither supports nor contradicts the mental speed hypothesis.

Consider the notion that mental speed is the primary determinant of individual differences in performance on the IT task, with other cognitive factors--such as individual differences in higher order strategic processes or attention--also influencing performance, albeit in a non-systematic manner with respect to IQ. As a result, practice should result in one of two outcomes. First, if practice serves to reduce individual differences in the cognitive factors (i.e., nuisance variables), then an increase in mean performance on the IT task should occur, coupled with a decrease in IT variability and an increase in the correlation between IT and IQ. Hence, as noise is reduced, the variability in scores due to error (i.e., error variance) should decrease. Consequently, performance will become less variable and the correlation between IT and IQ will increase because the
true correlation between these factors will become more apparent.

Second, if practice serves to increase individual differences in the cognitive factors, then an improvement in mean performance on the IT task would still be expected, however, an increase in variability and an attenuation in the correlation between IT and IQ should occur. Thus, as more noise is added, the variability in scores due to error will increase. Consequently, an increase in error variance will produce greater variability in performance and the correlation between IT and IQ will decrease because the true correlation between these factors will become less apparent.

If, on the other hand, some higher order cognitive factor is the primary determinant of individual differences in performance on the IT task, with mental speed influencing IT performance in a non-systematic manner with respect to IQ, one of two outcomes should occur. First, there should be an improvement in mean performance on the IT task, a decrease in variability, and a decrease in the correlation between IT and IQ, if practice serves to decrease individual differences in the higher order cognitive factor. Thus, if some higher order cognitive factor is the primary determinant of individual differences in performance on the IT task and practice serves to make subjects more alike on this variable, then there should be less variability in performance, and consequently the correlation between IT and IQ should decrease.
Second, if practice serves to increase individual differences in the higher order cognitive factor, then an improvement in mean performance on the IT task would still be expected, however an increase in variability and an increase in the correlation between IT and IQ should occur. Thus, if some higher order cognitive factor is the primary determinant of individual differences in performance on the IT task and practice serves to make subjects less alike on this variable, then there should be more variability in performance, and consequently the correlation between IT and IQ will increase.

In short, the previously reported improvements in mean IT performance over time neither support nor contradict the mental speed hypothesis. Instead, further examination of the effects of practice both on the variability in IT performance and on the correlation between IT and IQ is needed to establish whether "pure" mental speed or some cognitive factor is the primary determinant of individual differences in IT performance and its correlation with IQ.

**Potential Limitations of the IT Task**

Limitations have been found with respect to the IT task which make interpretation of the results difficult. First, there is no standard procedure for measuring IT (MacKenzie & Bingham, 1985). The stimuli used in various IT tasks have ranged from
two, three, and four tachistoscopically presented lines to light bulbs topped with lenses to identifying the temporal order of two tones or the relative pitch of two tones. Furthermore, the predetermined level of accuracy has also differed dramatically across studies. MacKenzie and Bingham (1985) have concluded that the great procedural variations across studies make it impossible to compare absolute values of IT from one study to another.

A second limitation is that difficulties can arise in the interpretation of the association between IT and IQ as a result of the failure of the backward-masking procedure to limit sensory information available to the subject. This problem was first observed by Nettelbeck (1982), who commented that

In virtually all of our studies some subjects have appeared able to make use of other sources of information than the briefly exposed figure, such as subtle post-masking cues associated with apparent movement, and small changes in brightness. (p. 307)

Introspective accounts reported by some subjects suggest that when the stimulus lines are covered by the longer masking lines, the stimulus lines seem to grow or stretch to the length of the masking lines, such that the ends of the stimulus lines seem to move to the points that mark the end of the mask (MacKenzie & Bingham, 1985). In addition to apparent movement, some subjects report seeing an instantaneous flash, visible at mask onset, on the side of the target with the shorter line (Evans & Nettelbeck,
The nature of the apparent movement cue reported by strategy users on an IT task. The arrow indicates the apparent movement seen as the IT target stimulus is replaced by the shadow mask, which can give rise to the appearance of movement, flickering, or brightness (Adapted from Egan, 1994, p.307).

Reported use of response strategies is problematic for the original position suggested by Vickers et al. (1972) which stated that IT estimates the rate of sampling of sensory input in the initial stages of information processing. If the masking procedure fails to control the amount of sensory information available to some subjects, then this task cannot be used to measure how much time is needed to extract enough information from the stimulus to make the discriminative judgment (MacKenzie & Cummings, 1986). Hence, among strategy users, regardless of its correlation with IQ, the IT task will not be estimating the
MacKenzie and Bingham (1985) were the first researchers to thoroughly investigate the use of strategies among their subjects, and the subsequent impact that strategy use may have on the IT-IQ association. In their study, the stimuli were two horizontal parallel lines, 55 mm and 82 mm long, one 20 mm above the other. On each trial, the two lines began on the left of the screen, and the differences in length were always on the right (see Figures 3a and 3b for the stimuli and mask, respectively). The vertical placement of the lines was always constant; however, the distance from the left hand side of the screen that the two horizontal lines began varied from trial to trial. The assumption underlying the varied position of the stimuli was that subjects would no longer be able to focus attention only on the part of the screen where the extra 27 mm of the longer line would appear, a strategy that was reported by several subjects during pilot testing. It should be noted, however, that by varying the position of the stimuli, their IT task became a visual search task in addition to a simple discrimination task.

Results indicated that among their sample of 29 university students, 16 of the subjects spontaneously adopted a strategy based on apparent motion. Although there were no significant
differences between the two subsamples (users and non-users of strategies) on any IQ measure, it was found that strategy users' mean IT was significantly shorter than that of the non-users. For the full sample, IT correlated -.50 with Performance IQ on the WAIS. When analyzed separately, however, it was found that there were no significant correlations between IT and IQ for strategy users \((r = -.20)\), whereas among non-users, IT was highly correlated with Performance IQ \((r = -.72)\) and particularly with scores on the Block Design and Object Assembly subtests of the WAIS. Furthermore, attempts to teach the apparent motion strategy to non-users were unsuccessful. Thus, MacKenzie and Bingham (1985) concluded that the IT task does not measure the same process or capacity in the two groups; it measures some aspect of mental speed in the non-users, and something indeterminate in the users.

Figure 3

An example of (a) one of the target stimuli and (b) mask used in MacKenzie and Bingham's (1985) study. This figure illustrates that the distance from the left hand side of the screen that the two horizontal lines began varied from trial to trial (adapted from Alexander & MacKenzie, 1992, p. 1204).
Similar findings were reported by MacKenzie and Cummings (1986). In their study, 22 of the 37 subjects reported that they were attending to apparent-motion cues. The correlation between IT and IQ was \(-0.66\) for the cue non-users, and significantly smaller for the cue users \((r = -0.19)\). Furthermore, the two groups did not differ with respect to IQ or in the ability to perceive apparent motion. Thus, these findings are consistent with those of MacKenzie and Bingham's (1985) study, suggesting that the relation between IT and intellectual level is quite different in apparent motion cue users and non-users. MacKenzie and Cummings (1986) concluded that among non-users, the IT procedure measures some mental process that is strongly related to individual differences in intellectual ability, however, among cue users it does not. Additionally, they warned that attempts to estimate the relation between IT and intellectual level in a mixed sample may consequently be misleading.

Knibb (1992) attempted to eliminate the use of apparent movement cues by devising a dynamic masking procedure. He proposed that rather than avoiding apparent movement cues, the dynamic mask would swamp the subject with irrelevant apparent movement, so that although apparent movement would still be evident in the display, the form of this movement would not provide the subject with information about the stimulus. This was achieved by using six different masking frames. In each
masking frame, black or white bars, longer than the short stimulus bar but shorter than the long stimulus bar, were randomly positioned in the region of the target bar (see Figure 4). When the masking frames were shown in sequence, the bars appeared to move about, producing apparent movement that was useless for stimulus interpretation. Results indicated that with respect to the relation between IT and IQ, the dynamic masking procedure explained nearly four times the variance compared to the traditional procedure. Thus, it appeared as though the dynamic masking procedure was successful in overcoming inadequacies inherent in the typical masking procedure.

Figure 4

Examples of the dynamic masks used in Knibb's (1992) study. The masks were designed to swamp the subjects with irrelevant apparent movement (adapted from Knibb, 1992, p. 240).
Evans and Nettelbeck (1993), however, have noted a limitation with respect to Knibb's (1992) study: Knibb found it necessary to adjust the size of the difference between the target lines while varying the duration between target onset and mask onset. For instance, at an SOA of 20 msec, the pixel difference between the stimulus legs for the dynamic mask was 5, but for each 20 msec increment in SOA, the pixel difference increased by 1 until a ceiling of 15 was reached at 220 msec. One consequence of this procedure was that subjects performing at shorter SOAs encountered differences in line length that were relatively smaller and more difficult to discriminate.

Accordingly, Evans and Nettelbeck (1993) conducted a number of preliminary experiments testing the effectiveness of various backward masking procedures. Based on post-experimental discussions with subjects, they found that some subjects were using subtle cues which were associated with the apparent extension of the squared 5mm wide ends of the stimulus lines to the legs of the mask. After a number of preliminary attempts, a mask consisting of two vertical lines, jagged in the centre, resembling lightening bolts was chosen (see Figure 5). The purpose of this mask was to locate cues of apparent movement and brightness changes within the two flashes at the centre of the mask display. Accordingly, this mask has been termed the "flash" mask.

