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The effects of training strategy on Stroop color-word interference

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THE EFFECTS OF TRAINING STRATEGY ON STROOP COLOR-WORD INTERFERENCE

A Thesis

Presented to

The Faculty of the Department of Psychology

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In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

Susan T. Heers

August, 1992

APPROVED BY THE MASTER'S THESIS COMMITTEE

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APPROVED FOR THE UNIVERSITY

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instilled in me a desire to learn about new things and ideas that provided the foundation for my academic career, which has culminated in this accomplishment.

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Abstract

In the Stroop color-word test subjects take longer to identify the hue of a word naming an incongruent color than to identify the hue of a non-word stimulus. It has been proposed that this delay results from the automatic word-reading response interfering with the controlled color-naming response. This automaticity has been attributed to extensive practice of the word reading behavior. The present experiment investigated the effects of training manipulations on the development of an automatic motor response to Stroop color-words. It was found that alternating between color and word identification training resulted in slower reaction times on test trials than did blocking all the training for each task together. It was also found that subjects who practiced on integrated color-words produced a symmetrical interference pattern following training, while subjects given equivalent training on control stimuli still exhibited greater interference on naming colors with Stroop stimuli. This indicates that experience with the multi-dimensional nature of Stroop stimuli affects the pattern of interference which is developed. Finally, both training stimulus groups demonstrated some positive transfer of training to the stimuli on which they had not trained.

The Effects of Training Strategy on Stroop Color-Word Interference

As early as 1886 it was reported by Cattell (cited in Jensen & Rohwer, 1966) that subjects were slower at naming colors than at reading color names. Several early hypotheses attributed this disparity to differential amounts of practice for these tasks. In an effort to study the role of practice in associative inhibition, Stroop (1935) devised a novel task incorporating both color naming and word reading. The law of associative inhibition (see Kline, 1921) states that when two stimuli have some prior association, attempts to associate one of the stimuli with a new, third stimulus will be interfered with by the previously existing connection.

Stroop's experiment was designed to compare the interfering effects of color stimuli on reading color names with the interfering effects of word stimuli on naming colors. The task he developed provided an unusual method for examining associative interference in that the conflicting associations were both inherent aspects of the same stimulus. Subjects were presented with a matrix of words representing various color names which were printed in colored ink (e.g., the word "RED" printed in *green* ink) (see Figure 1). Each stimulus contains two different types of color information: (1) the semantic meaning of the word, and (2) the chromatic hue of the ink. These color-words thus represent a type of multi-dimensional integrated stimulus in which two separate, meaningful pieces of related information are combined into a single visual stimulus. Traditionally, these two stimulus dimensions conflict; however, later studies also introduced the use of congruent color-word stimuli (e.g., the word "BLUE" printed in *blue* ink). Although the method of presentation has varied much since the task was first developed by Stroop, the color-word stimulus remains its principle component.

Figure 1. Example of a Stroop color-word matrix.

Subjects perform two different tasks using Stroop color-words. *Color naming* involves identifying the ink hue while ignoring the word aspect of the stimuli. *Word reading* entails identifying what the word is while ignoring the color of ink it is printed in. The degree of interference is determined by measuring the time taken to complete each of these tasks using color-word stimuli and comparing that to the time required for the tasks under non-ambiguous control conditions (i.e., reading achromatic color names or naming colors of non-lexical color patches).

Stroop's original findings revealed a large asymmetry in the interference effects. While the presence of conflicting colors had virtually no effect on the word reading times, incongruent color names slowed the time required for reporting hues by 74% (Stroop, 1935). This pronounced asymmetrical interference pattern between word reading and color naming represents the primary feature of what has come to be known as the Stroop effect or Stroop phenomenon.

Since the time it was first reported the Stroop effect has been of considerable interest to researchers. A primary reason for this is the extreme reliability of the effect. Jensen and Rohwer (1966) go so far as to say, "... apparently all literate persons are subject to [the effect]." (p. 58). Experimentally, the Stroop effect has also been demonstrated as remarkably robust. It can be produced using not only integrated color-word stimuli but also through sequential presentation, where the color stimuli are preceded by black color names (Dyer & Severance, 1973), as well as bilaterally, with the color stimuli presented to one side of the visual field and the word stimuli presented to the other (Dyer, 1973a). This universally experienced phenomenon reveals a limitation in our ability to process complex stimuli and makes an important contribution to understanding the processes of reading, stimulus recognition and identification, and attentional control.