Subjects completed approximately 200 trials of the IT task
with both the typical mask and the flash mask. Results indicated that of the 19 subjects that participated, 10 reported adopting a strategy based on apparent movement effects with the typical mask whereas only 3 reported using cues for the flash mask. Furthermore, none of these 3 reported adopting a strategy that specifically involved apparent movement or flash cues. Although the two masking procedures were highly correlated \((r = .72)\), ITs derived from the flash mask were significantly longer than those derived from the typical mask. A significant negative correlation was found between Performance IQ on the WAIS and IT as estimated by the original mask \((r = -.61, p < .001)\) and the flash mask \((r = -.65, p < .001)\). Unlike previous studies, when subjects were divided into groups based on strategy use (users vs. non-users), no differences in the IT-IQ correlations were found. Thus, the authors concluded that the results supported the notion that ITs obtained with the flash mask were less affected by the problems of strategies than were estimates of IT obtained using the typical mask.

Bors et al. (in press) argued, however, that because the subjects in Evans and Nettelbeck's (1993) study were from widely differing age groups (subjects ranged in age from 19 to 51), and the fact that strategy use was not reported by age, there is the possibility of a Mask X Age interaction. For example, Craik (1977) reported that older participants are less likely to employ
strategies in other situations, such as the organization of information. As a result, Bors et al. (in press) compared the performance of young-adult participants on the typical IT mask with that on the Evans and Nettelbeck (1993) flash mask in terms of reported use of apparent movement cue strategies and correlations with IQ.

Results were consistent with the findings of Evans and Nettelbeck (1993) and Nettelbeck and Rabbitt (1992) in that participants required significantly longer exposure durations with the flash mask than with the original mask. When asked, however, how they made their decision about which line was longer, 14 of the 16 participants who were tested first with the standard mask reported using a strategy and 13 of the 15 participants who were tested first with the flash mask reported
using a strategy. Thus, Bors et al. (in press) concluded that although the flash mask yields lower accuracy rates and longer ITs than the standard mask of Vickers et al. (1972), the flash mask does little to reduce the use of strategies based on apparent movement cues. Hence, they argued that differences in performance across the two types of masks are not likely the result of differences in strategy use.

Chaiken and Young (1993) made yet another attempt to develop a backward masking procedure that would bring the use of apparent movement cues under experimental control. First, rather than using an asterisk as a fixation cue, they used a rectangular box that surrounded the area of the screen in which the IT stimulus occurred. Because the asterisk was located between the shorter and longer lines of the test stimulus, it was assumed that this fixation point may have encouraged the use of apparent movement cues by allowing subjects the opportunity to fixate near the apparent movement prior to stimulus presentation. The assumption underlying the use of the new fixation cue, on the other hand, was that the abrupt onset of the rectangular box would divert some attention away from the location of the original fixation point.

In addition to the original mask, a second mask was used that consisted of unfilled bar-shaped boxes closely surrounding the areas where each of the vertical lines of the test stimulus had previously been exposed. This mask was intended to be a
metacontrast mask (Haber & Hershenson, 1980), which has been shown to inhibit perception of stimuli presented within it and is potentially related to the phenomenon of apparent movement. The notion was that if the metacontrast mask operated at the same cognitive level as the apparent movement phenomenon, then this mask might be more effective at reducing apparent movement in the IT task. Results indicated, however, that neither the change in the fixation cue nor the change in the mask were able to eradicate the use of apparent movement cues.

In contrast to the results of the aforementioned studies, Egan (1994) failed to find any effect of strategy use on the IT-IQ association. In this study, 43 of the 74 subjects reported using apparent motion cues to guide IT discriminations. As found in previous studies, cue users had faster ITs than non-users and no differences were found between the two groups in verbal or non-verbal IQ. Although IT correlated negatively with scores on the Standard Progressive Matrices (Raven, 1977), when the sample was divided into groups based on strategy use (users vs. non-users), the size of the correlation did not change. Egan concluded that despite motion cues enhancing performance on the IT task, the perception of these cues neither causes, nor reduces, the correlation between IT and IQ.

In short, at least 50% of subjects within university samples will spontaneously adopt strategies based on apparent motion cues. It has been argued that because IT becomes bunched around
lower values among cue users, strategy use likely produces an attenuation in the IT-IQ correlation (Nettelbeck, 1987). Hence, it is said that apparent movement strategies tend to disrupt rather than cause the IT-IQ association (MacKenzie & Bingham, 1985). Furthermore, no differences in IQ have been found between users and non-users of strategies. This finding is favourable for IT research because it has been suggested that if superior performance on IT tasks was simply a consequence of having high intelligence, then the IT measure would lose much of its apparent attraction for intelligence researchers because it would become just another task on which clever people perform well (Deary & Stough, 1996).

Consequently, a number of attempts have been made to develop a backward masking procedure that would eliminate the apparent movement effect. Although many of these procedures produced longer calculated ITs and increased error rates, none has been able to eliminate apparent movement cues altogether. As noted by Chaiken and Young (1993), it is difficult to explore the relation of IT to psychometric intelligence when a second individual differences variable (reported use of apparent motion cues) influences measurement of the first.

Experiment 1

A significant problem with IT research is the effect that strategy use can have on the measurement of IT, and hence, the ensuing correlation between IT and IQ. Although past researchers
have attempted to devise new masking procedures to overcome the inadequacies of the original mask, none has been able to eradicate the use of systematic cues, which drastically affect the IT measure. The purpose of Experiment 1 is to develop a new IT procedure that will completely eliminate systematic strategy use.

Due to the failure of past attempts to devise a new backward masking procedure that could successfully overcome the inadequacies of the original mask, I decided to change not only the mask but the stimuli as well. Hence, rather than attributing the use of systematic strategies, such as those based on apparent motion cues, entirely to the failure of the backward masking procedure, it is possible that there is something inherent in the 2-line stimulus itself that may contribute to the development of systematic movement cues. As a result, I tested subjects on both the typical 2-line IT task and on a letter IT task, which can be viewed as a variant of the Posner and Snyder (1975) 'physical' condition (e.g., a a), involving judging whether two letters are physically the same or different. The letter IT task is otherwise nearly identical to the line IT task with respect to the physical context, equipment used, number of trials (both training and actual experimental trials), pacing, and method of response.

The letter IT task was first used by MacKenzie, Molly, Martin, Lovegrove, and McNicol (1991), where they compared ITs
derived from the physical condition to those derived from the lexical condition, in an attempt to analyze the cognitive content of the IT task. MacKenzie et al. (1991) found that ITs for identifying two lexically identical letters as the same (e.g., A a) were longer than those for identifying two physically identical letters as the same (e.g., A A), indicating that the IT task is more cognitively complex than originally believed (Experiments 2, 3, and 4 of the current thesis will explore in further detail the extent to which higher order cognitive processes influence IT).

MacKenzie et al. (1991), however, did not investigate the extent to which the letter task reduces the use of apparent movement and/or flash cues. If I could devise a task that was as cognitively minimal as the line IT task, insofar as it would require making a simple discrimination, yet consisted of multiple stimuli, rather than the traditional two, then strategy use might be drastically reduced because participants would no longer be able to focus their attention on a single area of the stimulus display to detect cues such as apparent movement or flashes. Consequently, if the new IT task achieves this goal, I will be able to derive a purer estimate of IT that is uninfluenced by a second individual difference variable, namely, apparent movement cue use.

Thus, the aim of Experiment 1 is to test a new IT procedure and to explore the effects of strategy use on IT and its
correlation with IQ.

Method

Participants

Forty-five volunteers with normal or corrected to normal vision were recruited from the introductory psychology class at the University of Toronto at Scarborough. One participant was dropped from the sample because performance on both of the IT tasks was not above chance. The 44 remaining participants, 27 female and 17 male, ranged in age from 17 to 39 ($M = 19.61$, $S.D. = 3.39$). Participants were preselected by the experimenter based on scores obtained on the 12-item version of the Ravens Advanced Progressive Matrices test (Bors & Stokes, in press; Short Raven). The Short Raven, consisting of 12 items extracted from the original 36, was preferred because it substantially reduced administration time (15 vs. 40 min., respectively) despite maintaining high test-retest reliability ($r = .82$; Bors & Stokes, in press). Furthermore, consistent with that found when the 36-item test has been used to estimate IQ, past research has found a moderate correlation between the Short Raven and IT ($r = -.42$; Bors & Stokes, in press). All subjects were naive with respect to the aims of the experiment and received either course credit or ten dollars for their participation.

Psychometric Test

The Short Raven was administered to all students in the
introduction to psychology course to estimate subjects' IQs. Standard instructions, conforming with those of the full-length test, were read aloud by the experimenter, and 15 minutes were allotted to complete the 12 items. Due to the lack of variability in scores that has typically been found in studies that have administered the full-length Raven to university students (Bors et al., in press), an extreme groups design was used enabling me to compare those scoring in the top and bottom quartiles. Thus, those students scoring above 8 or below 5 were contacted and invited to participate in the study.

Apparatus

For the four experiments reported in this thesis, an IBM-286 compatible computer controlled the stimulus display and recorded the participants' responses. The stimuli were displayed on a Hyundai 35 cm high-resolution (Super VGA) colour monitor. Machine language subroutines with millisecond accuracy developed by Graves and Bradley (1988, 1987) were used to control the exposure durations of the stimulus displays.

Design and Procedure

Each subject, tested individually, participated in a single experimental session that lasted approximately 1 hour. Subjects were seated in a dimly lit room approximately 40 cm from the monitor, and responses were made by pressing one of two keys located beneath the index fingers of each hand. The experimenter was present in the room at all times. Each subject completed
both the 2-line IT task and the letter IT task. Order of IT tasks was counterbalanced such that odd-numbered subjects first completed the letter IT task and even-numbered subjects first completed the line IT task.

Each trial began with the simultaneous presentation of a warning beep and a focal point (a plus sign 4 mm high and 4 mm wide) displayed for 2 seconds, positioned midway between where the two letter stimuli would appear. The focal point was then replaced by the target stimulus which was exposed at a duration of 14, 28, 42, 56, 70, 84, 98, 112, 126, or 140 msec. The mask was presented immediately following the offset of the stimulus and remained on the screen until the subject made a response. To ensure comprehension of instructions, each subject underwent a training session before engaging in the actual experiment. The training session consisted of 10 trials presented at the longest exposure duration (140 msec), and responses were made both manually and verbally to enable the experimenter to determine whether the subject understood the task.

Line IT. The target line IT stimulus consisted of two vertical lines 28 mm and 38 mm in length, 8 mm apart, and aligned at the top by a horizontal line 18 mm long. The longer line appeared on either the right or the left side of the stimulus with equiprobability. The mask, from Nettelbeck and Rabbitt (1992), was composed of two vertical lines, both 46 mm in length, appearing slightly thicker in the centre of the line between 18
cm and 38 cm from the top (see Figure 6a for the sequence of cue, target stimulus, and mask). The mask completely overlaid the stimulus lines, with the intention of preventing further extraction of stimulus information. The target stimulus was presented at each duration 30 times, on 15 of which the longer line appeared on the left side, and on 15 of which it appeared on the right side. The side on which the longer line appeared and the stimulus exposure duration were random. The subjects' task was to determine on which side of the stimulus the longer line appeared.

Figure 6

(a) Temporal sequence of events for the line inspection time task. From left to right: cue, target stimulus, and mask. In this example, the correct response would be to press the key corresponding to "right". (b) Temporal sequence of events for the letter inspection time task. From left to right: cue, target letter set, and mask. In this example, the correct response would be to press the key corresponding to "same".
On each trial, subjects indicated the position of the longer line of the target stimulus by pressing the "z" key if the long line appeared on the left or the "/" key if the long line appeared on the right. There were 12 blocks consisting of 25 trials each, for a total of 300 trials, in 150 of which the longer line appeared on the left side of the stimulus display and in 150 of which the longer line appeared on the right side. Subjects were given a short rest period between blocks, with the length of this period determined by the subject and ranging from 10 sec to 2 min (M = 30 sec).

**Letter IT.** The letter IT stimulus consisted of two lower case letters presented in the centre of the screen and separated by 3 spaces between the letters. Half of the pairs of letters were physically the same and half were physically different. Letters that share orthographic features, such as curves or straight lines, were paired together to increase the difficulty of the task. Based on pilot work, the following letter pairs appeared most effective and hence, comprised the stimulus set: aa, cc, xx, vv, oo, ee, nn, uu, ca, ac, vx, xv, eo, oe, un, and nu. The mask, which varied from trial to trial, consisted of a random set of five letters from the entire alphabet (see Figure 6b for the sequence of cue, target letter set, and mask). The mask completely overlaid the target letters, with the intention of preventing any further extraction of stimulus information. On
any given trial, the mask did not include letters that comprised the stimulus set presented on that trial.

There were 16 pairs of letters in total, 8 of which consisted of same pairs and 8 of which consisted of different pairs. Each letter pair was presented twice at each duration, for a total of 320 trials; stimulus exposure duration was randomized. The subjects' task was to determine whether the target letters were the same or different. On each trial, subjects indicated their response by pressing the "z" key if the target letters were different or the "/" key if the target letters were the same. There were 10 subblocks consisting of 32 trials each, for a total of 320 trials, in 160 of which the letter pairs were different and in 160 of which the letter pairs were the same. As with the line IT task, subjects were given a short rest period between subblocks, the length of this period being determined by the subject and ranging from 10 sec to 2 min (M = 30 sec).

**Questionnaires.** Upon completion of the IT tasks, subjects completed two brief questionnaires to assess the extent to which strategies were used on the two tasks (see Appendices A and B). Odd-numbered subjects first completed the letter IT questionnaire and even-numbered subjects first completed the line IT questionnaire. The format of the questionnaires was identical but the wording was slightly different to accommodate the
different IT tasks. The first three questions, taken from Chaiken (1994), were warm-up fillers inquiring about task difficulty, frequency of guessing, and improvement over time. The fourth question was open-ended and attempted to ascertain whether subjects used a strategy by asking them to describe how they made the decision about which side the long line occurred on (line IT task) or about whether the two letters were the same or different (letter IT task). The fifth and sixth questions were crucial questions that marked the subjects as users of the apparent movement strategy and/or flash strategy. Thus, although some subjects may have been aware of movement or flashes, they may not have necessarily used them as part of a strategy in determining their response. Hence, questions 5b and 6b specifically asked subjects whether they used such cues as part of a strategy in determining their response.

Results and Discussion

Due to the high correlations that have been found between total accuracy on the IT task and calculated IT ($r = .89, p < .001$; Stokes, 1995), all results will be expressed in terms of total accuracy rather than IT. ITs were not calculated and analyses were conducted using total accuracy only, rather than using IT per se. Furthermore, to allow comparisons across tasks, all results are expressed in terms of percentage correct.
Strategy Use

The analysis of the responses to the questionnaires indicated that the number of users and nonusers of strategies was dramatically different across the two IT tasks. Answers to Questions 5 and 6, the crucial questions that marked the subjects as users or nonusers of the apparent movement and/or flash strategy, indicated that of the 44 subjects tested, 42 reported using a strategy on the line IT task, whereas only 1 reported having used a strategy based on one of these cues on the letter IT task. The number of subjects reporting to have noticed at least one of these cues on the line and letter IT tasks were 42 and 11, respectively. A test of the change in the proportion of subjects reporting use of a strategy across the two tasks indicated that the change was significant \((k = 6.00, p < .001)\), with 100% of the changes occurring in the direction from being a strategy user on the line task to being a nonuser on the letter task.

Further analysis of Question 4, the open-ended question which allowed participants to describe how they made the decision on each trial, indicated that whereas there was a clear consensus of how such strategies were used during the line IT task, none of those who reported noticing a strategy on the letter IT task reported adopting a systematic strategy that specifically involved apparent movement or flash cues. For example, among those who reported using such cues on the line IT task, when
given the opportunity to describe these cues in their own words, self reports such as "the line that looked like it grew was the shorter one", "I noticed that the masks for each side dropped at different speeds...I just chose the side where the mask dropped first as the longer side", "one line would end up covering empty space, so I knew that had to be the shorter line", and "I could see a line growing faster for the very quick ones" were frequently given.

On the other hand, when given the opportunity to describe how they made the same-different distinction on the letter IT task, among those claiming to have noticed movement or flashes, statements such as "whatever I saw determined it", "I scanned the letters as quickly as possible from left to right and determined if they had the same shape or not", and "... the mask end letter helped", were reported. Thus, although there was clear consensus as to how such strategies worked on the line IT task, I failed to find evidence for the presence of systematic strategy use on the letter IT task, indicating that my attempt to develop an IT task that would eliminate strategy use was largely successful, at least as measured by post-experimental subject reports.

**Line vs. Letter IT Tasks**

A 2(task) X 2(block) x 2(IQ) ANOVA indicated a significant main effect of task \([F(1,42) = 102.33, MSE = 72.60, p < .001]\), and of block \([F(1,42) = 6.40, MSE = 12.23, p < .05]\), and a
significant interaction between task and block \([F(1,42) = 7.38, \text{MSE} = 14.72, p = .01]\). The main effect of task indicated that the two tasks differed in difficulty (see Table 1 for descriptive statistics), with the letter IT task \((M = 88.1\%)\) being significantly easier than the line IT task \((M = 75.2\%)\). The main effect of block indicated that accuracy increased over time. The significant Block X Task interaction was further explored by examining the simple effect of block at each task. The simple effect of block on the line IT task was significant \([F(1,42) = 8.10, \text{MSE} = 22.92, p < .01]\), indicating that accuracy rates significantly increased from block 1 to block 2 on the line task. The simple effect of block on the letter IT task was not significant \([F(1,42) < 1, \text{MSE} = 10.33]\), indicating that no increase in accuracy occurred across blocks on the letter task. This finding may, at least in part, be due to the presence of a ceiling effect which prevented subjects from significantly increasing their accuracy rates across the two blocks on the letter IT task.

The finding that accuracy, as assessed by the line task, increased with practice is consistent with past studies (Nettelbeck et al., 1982; Nettelbeck & McLean, 1984; Nettelbeck & Wilson, 1985; MacKenzie & Bingham, 1985). This finding also indicates that there may be perceptual or cognitive processes, perhaps strategic in nature, related to performance on the line
IT task that become more efficient over time (Bors et al., in press). The notion that strategic processes affect performance is indicated by the overwhelmingly large proportion (89%) of participants who reported adopting a strategy based on either apparent motion or flash cues, or both, on the line task (see Strategy Use section). The influence of cognitive processes on IT performance will be explored further in Experiments 2, 3, and 4.

Table 1
Experiment 1: Descriptive statistics for the line and letter IT tasks as a function of block.