Central to the study of this phenomenon is understanding the source of this differential interference. Theories explaining the Stroop effect have evolved through several stages over time. Initial explanations centered on the strength of the association between the dimensions of the stimulus and the responses they elicited. Later theories proposed that interference occurs when the two responses, one for the word information and the other for the color information, compete to be output as an overt response. Another class of theories focuses on the encoding of the stimulus and the failure in selective attention as a key issue. Acting as a compromise between these views, automaticity theory has provided an explanation of Stroop interference which encompasses both the competition between the two processes and the attentional failure.

Theoretical Background

Differential Habit Strength

When Stroop (1935) first reported his findings, he attributed the effect to differential amounts of practice for word reading and color naming resulting in two habits of unequal strength. He reasoned that there is a stronger association between the word stimulus and a reading response which interferes with the subject's ability to make the appropriate labeling response to the color component of the stimulus. He conjectured that these different habit strengths result from the fact that while words are paired with only a single response (i.e., reading), colors are host to a variety of responses such as evaluation, admiration of aesthetic qualities, as well as labeling. Due to this diversity, the naming response is less practiced and is, therefore, more weakly associated with the color stimulus.

To test this differential practice hypothesis, Stroop had subjects practice only the color naming response to color-word stimuli for eight consecutive days. He found that immediately following training, color-naming times decreased dramatically while word-reading times concurrently increased. In other words, the ability to read words exhibited interference in the presence of conflicting colors as a result of the color-naming practice. The combination of these two changes led to roughly equivalent times for both the color naming and word reading tasks in the color-word condition. This finding provides early evidence that interference can be a function of practice.

The majority of studies which followed Stroop's in the next several decades (see review by Jensen & Rohwer, 1966) also attributed the interference to differences in the strength of the association between the stimulus and each of the two conflicting responses. It was assumed that the delay in color naming resulted from the necessity of suppressing a stronger habit in favor of a weaker one. These early theories viewed interference strictly as a function of the strength of stimulus-response (S-R) bonds which were developed through repeated associations. Not until the 1960s did theories begin to shift direction. At that time researchers began to consider the complexity of stimulus processing. Indeed, not until the end of their extensive review do Jensen and Rohwer suggest that the Stroop effect might instead reflect "... a difference in response latency due to a *lesser degree of complexity* of the S-R connection for word reading rather than for color naming." (p. 88, italics added). That insight would herald the approach utilized by ensuing response competition theories.

Response Competition Theory

As the conceptualization of how the human mind works shifted to a computer-like information processor, new explanations of the Stroop effect rapidly followed. Response competition theories now pointed to the difference between times for color naming and color name reading as evidence that reading was an inherently faster and qualitatively different process than color naming (e.g., Fraisse, 1969).

A variety of models have been developed under the basic principles of response competition theory. Although several have incorporated components unique to their own particular model (e.g., Morton's (1969) logogen system and Glaser and Dolt's (1977) and-/or-gates), there are several common characteristics. Figure 2 presents a generalized model encompassing the primary components of the response competition approach. According to this explanation, both the color and word aspects of the stimulus are encoded and processed independently of each other and in parallel. Response competition approaches have also been referred to as horse race models since the color naming and word reading processes are described as "racing" to a single channel response buffer for output. Stroop interference occurs because the response from the faster word reading process enters the response buffer first, thus delaying the appropriate color naming response. The buffer is serial in nature and accepts only one response at a time. The inappropriate word response must be disposed of before the desired color response can enter. Response latency, therefore, results from having to contend with the presence of the unwanted word response when trying to elicit the desired color response.

Support for the horse race model has been found using a visual scanning task with Stroop stimuli. Contrary to verbal color identification, reaction times in visual scanning are reportedly faster for colors than for color names (Lund, 1927, cited in Uleman & Reeves, 1971). Uleman and Reeves (1971) reasoned that if interference results from one type of response arriving at the single channel buffer prior to the other, then scanning Stroop color-names for a particular hue should be unaffected, while scanning for a color name should produce interference. The experimenters presented subjects with matrices composed of either control colors, control words, or color-words. They were instructed to scan each one for a particular hue or color name and to specify every