<table>
<thead>
<tr>
<th></th>
<th>Line Task</th>
<th>Letter Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Percent Correct</td>
<td>75.20</td>
<td>88.10</td>
</tr>
<tr>
<td>overall</td>
<td>73.70</td>
<td>88.20</td>
</tr>
<tr>
<td>block 1</td>
<td>76.60</td>
<td>88.00</td>
</tr>
<tr>
<td>High IQ</td>
<td>78.55</td>
<td>89.81</td>
</tr>
<tr>
<td>Low IQ</td>
<td>71.51</td>
<td>86.27</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>9.48</td>
<td>5.30</td>
</tr>
</tbody>
</table>

IT Performance and IQ

A main effect of IQ was found \(F(1,42) = 9.02, \text{MSE} = 136.36, p < .005\), indicating higher accuracy rates on the line IT task among the high IQ subjects (see Table 1). This finding fits well with past studies that have found higher IQ participants, on average, able to detect the stimulus at shorter exposure durations than their lower IQ counterparts (see Kranzler & Jensen, 1989; Nettelbeck, 1987; for a review). The Task X IQ interaction and the Task X IQ X Block interaction did not reach
significance \[ F(1,42) = 1.85, \text{MSE} = 72.60, p > .1, \text{and} F(1,42) < 1, \text{respectively} \]. Hence, the finding that the high IQ group outperformed the low IQ group was consistent across blocks and both tasks.

**Bias Effect on the Letter IT Task**

Further investigation of accuracy rates obtained on the letter IT task indicated that subjects were more accurate on letter sets that were different than they were on letter sets that were the same \[ F(1,42) = 75.51, \text{MSE} = 16.19, p < .001 \]. Analysis of accuracy rates at each exposure duration for same and different stimuli indicated a systematic bias to respond "different" at the shorter durations, resulting in questionably high accuracy rates for the different stimulus letter sets at these durations (see Table 2). The significant Duration X Letter Set Type (i.e., same or different stimulus pairs) interaction \[ F(9,936) = 118.27, \text{MSE} = 1.83, p < .001 \], indicated that the bias became less apparent as the exposure duration increased. This finding, however, is a result of a ceiling effect that occurred across all exposure durations for the letter stimulus sets that were different; a ceiling effect for the letter stimulus sets that were the same did not occur until the exposure duration of 70 msec.

In addition, a significant positive correlation of .30 (\( p < .05 \)) was found between \( d' \), a measure which corrects hit rates for
false alarms rates, and IQ, indicating that higher IQ subjects better discriminated between the same and different letter sets than did their lower IQ counterparts.

Table 2
Experiment 1: Mean accuracy for same and different stimuli on the letter IT task as a function of duration in msec.

<table>
<thead>
<tr>
<th>Duration</th>
<th>Stimulus Set Same</th>
<th>Different</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>4.47</td>
<td>14.58</td>
</tr>
<tr>
<td>28</td>
<td>9.29</td>
<td>14.00</td>
</tr>
<tr>
<td>42</td>
<td>11.69</td>
<td>15.09</td>
</tr>
<tr>
<td>56</td>
<td>13.58</td>
<td>15.04</td>
</tr>
<tr>
<td>70</td>
<td>14.07</td>
<td>15.24</td>
</tr>
<tr>
<td>84</td>
<td>14.78</td>
<td>15.38</td>
</tr>
<tr>
<td>98</td>
<td>14.87</td>
<td>15.53</td>
</tr>
<tr>
<td>112</td>
<td>15.09</td>
<td>15.62</td>
</tr>
<tr>
<td>126</td>
<td>15.09</td>
<td>15.71</td>
</tr>
<tr>
<td>140</td>
<td>15.51</td>
<td>15.53</td>
</tr>
</tbody>
</table>

Note: accuracy for each letter set type is out of 16 (16 same and 16 different letter sets per duration).

Summary of Experiment 1

A new IT task was developed that successfully eliminated systematic strategy use. The relation between IT and IQ was found to be as strong under the letter task condition as it was under the line task condition, with higher IQ participants outperforming their lower IQ counterparts across both IT tasks. Because the letter IT task was effective at eliminating systematic strategy use arising from apparent movement and flash cues, it may be reasonable to conclude that the letter IT task provides a more pure measure of simple speed of sensory input, whereas the typical 2-line IT task measures higher order cognitive processes, such as the ability to adopt effective
strategies, in addition to speed of sensory input. This does not mean, however, that speed of sensory input is the primary basis for individual differences in IT. For example, in addition to mental speed, higher order cognitive processes other than systematic strategy use, such as individual differences in attention, may continue to underlie the IT-IQ association.

Experiment 2

Experiment 1 introduced a new IT task (letter IT) that successfully eliminated the use of systematic strategies such as apparent motion and flash cues. In Experiment 2, I will explore the effects of practice on IT, as assessed by the letter IT task, and the impact that it may have on the IT-IQ relation.

Bors et al. (in press) tested the reliability of the typical IT measure by having subjects complete 300 trials of the 2-line IT task per day, over three consecutive days. They found correlations among ITs of .76, .72, and .90 for Days 1 and 2, Days 1 and 3, and Days 2 and 3, respectively. Thus, the available evidence suggests that IT, as assessed by the typical 2-line task, is quite stable across days.

By examining the influence practice exerts on the IT-IQ correlation and on IT variability, I hope to shed some light on the issue of whether mental speed (i.e., a cognitively effortless) or some higher order cognitive factor (i.e., a cognitively effortful process) is the primary determinant of individual differences in IT. For example, if mental speed is
the primary determinant of individual differences in performance on the IT task, with other cognitive factors also influencing performance, albeit in a non-systematic manner with respect to IQ, practice should result in one of two outcomes. First, if practice serves to reduce noise from nuisance variables (i.e., cognitive factors), then an increase in mean performance on the IT task should occur, coupled with a decrease in IT variability and an increase in the correlation between IT and IQ. That is, as noise is reduced, the variability in scores due to error (i.e., error variance) will decrease. Consequently, the influence of the mental speed component of the task will become clearer, resulting in a strengthening of the correlation between IQ and IT over time.

Second, if practice serves to increase noise from other cognitive factors, then an improvement in mean performance on the IT task would still be expected, however, an increase in variability and an attenuation in the correlation between IT and IQ should occur. Thus, as more noise is added, the variability in scores due to error will increase. Consequently, the influence of the mental speed component of the task will become less clear and the correlation between IT and IQ will decrease.

If, on the other hand, some higher order cognitive factor is the primary determinant of individual differences in performance on the IT task, with mental speed influencing IT performance in a non-systematic manner with respect to IQ, one of two outcomes
should occur. First, an improvement in mean performance on the IT task, a decrease in variability, and a decrease in the correlation between IT and IQ would be expected if practice serves to decrease individual differences in the higher order cognitive factor. That is, if some higher order cognitive factor is the primary determinant of individual differences in performance on the IT task and practice serves to make subjects more alike on this variable, then there should be less variability in performance, and consequently the correlation between IT and IQ should be attenuated.

Second, if practice serves to increase individual differences in the higher order cognitive factor, then an improvement in mean IT performance would still be expected, however, an increase in variability and an increase in the correlation between IT and IQ should occur. That is, an increase in variability and an attenuation in the correlation between IT and IQ over time would suggest that other higher-order processes sensitive to practice may be important factors underlying this correlation.

Thus, the purpose of Experiment 2 is to estimate the reliability of the letter IT task, as well as to explore the effects of practice on IT variability and on the IT-IQ correlation.

**Method**

**Participants.** Forty-eight volunteers with normal or
corrected to normal vision were recruited from the introductory psychology class at the University of Toronto at Scarborough. Nine failed to complete all five days of testing, and their data were subsequently discarded. The remaining group of 12 men and 27 women ranged in age from 18 to 24 years ($M = 19.92, S.D. = 2.76$). All subjects were naive with respect to the aims of the experiment and received either course credit or $35.00 for their participation. Because the number of volunteers interested in returning for five consecutive days was limited, an extreme groups design was not used in this experiment. Instead, all interested students in the introduction to psychology course were invited to participate.

**Apparatus.** Equipment used was identical to that described in Experiment 1.

**Psychometric Test.** The 12-item short form of the Raven Advanced Progressive Matrices test (Bors & Stokes, in press), as described in Experiment 1, was used to estimate subjects' IQs.

**Design and Procedure.** Subjects were tested over five consecutive days, at approximately the same time each day, on the letter IT task identical to that described in Experiment 1. The training session, which familiarized the subject with the IT task, preceded testing on the first day only. After each session, subjects were questioned about how they made the same-different decision from trial to trial and about their use of
strategies.

Results and Discussion

Accuracy Rates and Practice. The descriptive statistics for accuracy on the letter IT task are presented in Table 3. Practice resulted in a significant linear increase in accuracy \([F(1,38) = 110.32, \text{MSE} = 62.89, p < .001]\). Furthermore, a significant quadratic trend was found \([F(1,38) = 26.93, \text{MSE} = 26.39, p < .001]\), indicating that subjects were approaching asymptotic performance. The finding of a linear trend is consistent with that found when performance on the typical 2-line IT task was tested over a period of three consecutive days (Bors et al., in press). The absence of a quadratic trend in the Bors et al. (in press) study may simply indicate that three days were not sufficient practice to produce asymptotic performance. In the current study, however, a significant quadratic trend was found for the first 3 days of testing \([F(1,38) = 7.14, \text{MSE} = 34.65, p = .011]\), suggesting that three days may be sufficient practice to produce asymptotic performance on the letter IT task.

Table 3

<table>
<thead>
<tr>
<th>Day</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>235</td>
<td>249</td>
<td>260</td>
<td>236</td>
<td>260</td>
</tr>
<tr>
<td>Maximum</td>
<td>297</td>
<td>308</td>
<td>313</td>
<td>317</td>
<td>311</td>
</tr>
<tr>
<td>Mean</td>
<td>278</td>
<td>287</td>
<td>291</td>
<td>294</td>
<td>296</td>
</tr>
<tr>
<td>S.D.</td>
<td>13.2</td>
<td>12.6</td>
<td>11.7</td>
<td>14.4</td>
<td>12.0</td>
</tr>
</tbody>
</table>

Note: accuracy out of 320; *standard deviation
In addition, with the exception of Day 4, practice resulted in a systematic decrease in variability (see Table 3). Hence, practice served to increase mean IT performance and decrease variability.

**Same vs. Different Stimuli.** As found in Experiment 1, further investigation of accuracy rates obtained on the letter IT task suggested that subjects were more accurate on letter sets that were different than they were on letter sets that were the same \[F(1,38) = 3.44, \text{MSE} = 908.19, p = .07\]. The significant Test Day X Letter Set Type (i.e., same or different stimulus pairs) interaction \[F(4,152) = 6.98, \text{MSE} = 25.10, p < .001\], indicated that the bias became less apparent over the five days (see Table 4). This bias was particularly pronounced on the first 3 days of testing, indicating that greater familiarity with the task led to increased accuracy rates and a decreased tendency to favour the response of "different." The finding that the bias decreased over time suggests that, with practice, sufficient information becomes available to make the appropriate decision.

**Reliability of the Letter IT Task.** As illustrated by the correlations among accuracy rates for the five days (see Table 5 for correlations), the letter IT task was quite reliable across days. On average, the highest correlation occurred on consecutive days, suggesting extremely high reliability from day to day. An average correlation of .80 was found over the five
testing days, suggesting that the letter IT task is highly reliable. Furthermore, the reliability of the letter task compares satisfactorily with the average correlation of .79 that was found when the typical 2-line IT task was tested over three consecutive days (Bors et al., in press).

Table 4
Experiment 2: Descriptive statistics for same and different stimuli of the letter IT task across five consecutive days.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Same Stimuli</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>100</td>
<td>110</td>
<td>116</td>
<td>126</td>
<td>128</td>
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<tr>
<td>Maximum</td>
<td>157</td>
<td>158</td>
<td>158</td>
<td>159</td>
<td>159</td>
</tr>
<tr>
<td>Mean</td>
<td>134</td>
<td>140</td>
<td>143</td>
<td>145</td>
<td>146</td>
</tr>
<tr>
<td>S.D.*</td>
<td>14.6</td>
<td>12.0</td>
<td>11.0</td>
<td>9.1</td>
<td>9.1</td>
</tr>
<tr>
<td><strong>Different Stimuli</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>115</td>
<td>95</td>
<td>105</td>
<td>126</td>
<td>103</td>
</tr>
<tr>
<td>Maximum</td>
<td>159</td>
<td>159</td>
<td>160</td>
<td>159</td>
<td>159</td>
</tr>
<tr>
<td>Mean</td>
<td>144</td>
<td>147</td>
<td>148</td>
<td>146</td>
<td>149</td>
</tr>
<tr>
<td>S.D.*</td>
<td>12.8</td>
<td>12.7</td>
<td>10.9</td>
<td>14.2</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Note: accuracy out of 160 (320 trials in total: 160 same, 160 different); *standard deviation

**IT-IQ Correlations.** The correlation of .41 that was found between accuracy on Day 1 and Short Raven scores is consistent with that found in Experiment 1 and is well within the range of those found to be significant in other studies that have used the typical 2-line procedure to estimate ITs. The correlation between IQ and accuracy on the letter IT task decreased over the five day period, suggesting that practice attenuated this relation. These findings are consistent with those found when the line IT task was tested over three consecutive days (Bors et al., in press).
The finding of a linear increase in accuracy across days, together with an attenuation in the correlation between accuracy and IQ and a decrease in variability, suggests that there may be cognitive processes related to performance on the IT task that become more efficient over time (Bors et al., in press).

**Strategy Use.** Each day, upon completion of the letter IT task, subjects were asked whether they had used a strategy to help guide their decision about the same-different distinction. As with the previous experiment, subjects did not report using systematic strategies. More important, none of the subjects reported noticing or using such cues on subsequent testing days, even after having been directly asked about apparent motion or brightness cues the day (or days) before. Thus, as with Experiment 1, I failed to find evidence for the presence of systematic strategy use on the letter IT task, indicating that my attempt to develop an IT task that would eliminate strategy use was largely successful, even after having received substantial practice over five consecutive days.
Summary of Experiment 2

Subjects were tested on the letter IT task over a period of five consecutive days. Practice on the letter task resulted in a significant linear increase in accuracy and a systematic decrease in variability. A significant quadratic trend was also found, indicating that subjects were approaching asymptotic performance.

The letter IT task was found to be as reliable as the line task, with a mean correlation of .80 obtained over the five testing days. As found in previous studies with the line task, the correlation between IQ and accuracy on the letter task decreased over the five day period, suggesting that practice attenuates the relation between accuracy on the letter IT task.

The findings of a linear increase in accuracy across days, an attenuation in the correlation between accuracy and IQ, and decreased variability, suggest that other higher order processes sensitive to practice may be important factors underlying the IT-IQ correlation, with practice serving to reduce individual differences in these cognitive processes. In addition, the findings suggest that cognitive processes, rather than mental speed, may be the primary determinants of individual differences in performance on the IT task, with practice serving to reduce individual differences in these cognitive processes. Experiments 3 and 4 begin exploring the alternative hypothesis and, hence, the extent to which higher order cognitive processes affect the correlation between IQ and accuracy on the letter IT task.
Experiments 1 and 2 introduced a new IT task (letter IT) that successfully eliminated systematic strategy use, such as those arising from apparent motion and flash cues. In Experiment 3, I will begin exploring the extent to which higher order cognitive processes--specifically, higher level strategic processes--affect performance on the letter IT task and the impact that this may have on the IT-IQ relation. To do so, participants will be tested on the letter IT task, as described in Experiment 1, under each of two conditions: with and without feedback.

If mental speed is the primary determinant of individual differences in performance on the IT task, with other cognitive factors, such as higher level strategic processes, also influencing performance, albeit in a non-systematic manner with respect to IQ, then the effect of feedback should result in one of two outcomes. First, if feedback serves to reduce noise from other cognitive factors, then performance should become less variable and the difference in performance between the high and low IQ groups should increase. That is, as noise is reduced, the variability in scores due to error (i.e., error variance) should decrease. Consequently, performance should become less variable and the difference in performance between the high and low IQ groups should increase as the true difference between these groups becomes more apparent.
Second, if feedback serves to increase noise from other cognitive factors, then performance should become more variable and the difference in performance between the high and low IQ groups should decrease. That is, as noise is increased, the error variance will increase. Consequently, performance should become more variable and the difference in performance between the high and low IQ groups should decrease as the true difference between these groups becomes less apparent.

If, on the other hand, some higher order cognitive factor, such as individual differences in higher level strategic processes, is the primary determinant of individual differences in performance on the IT task, with mental speed influencing IT performance in a non-systematic manner with respect to IQ, and if this cognitive factor is sensitive to feedback, then one of two outcomes should occur. First, a decrease in variability and a decrease in mean IT performance between high and low IQ groups would be expected if feedback serves to decrease individual differences in the cognitive factor. For example, feedback may provide participants with the opportunity to evaluate and modify the influence of higher level strategic processes. If brighter subjects already employ the best cognitive strategy, then feedback will serve to increase performance among their lower IQ counterparts only; accordingly, individual differences in IT performance will decrease and the IQ-IT relation will become less apparent.
Second, if feedback serves to increase individual differences in the cognitive factor, there will be an increase in variability, and consequently the difference between high and low IQ should become more apparent. For example, feedback may provide participants with the opportunity to evaluate and modify the influence of such processes, enabling those with superior higher order cognitive processes to improve their performance to a greater extent than others; accordingly, individual differences in IT performance will increase and the IQ-IT relation will become more apparent.

In short, the aim of Experiment 3 is to determine whether individual differences in higher level strategic processes (other than apparent movement strategy use) continue to influence performance on the letter IT task. Furthermore, I will address the issue of whether mental speed or some higher level strategic process is the primary determinant of individual differences in IT performance by examining the effect that feedback has on the variability in IT performance and on the relation between IT and IQ.

Method

Participants. Thirty-three volunteers with normal or corrected to normal vision were recruited from the introductory psychology class at the University of Toronto at Scarborough. One participant was dropped from the sample because performance on both of the IT tasks was not above chance. The remaining 32
participants, 23 female and 9 male, ranged in age from 18 to 28 \(M = 19.78, \text{ S.D.} = 1.76\). As in Experiment 1, and extreme groups design was used and participants were preselected by the experimenter based on scores obtained on the Short Raven. All subjects were naive with respect to the aims of the experiment and received either course credit or ten dollars for their participation.

Apparatus. All equipment used was identical to that described in Experiment 1.

Design and Procedure. Each subject, tested individually, participated in a single experimental session that lasted approximately 30 minutes. Subjects completed the letter IT task under each of two conditions: with and without feedback. Order of the feedback conditions was counterbalanced such that odd numbered subjects first completed the letter IT task without feedback and even numbered subjects first completed the letter IT task with feedback.