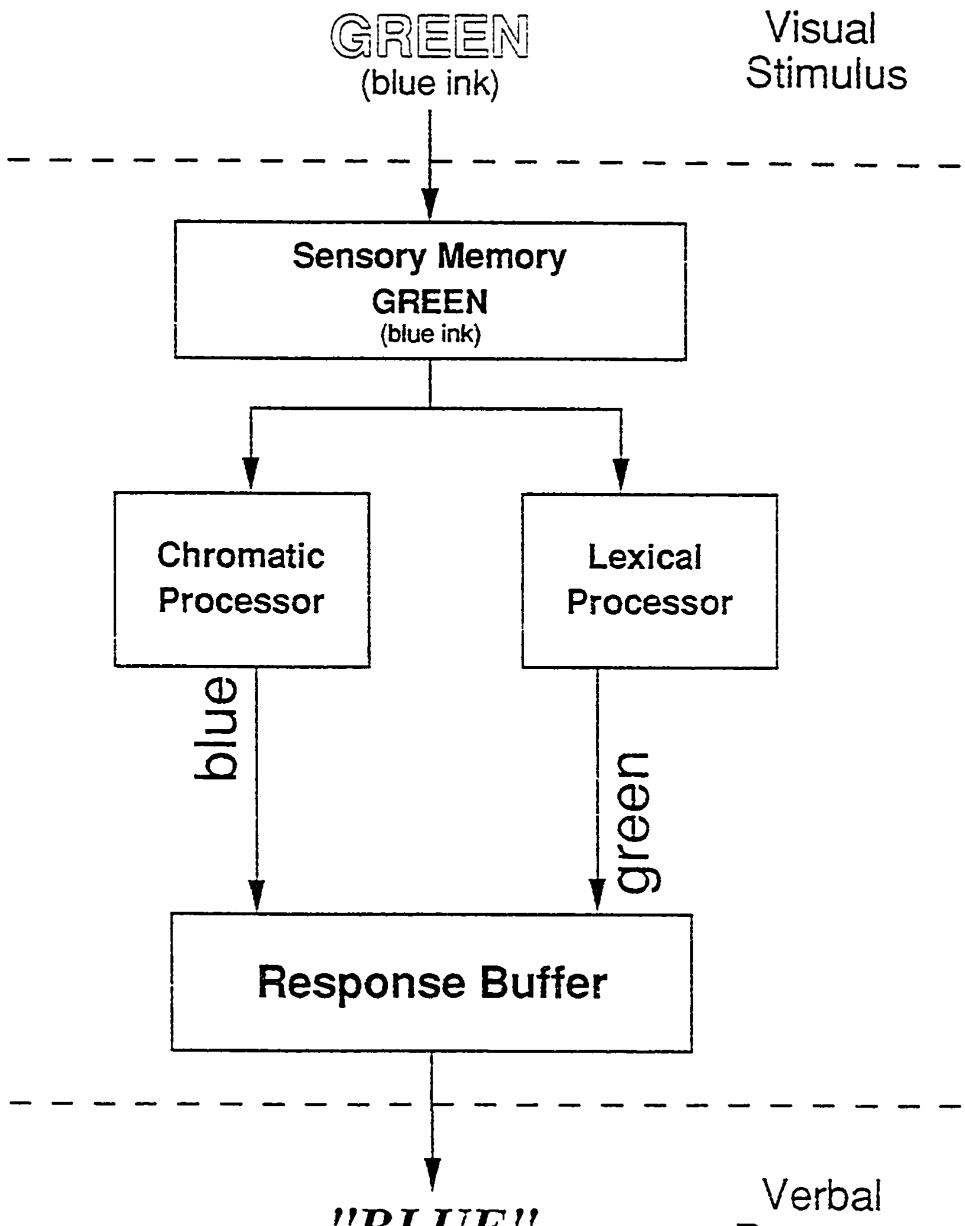

Figure 2. Schematic of a generalized response competition model of Stroop interference.

instance of that color on the matrix. The results demonstrated a reverse Stroop effect; word scanning was subject to interference while color scanning was not. This indicates that relative processing times, as determined by the task, do affect which component is subject to interference.

Dyer (1973b) suggests that interference is not determined solely by which stimulus is processed faster, but that there is an optimal relative processing rate. If word processing is delayed sufficiently, then the color response will have the opportunity to arrive at the output buffer first, avoiding any interference. Several studies have found that slowing the reading task by reducing legibility (Gumenik & Glass, 1970) or by changing orientation (Liu, 1973) did reduce the interference of words on color naming.