The letter IT task without feedback was identical to that described in Experiment 1, with the exception of the number of trials. Further examination of the results of the letter IT task in Experiment 1 indicated that most subjects (91%) were performing at or above 90% accuracy at exposure durations longer than 112 msec (Duration 8). As a result, to shorten the length of the present experiment, the two longest exposure durations
were removed and each stimulus set was presented once at the exposure durations of 14, 28, 42, 56, 70, 84, 98, and 112 msec. Thus, the 16 letter pairs (8 same and 8 different; see Procedure section of Experiment 1 for stimuli) were presented once at each of eight exposure durations, for a total of 128 trials. Subjects were given a brief rest period after every 32 trials; the length of this period was determined by the subject.

For the feedback condition, training, number of trials, and procedure was the same as the no-feedback condition. Under this condition, however, a message appeared on the screen for 500 msec after each trial indicating the accuracy of the subjects' response. Hence, for trials that were responded to incorrectly, the word "WRONG" was displayed in the centre of the screen for 500 msec immediately after the subject responded. For trials that were responded to correctly, the word "RIGHT" was presented in the centre of the screen for 500 msec immediately after the subject responded.

Results and Discussion

Feedback vs. No-Feedback. Unexpectedly, feedback had no effect on IT performance. A 2(task) X 2(IQ) ANOVA failed to indicate a main effect for task \([F(1,31 < 1, \text{MSE} = 11.28)]\), with subjects achieving accuracy rates of approximately 87% under the feedback and no-feedback conditions (see Table 6 for descriptive statistics). This result may be interpreted as indicating that
(1) no higher level strategic processes influence performance on the letter IT task; (2) higher level strategic processes do influence performance, but feedback is an ineffective means of increasing individual differences in these processes; or (3) higher level strategic processes do influence performance, but because performance approached ceiling, feedback was unable to produce differences.

Table 6
Experiment 3: Descriptive statistics for the feedback and no-feedback conditions of the letter IT task.

<table>
<thead>
<tr>
<th></th>
<th>Feedback</th>
<th>No-Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Accuracy overall'</td>
<td>86.82</td>
<td>87.21</td>
</tr>
<tr>
<td>Low IQ</td>
<td>86.39</td>
<td>85.61</td>
</tr>
<tr>
<td>High IQ</td>
<td>87.07</td>
<td>88.16</td>
</tr>
<tr>
<td>S.D.*</td>
<td>5.33</td>
<td>5.82</td>
</tr>
</tbody>
</table>

Note: 'accuracy reported in terms of percentage correct
*standard deviation

IT Performance and IQ. The main effect of IQ was not significant \([F(1,30) < 1, MSE = 51.37]\), nor was the Task X IQ interaction \([F(1,30) < 1, MSE = 11.28]\). Two reasons may explain why the main effect of IQ did not approach significance. First, reliability is an issue. The IT task in the present study consisted of less than half of the trials used in the letter IT tasks of Experiments 1 and 2; hence, it is possible that 128 trials were insufficient to produce significant performance differences among the high and low IQ groups. Second, because the total number of subjects used was small \((n = 32)\), sampling error may have been responsible for failing to find a main effect
of IQ under the no-feedback condition. Furthermore, this finding may be attributed to the partial ceiling effect that was obtained. That is, had the partial ceiling effect not occurred, individual differences in IT performance, and the IQ-IT relation, may have been more apparent.

**Summary of Experiment 3**

Subjects were tested on the letter IT task under each of two conditions: with and without feedback. No differences were found between accuracy rates obtained under the feedback and no-feedback conditions. This finding may be interpreted as indicating that (1) no higher level strategic processes influence performance on the letter IT task; (2) higher level strategic processes do influence performance, but feedback is an ineffective means of increasing individual differences in these processes; or (3) higher level strategic processes do influence performance, but feedback was unable to increase such differences because performance approached ceiling.

**Experiment 4**

Experiment 3 began exploring the extent to which higher order cognitive processes--specifically, higher level strategic processes--continue to influence performance on the letter IT task by testing subjects under each of two conditions: with and without feedback. Unexpectedly, results indicated that individual differences in IT performance were uninfluenced by feedback. The findings of Experiment 3, however, are
inconclusive because a partial ceiling effect was obtained which may have prevented feedback from increasing individual differences in IT performance. Accordingly, I seek to further explore the notion that other cognitive processes influence performance on the IT task. Specifically, I will explore the extent to which individual differences in attention influence performance on the letter IT task.

Past studies have shown that strategy use has not been the only factor to influence IT. Recently, a number of studies have concluded that attention (i.e., ability to remain focused on the task) may be another factor. For example, Nettelbeck and McLean (1984) investigated the notion that the longer average ITs that are typically found among retarded subjects may reflect less effective sensory registration caused by poor attention and focusing. Sixteen retarded subjects and 16 non-retarded subjects were tested on the typical IT task. In the mask condition, the target figure was immediately followed by the masking figure, whereas in the no mask condition, a dark screen appeared immediately after the target stimulus presentation.

Results indicated a significant effect of group and session in the mask condition, suggesting that overall practice effects were similar for both groups, with lower levels of performance overall for the retarded subjects. A significant group difference was also found in the no mask condition, indicating that whereas non-retarded subjects displayed asymptotic
performance from the initial session, retarded subjects showed considerable variability in performance across sessions. Nettelbeck and McLean (1984) have suggested that early improvement in the mean IT of the non-retarded group reflects more efficient encoding from sensory registration as a consequence of experience during the initial session. Although a similar trend was found among the retarded subjects, their performance was less effective in the no mask condition, suggesting that retarded subjects had poorer control of attentional processes directing registration.

Nettelbeck, Hirons, and Wilson (1984; Experiment 3) also tested the suggestion that attention may influence performance on the 2-line IT task. Fifteen mildly retarded subjects and 14 non-retarded subjects were required to fixate and follow an oscillating pendulum with their eyes. Video records for each subject were monitored to detect occurrences of eyeblinks and inattentiveness. An analysis uncovered a significant group effect reflecting less effective tracking among retarded subjects. Results of the video records indicated that the retarded group experienced more attentional lapses than did the non retarded group. The deviant eye movements found in this study were presumed to reflect some involuntary, central, attentional process, hence, these authors attribute the markedly deviant eye-tracking among retarded subjects to an attentional impairment that is also reflected by IT.
Finally, Bors et al. (in press) tested subjects on the typical 2-line IT task, the full length Raven, and on an attention task. The attention task was identical to the IT task with respect to the physical context, equipment used, number of trials (both training and actual experimental trials), pacing, and method of response. Each trial began with the simultaneous presentation of two short beeps and the asterisk located in the centre of the screen. Following a 1 to 3 sec exposure period, the asterisk was removed for a period of 14 msec on half of the trials. The subjects' task was to determine whether the asterisk briefly flickered during each trial by pressing the appropriate response key. The duration of 14 msec for the disappearance of the asterisk was chosen after pilot work which indicated that all subjects are able to detect the flash at this speed with nearly 100% accuracy. Thus, the purpose was not to determine whether the subject was able to detect the flash, but whether they had paid sufficient attention to the task on any given trial to detect it.

A significant negative correlation was found between Raven scores and IT. Hence, consistent with the mental speed hypothesis, subjects with high IQs had brief ITs. Raven scores were positively correlated with hit rate and negatively correlated with false alarm rate on the sustained attention task, suggesting that those with high Raven scores made more hits on the sustained attention task without making more false alarms.
Raven scores were significantly correlated with d's derived from the attention task, suggesting that subjects with high Raven scores can better focus their attention on the task at hand than their lower scoring counterparts. Finally, a nonsignificant difference was found between the regression of IQ on d' alone and the regression of IQ on both d' and IT, suggesting that IT contributes little to IQ above and beyond that already contributed by d'. In short, Bors et al. (in press) concluded that the correlation between IT and IQ may not be based on anything other than what is measured by the sustained attention task. Thus, their results provide support for the view that attention influences the relation between IT and IQ.

In short, these findings (Bors et al., in press; Nettelbeck & McLean, 1984; Nettelbeck et al., 1984) offer support for the notion that attention influences the relation between IT and IQ. The purpose of Experiment 4 is to further explore the role of individual differences in attention on the relation between accuracy on the letter IT task, a task that is presumably less cognitively effortful than the line IT task due to the elimination of response strategies, and IQ. To achieve this, subjects will be tested on the letter IT task under each of two conditions: with and without a concurrent shadowing task.

If mental speed is the primary determinant of individual differences in performance on the IT task, and individual differences in attention also influence performance, albeit in a
non-systematic manner with respect to IQ, then reducing attentional resources should result in one of two outcomes. First, if reducing attentional resources serves to reduce noise, then a decrease in IT variability and an increase in the correlation between IT and IQ should occur. Hence, if the shadowing task serves as an effective load, it will reduce individual differences in attention by decreasing attentional resources to a minimum among all subjects, thus reducing the error variance and providing a measure of IT that is uninfluenced by another individual differences variable (i.e., attention). Consequently, performance should become less variable and the correlation between IQ and IT should increase because the true correlation between these factors will become more apparent.

Second, if reducing attentional resources serves to increase noise by increasing individual differences in attention, then performance should become more variable, and consequently the correlation between IT and IQ should decrease. For example, adding a concurrent secondary task may have little impact on attentional resources among some subjects, whereas it may drastically reduce attentional resources among others. That is, as noise is increased, the error variance will increase. Consequently, performance should become more variable and the correlation between IQ and IT should decrease because the true correlation between these factors will become less apparent.

If, on the other hand, attention is one of the primary
determinants of individual differences in performance on the IT task, then the mean IT performance under the control condition (i.e., full attention) should be greater than that found under the divided attention condition. That is, if attentional resources are required for effective performance on the IT task, then reducing attentional resources should reduce mean IT performance.

Additionally, with respect to IT variability and the IT-IQ correlation, one of two outcomes should occur. First, if reducing attentional resources serves to make subjects more alike on this variable (by decreasing attentional resources to a minimum among all subjects), then there should be less variability in performance, and consequently the correlation between IT and IQ should decrease.

Second, if reducing attentional resources serves to increase individual differences in attention, then there should be more variability in performance, and consequently the correlation between IT and IQ should increase. For example, if attention is one of the primary determinants of individual differences in performance on the IT task, then adding a concurrent task may be more detrimental to the IT performance of those with fewer attentional resources than it is to those with greater attentional resources.

In short, the aim of Experiment 4 is to assess the extent to which individual differences in attention influence performance
Method

Participants. Thirty-two volunteers with normal or corrected to normal vision participated in this experiment. One participant was dropped from the sample because performance on both of the letter IT tasks was not above chance. The 31 remaining participants, 22 female and 9 male, ranged in age from 18 to 30 \( (M = 20.28, S.D. = 2.72) \). Unlike Experiments 1 and 3, subjects were not preselected by the experimenter based on scores obtained on the Short Raven\(^1\). All subjects were naive with respect to the aim of the experiment and received either course credit or ten dollars for their participation.

Apparatus. All equipment used was identical to that described in Experiment 1.

Design and Procedure. Each subject, tested individually, participated in a single experimental session that lasted approximately 45 minutes. Subjects completed the letter IT task under each of two conditions: with and without a concurrent shadowing task. Order of the shadowing tasks was counterbalanced such that odd numbered subjects first completed the letter IT task without the concurrent shadowing task and even numbered subjects first completed the letter IT task with the concurrent shadowing task.

The letter IT task without the concurrent secondary task
(no-load condition) was similar to the no-feedback condition described in Experiment 3, with the exception of the stimuli used and number of trials. As a result of the high accuracy rates obtained in Experiment 3, 12 new sets of letter pairs that appeared to be more similar in terms of orthographic features were selected to increase the difficulty of the task and to reduce the likelihood of a ceiling effect occurring again. In addition, Duration 8 (98 msec) was deleted because the majority of subjects (about 90%) were performing at or above 90% accuracy at this exposure duration in the previous experiment, resulting in 112 trials in total for Experiment 4. Thus, the following letter pairs comprised the stimulus set: cc, ee, nn, uu, hh, bb, qq, gg, ce, ec, nu, un, hb, bh, qg, and gq. As with the first two experiments, the mask, which varied from trial to trial, consisted of a random set of five letters that completely overlaid the target letters, preventing any further extraction of stimulus information.

For the condition with the concurrent secondary task (load condition), training, number of trials, and procedure was the same as for the no-load condition. In the load condition, however, participants simultaneously performed a shadowing task while completing the letter IT task. For the shadowing task, subjects wore headphones and listened to a prerecorded tape of random numbers, ranging from 1 to 10, presented at a rate of 1 per second. The subject's task was to repeat the number aloud
immediately after it had been presented. To ensure subjects understood the secondary task, the experimenter demonstrated by shadowing the first 5 numbers presented on the tape. Immediately afterwards, the subject was instructed to shadow the next five numbers presented on the tape. Following this, subjects completed 10 training trials of the letter IT task, while simultaneously performing the shadowing task, before engaging in the actual experiment.

Results and Discussion

**Load vs. No-load.** A one way ANOVA indicated a main effect for condition \[F(1,29) = 24.68, \text{MSE} = 41.31, p < .001\], with mean accuracies of 81.5% and 73.3% obtained under the no-load and load conditions, respectively. Hence, overall accuracy on the letter IT task dropped significantly when subjects were required to divide their attention between the letter IT task and a concurrent secondary task, supporting the notion that individual differences in attention may be, at least in part, responsible for performance on IT tasks. If attentional resources were not important for performance on IT tasks, then a decline in mean performance should not have occurred under the divided attention condition.

The finding that variance in IT performance obtained under the load condition (95.26) was greater than that obtained under the no-load condition (60.06) also suggests that individual
differences in attention may be, in part, responsible for performance on IT tasks. Consequently, reducing attentional resources serves to increase individual differences in attention, resulting in greater variability in performance on the IT task.

The correlation between the two letter IT tasks (with and without a concurrent load) was positive and significant \( (r = .48, p = .007) \). The finding that the relation between the two conditions appears to be only moderate suggests that, in addition to a shared underlying component (e.g. mental speed), at least one of these tasks is tapping an additional process. The fact that the correlation between the load and no-load conditions was less than the average test-retest reliability of the IT task (.48 vs. .80, respectively), suggests that different cognitive components may be required for effective performance under the conditions of full and divided attention. That is, if the correlation between the two conditions did not differ from the test-retest reliability coefficient, then it would suggest that similar cognitive processes were required under both conditions, with the decrease in mean IT performance simply being attributed to the greater difficulty of the divided attention condition. The finding that the correlation between the two conditions was smaller than the test-retest reliability coefficient, however, suggests that different components may be required under the two conditions of full and divided attention. Accordingly, because
performance dropped substantially when subjects were required to divide their attention between the two tasks, and because the variability in performance increased under the load condition, it appears that attentional resources may influence IT performance to a greater extent under the load condition than under the no-load condition.

**IT-IQ Correlations.** Unexpectedly, a correlation of -.13 was found between IQ, as estimated by the Short Raven, and accuracy under the no-load condition of the letter IT task and a correlation of .06 was found between IQ and accuracy under the load condition of the letter IT task; both correlations did not significantly differ from zero. Past research suggests that correlations around -.5 should be found between IQ and IT, at least under the no-load condition. The finding that IQ was not significantly related to IT performance, however, may be due to the reduced reliability of the shortened letter IT task or to sampling error, or both.

**Summary of Experiment 4**

Experiment 4 further explored the extent to which higher order cognitive processes influence performance on the letter IT task. Specifically, I examined the extent to which individual differences in attention influenced performance on this task. To examine this, subjects were tested on the letter IT task under each of two conditions: with and without a concurrent shadowing task. The finding that a reduction in attentional resources led
to a significant decline in mean IT performance suggests that individual differences in attention are, at least in part, responsible for performance on the letter IT task. Furthermore, the finding that the correlation between full and divided attention conditions was less than the test-retest reliability of the IT task suggests that different cognitive components may be required under conditions of full and divided attention. That is, this finding suggests that the increased difficulty of the divided attention task alone is insufficient to account for the significant drop in IT performance. Instead, the findings support the notion that attentional resources may influence IT performance to a greater extent under the load condition than under the no-load condition.

Unexpectedly, the correlation between IQ and accuracy obtained under both the no-load and the load conditions did not differ significantly from zero. This finding, however, may be due to the reduced reliability of the letter IT task or to sampling error, or both. Because near zero correlations were obtained between IT and IQ under both control (no-load) and experimental (load) conditions, it is not possible to conclude, on the basis of the findings of Experiment 4 alone, whether individual differences in attention were the primary determinant of IT performance, or whether attention simply added noise. Nonetheless, the findings that a decline in mean performance occurred under the divided attention condition and that the
variance obtained under the load condition was greater than that obtained under the no-load condition suggest that individual differences in attention play an important role in IT performance. If attentional resources were not important for performance on the IT task, then a decline in mean performance should not have occurred under the divided attention condition.

General Discussion

Experiment 1 introduced a new IT task that successfully eliminated the use of systematic strategies, such as those arising from apparent movement and flash cues. This is valuable because in the past such strategies have made the IT-IQ correlation difficult to interpret. The relation between IT and IQ was found to be as strong under the letter task condition as it was under the line task condition, with higher IQ participants outperforming their lower IQ counterparts across both IT tasks.

Experiment 2 was aimed at determining the reliability of the letter IT task, as well as exploring the effects of practice on accuracy rates of the letter IT task. Subjects completed 300 trials of the letter IT task each day, for a period of five days. The letter task was found to be an extremely reliable measure of IT. As previously found with the line task, the correlation between accuracy on the letter task and IQ decreased with practice. The findings of a significant linear increase in accuracy over the five day period, an attenuation in the correlation between accuracy and IQ, and a reduction in
variability, suggest that other higher-order processes sensitive to practice may be important factors underlying this correlation, with practice serving to decrease individual differences in these cognitive factors.

Experiment 3 sought to determine whether higher order cognitive processes—specifically, individual differences in higher level strategic processes—affect performance on the letter IT task by testing subjects under each of two conditions: with and without feedback. Results indicated that feedback had no effect on IT performance. Furthermore, IQ was not found to be associated with IT performance. These findings, however, were likely a result of the partial ceiling effect that was obtained. That is, had the partial ceiling effect not occurred, individual differences in IT performance, and its relation with IQ, may have been more apparent.

In Experiment 4, I further explored the extent to which higher order cognitive processes affect performance on the letter IT. Specifically, the role of individual differences in attention on IT performance was addressed. Subjects were tested under each of two conditions: with and without a concurrent shadowing task. The finding that a reduction in attentional resources led to a significant decline in mean IT performance supports the notion that individual differences in attention are, at least in part, responsible for performance on the letter IT task. Moreover, the finding that the correlation between full
and divided attention conditions was less than the test-retest reliability of the IT task suggests that the decrease in mean IT performance under the load condition may have resulted from the fact that different cognitive processes were required for successful performance under the conditions of full and divided attention. That is, this finding suggests that the increased difficulty of the divided attention task alone is insufficient to account for the significant drop in IT performance. Instead, the findings support the notion that attentional resources may influence IT performance to a greater extent under the load condition than under the no-load condition.