However, support of the predictions based on this model has not been universal. Dunbar and MacLeod (1984) manipulated the speed of the word-reading process by transforming the word stimuli, arranging the letters backwards in one condition and orienting the backwards words upside-down in a second condition. Although reading times were significantly slower for both types of transformed words, the color-naming task continued to exhibit interference.

Failure to produce a reverse Stroop effect through the manipulation of processing speeds also calls the horse race model into question. If the presence of the inappropriate response in the serial buffer is the cause of interference, then the premature arrival of the color naming response should produce interference on the word reading task. Glaser and Glaser (1982) used serial non-integrated presentation of the color and word dimensions to manipulate the length of the stimulus onset asynchrony. Even when the color stimulus preceded the word by as much as 400 ms, there was no interference of the color information on word reading times.

Dyer (1973b) also reasoned that *increasing* the processing rate of word information would reduce interference since that would allow sufficient time to dispose of the incorrect response before dealing with the color information. This was the interpretation attributed to results reported by Klein (1964) when he had subjects overtly read the word before naming the color. Color naming times were significantly faster in this condition than in the standard Stroop task, and subjects reported that this task was easier to perform. In essence, by saying the word aloud subjects were able to eliminate the extraneous response, thereby clearing the buffer.

This hypothesis was not supported in a test performed by Regan (1978), however. Although using desaturated colors reliably slowed the color-naming response times, a condition analogous to speeding-up the word-reading responses, there was no change in the amount of interference by words on color-naming. Manipulations of the serial presentation of the two stimulus dimensions also failed to support this prediction. While presenting the word more than 200 ms in advance of the color did reduce the amount of interference on color naming, statistically significant interference was still present even with a stimulus offset asynchrony as long as 400 ms (Glaser & Glaser, 1982).

In addition to relative processing speeds, other relationships between the competing responses have been characterized. A primary criterion for the applicability of response competition is that a conflict between the two responses must exist. Unless the response to the irrelevant component resembles the required response, there is no basis for interference. Pritchatt (1968) found that when subjects responded to Stroop stimuli by pressing appropriately labeled buttons instead of reporting verbally, interference patterns could be altered. If the buttons were labeled with color patches (i.e., no conflict with the irrelevant word stimuli), interference to color naming was reduced. However, when the buttons were labeled with color name words, typical Stroop interference returned.

In a study designed to demonstrate the importance of a correspondence between the appropriate and interfering responses, the task was modified so that the objective was to indicate whether two color stimuli were the same or different (Dalrymple-Alford & Azkoul, 1972). Subjects either responded "yes" or "no" in one condition or "right" or "wrong" in a second condition. The interfering stimulus component was manipulated by presenting the colors using three letter string pairs: xzn/jdlk, yes/no, or right/wrong. Response times were slowed only when the response words were the same as the letter strings, but not for either of the other two presentation conditions. The presence of interference, therefore, was dependent on the relationship between the interfering stimulus dimension and the required response rather than the two stimulus dimensions. When there was no conflict between these aspects, there was no interference. This notion of response conflict is a central component of response competition theories.

In addition to the response conflict properties of Stroop interference, some evidence has been found for a sequential relationship between the two responses. With the exception of Klein's (1964) manipulation, subjects are generally instructed not to emit the irrelevant response. Within the framework of the response competition model, the response buffer is monitored to prevent the inappropriate response from exiting while allowing the release of the correct response, once it is available for output. One study suggests that the irrelevant response is not merely retained but actively suppressed in a manner that reduces its ability to be output in the immediate future (Dalrymple-Alford & Budayr, 1966). Stimuli were ordered in such a way that the irrelevant response from the previous trial became the correct response for the next trial (e.g., the word **"BLUE"** printed in *red* ink followed by the word "green" printed in ***blue*** ink).

This created a condition where the response to be suppressed in one trial became the response to be emitted in the next trial. This manipulation produced longer color naming times as compared to conditions in which there was no relationship between subsequent stimuli.

A similar finding was observed in Klein's (1964) study when the subjects had to first report the color then immediately read the word. Word reading became more difficult for the subjects in this condition. This suggests that the word information had been suppressed in order to emit the color response first. As a result, it was more difficult to access this suppressed response for output immediately afterward.