Because near zero correlations were obtained between IT and IQ under both the load (experimental) and no-load (control) conditions, it was impossible to conclude, on the basis of the findings of Experiment 4 alone, whether individual differences in attention were the primary determinant of IT performance or whether attention was simply a nuisance variable. This finding is problematic because the correlation between IT and IQ under the control condition has been well established (see Experiments 1, 2 and 3). Nonetheless, the findings that the variance obtained under the load condition was greater than that obtained under the no-load condition and that a decline in mean performance occurred under the divided attention condition suggest that individual differences in attention play an important role in IT performance. If attentional resources were
not important for performance on IT tasks, then a decline in mean performance should not have occurred under the divided attention condition.

The main goal of this thesis was to devise an IT task that would eradicate systematic strategy use that, in the past, has made the IT-IQ correlation difficult to interpret. Although numerous attempts have been made to devise a new backward masking procedure that would successfully overcome the inadequacies of the original mask, none have been able to completely eliminate the use of cognitive strategies, although the number of subjects reported to have used a strategy in these improved studies has typically been reduced. Due to the failure of past attempts to devise a new backward masking procedure that could successfully overcome the inadequacies of the original mask, I decided to change not only the mask but the stimuli as well. As a result, the findings of Experiments 1 and 2 indicate that my primary goal was successfully achieved.

The second goal of this thesis was to assess the extent to which higher order cognitive processes, such as individual differences in higher level strategic processes and attention, influence performance on the IT task. To date, two perspectives exist with respect to what factor primarily determines IT performance: one favours mental speed, the other favours cognitive processes. The mental speed view argues that the IT task represents a research strategy aimed at isolating a more
general dimension of information processing in the brain thought to be fixed and relatively free of influence from higher-order cognitive activities (Brand & Deary, 1982). Proponents of this view argue that because the IT task measures the time required to make a single observation of the sensory input, it operates as a basic factor limiting perceptual and cognitive performance in general (Vickers & Smith, 1986). Alternative hypotheses, however, suggest that higher order cognitive processes, in addition to mental speed, influence performance on IT tasks. Although both perspectives agree that mental speed and cognitive factors influence IT, they disagree with respect to which factor is (1) the primary determinant of individual differences in performance on the IT task, and (2) responsible for the IT-IQ correlation. To date, most researchers adhere to the mental speed perspective, however, the results of 3 of the experiments reported here, particularly Experiments 2 and 4, seriously weaken this view.

First, if mental speed was the primary determinant of performance on the IT task, a strengthening of the association between IT and IQ should have been found once noise, as a result of individual differences in apparent movement strategy use, was reduced. Results indicated, however, that no differences in the strength of the association between IT and IQ, as assessed by the letter task (a task that eliminated systematic strategy use), and between IT and IQ, as assessed by the line task (a task that
permitted apparent movement strategy use), were found. If mental speed was the primary determinant of IT performance, differences in mean ITs between high and low IQ groups should have been greater under the letter condition where noise due to individual differences in strategy use was reduced and the influence of the mental speed component was made clearer.

Second, if mental speed was the primary determinant of performance on the IT task then (1) a decrease in IT variability and an increase in the correlation between IT and IQ should have been found if practice served to reduce noise from other nuisance variables (i.e., cognitive factors), or (2) an increase in variability and an attenuation in the correlation between IT and IQ should have occurred if practice served to increase noise from other cognitive factors. Results of Experiment 2, however, failed to meet these criteria, suggesting instead that cognitive factors play a greater role in IT performance than was once believed.

Finally, if mental speed was the primary determinant of performance on the IT task, then reducing attentional resources should have had no influence on mean accuracy. Results of Experiment 4, however, indicated that reducing attentional resources led to significantly more errors on the IT task. As already mentioned, if attentional resources were not important for performance on the IT task, then a decline in mean performance should not have occurred under the divided attention
Thus, the results of Experiments 1, 2, and 4 converge on the notion that higher order cognitive processes, such as individual differences in attention, influence performance on the IT task. Furthermore, these findings weaken the view that IT is "process pure", suggesting instead that, in addition to mental speed, cognitive factors substantially influence IT performance. The finding that attention influenced performance on the IT task suggests that the IT task is just as susceptible to higher order cognitive processes as other "mental speed" tasks, such as RT and its susceptibility to speed-accuracy tradeoffs.

The finding that attention influenced performance on IT tasks has serious implications for the interpretation of IT-IQ correlations. To date, much of the IT research argues that because IT is measuring mental speed, the existence of a correlation between IT and IQ suggests that mental speed is a cause of IQ differences (Deary & Stough, 1996). My findings indicate, however, that the correlation between IT and IQ may simply stem from a third underlying variable common to both IQ and IT tasks. Thus, rather than mental speed being responsible for the correlation between IT and IQ, my findings indicate that attention, or some other higher order cognitive process that has yet to be identified, may underlie this association.

In short, the purpose of this thesis was to devise an IT task that would eradicate systematic strategy use that, in the
past, has made the IT-IQ correlation difficult to interpret. The results of Experiments 1 and 2 indicate that my primary goal was successfully achieved. In addition, the finding that performance on IT tasks is influenced by cognitive processes, such as individual differences in attention, raises questions with respect to the theoretical rationale of the IT index. That is, IT was originally developed as the time needed for a single inspection, or minimal sample of sensory input, in Vickers' model of decision processes in visual perception (Vickers et al., 1972). My findings, however, suggest that the IT task may not be as cognitively minimal as the theoretical concept of an inspection would require (MacKenzie et al., 1991). Hence, the results of Experiments 1, 2, and 4 undermine the notion that IT is simply a measure of "the quickness of the brain to react to external stimuli prior to any conscious thought" (Kranzler & Jensen, 1989, p.330), and question the extent to which the correlation between IT and IQ simply reflects "mental speed".

Future Research and Work in Progress

Future research is needed to ascertain what, if any, other higher order cognitive processes influence IT. In the present thesis (Experiment 4), evidence was found suggesting that individual differences in attention may influence performance on the IT task. This finding raises implications with respect to the view that the IT measure is cognitively free.

The finding that attention influenced performance on the IT
task also makes past findings difficult to interpret. One possibility is that the average correlation of -.5 that is found between IT and IQ may be a gross underestimation due to the inclusion of a "nuisance variable", namely, individual differences in attention. Conversely, it is possible that the correlation between IT and IQ may disappear completely once individual differences in attention are eliminated or partialled out, indicating--as suggested by Bors et al. (in press)--that the IT-IQ relation may stem from the fact that sustained attention is a component of both the IT task and intelligence tests. I attempted to address these issues in Experiment 4, however, the correlations that were obtained between IT and IQ are questionable due to the unreliability of the IT measure (resulting from fewer trials), sampling error, or both.

Currently, I am further addressing the role of feedback, and hence of the influence of other higher order cognitive processes, by replicating Experiment 3. For example, feedback (see Experiment 3) may have been a more effective means of increasing individual differences in accuracy on the IT task had a ceiling effect not occurred. Currently, subjects are required to make a same/different discrimination among 3 letter stimulus sets (i.e., three same letters or two same and one different), as opposed to the two letter stimulus sets described in Experiment 3. Because this changes the IT task from a version of the Posner and Snyder (1975) task to a visual search task, I hope to increase the
difficulty of the task while retaining its basic instructions. By increasing the difficulty of the task, I hope to determine whether feedback failed to increase individual differences in IT performance because of the artificial ceiling effect that was obtained, which would have prevented a significant increase in individual differences, or because no higher order cognitive processes sensitive to feedback exist, with respect to IT performance.

Similarly, by increasing the difficulty of the task, I hope to determine whether practice successfully reduced individual differences in ITs, as indicated by the decreased variability and attenuated IT-IQ correlation, or whether the reduced variability and attenuated correlation simply resulted from the artificial ceiling effect. Hence, had the ceiling effect not occurred, would individual differences in IT performance have remained after five days of testing? By addressing these issues, future research will provide further insight into the relation between IT, IQ, mental speed, and cognitive processes.
References


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Footnote

1. Although I would have preferred to preselect subjects based on scores obtained on the Short Raven (for reasons stated in the method section of Experiment 1), I was unable to do so due to the limited number of subjects enroled in the introduction to psychology course during the summer session.
Appendix A

Traditional Inspection Time Task Questionnaire

1. How difficult did you find the task?
   Please give a numerical rating from 1 to 5. (1 = very easy, 5 = very difficult)

2. How often do you think you guessed? (give a percentage - %)

3. Do you think your performance improved over time?

4. How did you make a decision about which line was longer?
   Please be specific.

5a) On some trials did one line of the stimulus appear to move or grow faster than the other line at the time the mask came on to cover up the stimulus?

5b) If so, did you use this as part of a strategy to help you make your response?

6a) Did you notice a difference in flicker or flash on either of the two sides of the stimulus?

6b) If so, did you use this as part of a strategy to help you make your response?
Appendix B

Line Inspection Time Task Questionnaire

1. How difficult did you find the task?
   Please give a numerical rating from 1 to 5. (1 = very easy, 5 = very difficult)

2. How often do you think you guessed? (give a percentage - %)

3. Do you think your performance improved over time?

4. How did you make a decision about whether the letters were the same or different?
   Please be specific.

5a) On some trials did you notice if the lines that made up the 2 letters appeared to move differently at the time the mask came on to cover up the stimulus?
5b) If so, did you use this as part of a strategy to help you make your response?

6a) On some trials did you notice a difference in flicker or flash on either side where the 2 letters appeared?
6b) If so, did you use this as part of a strategy to help you make your response?