Response competition theories can be summarized by certain key characteristics: (1) the presence of interference is attributed to the relative processing speeds of the information; (2) when the irrelevant stimulus dimension is processed faster than the relevant dimension, it impedes the ability to emit the correct response; (3) all responses are output through a single channel processor which must mediate the inappropriate response if it arrives at the buffer first. These theories identify the conflict arising at this output stage as the source of the interference and the different relative speeds of processing as the cause of the asymmetry. A primary assumption of response competition models is that all aspects of the stimulus are encoded and processed in parallel, with the processing of one aspect being independent of the processing of the second. While simply assumed by the response competition explanation, this multidimensional stimulus encoding has actually been viewed by some as the source of interference in the Stroop effect.

Encoding Conflict

Despite the prominence of response competition explanations, a contrary viewpoint developed proposing that the irrelevant component actually interferes at the beginning of information processing. According to this approach, the presence of the irrelevant information at the time of encoding inhibits the ability to effectively process the relevant color information, thereby causing the delay.

Integral to the development of this position was a study by Hock and Egeth (1970). Subjects performed a Sternberg (1967) memory task in which they were asked to judge whether or not the color of ink presented on an index card was a member of a target memory set containing either one, two, or three colors. Despite the fact that the overt response, "yes" or "no," had no direct semantic relationship to the irrelevant words, interference was still found when the probe colors were presented in the form of a Stroop color-word. Using the additive factors methodology defined by Sternberg (1967) for interpreting task results, Hock and Egeth concluded that the longer response times for the Stroop stimuli probes relative to the control probes indicated an increase in the time needed to form the stimulus representation, i.e., to represent or encode the relevant color information. Based on the assumption that memory comparison could occur only after the color information was processed, it was also hypothesized that interference arising from conflicting responses to the color-word probes would be exhibited by a change in the relationship with the number of items in the memory set (i.e., a different slope). The lack of any interaction between the type of probe and the target set size failed to support the presence of response interference, leading to the conclusion that the interference occurs only at the encoding stage.

Further support for encoding interference was found when testing opposing predictions made by encoding and response theories regarding increases in information. Based on the assumption that larger set sizes produce a greater processing load, Williams (1977) manipulated the amounts of both relevant and irrelevant information in a standard Stroop task by using different set sizes for colors and names. The number of colors represented in each color-word matrix was either two, four, or eight colors. Concurrently, there could be either two, four, or eight different names used. According to the encoding conflict theory, increases in either dimension should increase interference since the overall processing load would be greater and encoding would be slowed. On the other hand, response competition theory predicts that only the large color set conditions would increase interference. Increasing the processing time of the irrelevant information through a larger word set would actually decrease interference since it should allow the color information time to catch-up. Results were consistent with the predictions made by the encoding approach. Interference was always greater with larger set sizes, regardless of whether it was the color or word set.

These findings support the position that more is involved in the generation of a Stroop effect than a competition between responses at output. Other proponents of this viewpoint regard the role of attention in stimulus encoding and task processing as a central issue in this phenomenon. These researchers address the question of why people are not able to successfully focus on the color aspect of the stimulus and filter out the irrelevant lexical information. Were it not for this attentional failure, the word dimension would not be able to influence color processing at all.

Selective Attention

Treisman and Fearnley (1966) were among the first to investigate the role of attentional filtering in the Stroop effect. A matching task was developed in which subjects sorted cards into 'same' or 'different' piles in order to remove any relationship between the stimulus components and the type of response. This procedure produced *symmetrical* interference. Card sorting was slower when matching the color component of a Stroop color-word to a control word, as well as when matching the word component to a control color (represented by a row of Xs).

The authors proposed that the ability to selectively attend to the desired component breaks down when the subject is forced to match across attributes in the presence of an interfering stimulus which shares the attribute. In other words, it is possible to selectively attend to the color component when matching to another color stimulus (same-attribute matching) even in the presence of an interfering word. However, selective attention fails when trying to match a word component to a color stimulus (cross-attribute matching) in the presence of another color.

The role of attention in the Stroop phenomenon and its limitations has been of considerable interest to investigators since Treisman and Fearnley first proposed their alternative explanation. Harvey (1984) hypothesized that the effect results not from a complete inability to focus attention on the relevant dimension, but rather that people are unable to maintain this focus over an extended period of time. When subjects were cued on which dimension of the stimulus to report prior to each individual presentation, interference was reduced. The amount of interference was an inverse function of the length of time between the cue and stimulus onset. Interference decreased as the interval increased from 50 msec to 950 msec, suggesting that subjects could develop some attentional focusing along the dimension for a single trial if given sufficient time. Since subjects are usually informed in advance on which dimension to attend to for a series of trials, a failure to maintain focusing for the full length of the task could explain why the ability apparent in Harvey's experiment does not seem to be present in a traditional Stroop task.

Zajano and Gorman (1986) also found support for some level of attentional filtering. The ratio of congruent to incongruent color-words in a list of 50 stimuli was varied from all incongruent to all congruent. According to the authors' rationale, if interference merely reflects the amount of time needed to overcome the irrelevant response in incongruent stimuli, this time should be fixed, producing a simple linear relationship between the percentage of congruent items and interference level. The observed pattern, however, was curvilinear. Response times actually showed a slight increase for very small percentages of congruent items, then declined as the percentage of congruent items grew. The rate of this decline then accelerated as number of congruent items surpassed 80%. This finding supports their hypothesis that, although selective attention is limited, some inhibition of irrelevant word information is present. They reasoned that the observed relationship results from a disruption of the inhibitory process which occurs whenever a congruent item is encountered.

Further evidence of the limitations of the attentional system is found with dilution effects. When non-integrated Stroop stimuli (a color bar with a color name written above it) were presented and a second, neutral word was added to the display, interference was dramatically reduced (Kahneman & Chajczyk, 1983). The presence of the neutral word diluted not only interference by incongruent words, but also diluted facilitation by congruent ones. Dilution also occurred when using a row of Xs rather than a word, even when its distance from the stimulus was increased from two to four degrees of visual angle. This chain of interference, that is the ability of a stimulus to interfere with the interfering capabilities of another stimulus, reveals systematic limitations in attentional focusing and processing capacities.

It is clear from the preceding discussion that the debate over whether interference should be attributed to response competition or attentional failure has not been resolved. Evidence supporting both positions has been reported with a failure to categorically discredit the opposing viewpoint. It has been noted, however, that these two viewpoints are not necessarily mutually exclusive, and several researchers have supported the idea of multiple mechanisms of Stroop task interference (e.g., Naish, 1985; Stirling, 1979).

Following his review of the research, Dyer (1973b) points out that Treisman's concept of selective attention failure could be combined with response competition to provide a more complete explanation. His resulting hypothesis sees the Stroop effect as a consequence of an attentional inability to gate the processing of the irrelevant information and a resulting competition between the two conflicting responses vying for an opportunity to exit via a single channel buffer.

A later approach which encompasses both the failure to selectively attend to specific stimulus dimensions and the competition between two processes is automaticity theory. According to this explanation, the automatic occurrence of the word-reading process interferes with the controlled color-naming process, delaying the response.

Automaticity Theory

Automaticity has been described as a qualitatively different type of information processing which is developed through consistent training (Shiffrin & Dumais, 1981). The conditions defining an automatic process have been summarized into two rules. The first addresses resource utilization:

> *Rule 1*: Any process that does not use general, nonspecific processing resources and does not decrease the general, nonspecific processing capacity available for other processes is automatic (Shiffrin, Dumais, & Schneider, 1981, p. 228).

The second centers on the issue of control:

> *Rule 2*: Any process that demands resources in response to external stimulus inputs, regardless of subjects' attempt to ignore the distraction, is automatic (Shiffrin, Dumais, & Schneider, 1981, p. 229).

Either rule provides a sufficient, although not necessary, condition for classifying a process as automatic. Generally, automatic responses are viewed as rapidly occurring, often involuntary processes which are independent of processing strategy and which do not rely on executive processing resources.

Shiffrin and Schneider (1977) investigated the properties of automatic and controlled processes in a visual search paradigm. Controlled search was represented by a variable mapping (VM) condition in which items served as targets in some trials and as members of the distractor set in other trials. In the consistent mapping (CM) condition the memory set remained constant across all trials, and target items never served as part of the distractor set. Repeated use of a CM paradigm led to the development of automatic detection, indicated by the extremely rapid and accurate detection of targets which was virtually unaffected by changes in processing load (Shiffrin & Schneider, 1977, Experiment 1).

To address the question of focused attention, a task was developed in which subjects were instructed to ignore certain positions in the visual array when making their judgments. When items which had been used in a VM search paradigm were placed in the to-be-ignored positions (VM foils), minimal decrements were found in the target detection for the valid positions. However, if items which were members of a prior CM target set were placed in the to-be-ignored positions (CM foils), performance on the focused attention task under variably-mapped (controlled processing) conditions was significantly decremented (Shiffrin & Schneider, 1977, Experiments 4a-d). Essentially, the presence of stimuli from the controlled search condition had little effect on task performance, but the presence of stimuli from the automatic condition severely affected the ability to do a controlled primary task. The authors explained this as the result of an automatic-attention response to the CM foil. Subjects were not able to ignore the CM target even though they knew it to be irrelevant and the target occurred in a consistently invalid location.

These results provide a framework for an automaticity explanation of the Stroop effect. Color naming represents a controlled, focused attention task. The word aspect of the stimulus is equivalent to the consistently-mapped foil. Although instructed to ignore its presence, the word dimension is automatically processed. The automatic word-naming process then interferes with the slower, controlled color-naming process, delaying the response. In accord with Shiffrin and Schneider's (1977) theory on automaticity development, word-reading automaticity is the result of consistent repetition of the task, i.e., practice.

Stroop's original explanation of the interference asymmetry is easily adapted to the automaticity approach. His description of word reading as a single-response task is similar to a consistently mapped condition, which would lead to the development of an automatic process. On the other hand, the association of color stimuli with a variety of responses describes a variably mapped condition. This lack of consistency, therefore, would not lead to automatic processing. Although the term "automaticity" had not been popularized at the time Stroop reported his findings, his conclusions that the asymmetrical interference normally found with Stroop stimuli was due to differential practice is consistent with this account.

Attention and Automaticity

In applying automaticity theory, the role of attention in the Stroop effect may vary depending on the criterion used to define the reading task as an automatic process. If the first rule described above is applied, reading is viewed as a rapidly occurring process which, once triggered, automatically runs to completion without infringing upon the generalized processing capacity. Automaticity thus provides the mechanism to explain the early arrival of the word response at the output buffer. The lack of intentionality results from the fact that, since the process occurring does not require any resources, the system has no way to exert control over its execution through resource allocation or withdrawal. Several studies have reported that extensive practice leads to task performance which is relatively immune to increases in information load in the cases of visual target detection (Shiffrin & Schneider, 1977), memory search (Palmer & Jonides, 1988), and stimulus identification (Regan, 1981), indicating processing which does not exhibit capacity limitations within these contexts.

According to this interpretation, word reading does not utilize any attentional resources. This is consistent with LaBerge and Samuels' (1974) model regarding the automaticity of reading. The development of an automatic reading response corresponds to the gradual decrease of attentional requirements for the processing of lexical stimuli. This model sees reading as a series of component processing stages which transform the visual stimuli through phonological, episodic memory, and semantic systems in order to extract the meaning of each word or phrase. It is assumed that initially attention needs to be allocated to each of these component processes in order for information to pass from one stage to the next. As learning progresses, however, the links between sub-processes become more direct, and information flows between them without the requirement of attention.

While this view of automatic reading does provide one explanation for the lack of control observed for an automatic reading process, a lack of intention does not necessarily indicate a lack of attention. If the second rule of automaticity described by Shiffrin et al. (1981) is applied instead, then automatic responses can actually demand attention. According to this position, the presence of a stimulus for an automatic process will capture attentional resources. This was the interpretation used by Shiffrin and Schneider (1977) concerning the target detection task described earlier. By practicing certain stimuli in a consistently mapped condition, attention was automatically attracted to those stimuli, despite the fact that they were to be ignored. Applied to the Stroop paradigm, the presence of the word in the stimulus automatically draws attention to that dimension, making attempts to ignore it extremely difficult.

Since either of the two rules above may be used as criteria for defining a process as automatic, then the automaticity of the word-reading process in a Stroop task can be described in more than one way. Depending on which of these two criteria is applied, the source of Stroop interference can be viewed quite differently. If the first rule is applied, automaticity remains primarily a response competition account wherein the attentional system is by-passed by the automatic reading process which is then free to generate a conflicting response. In the second case, the attentional system is usurped by the word information, thus creating an encoding conflict situation by temporarily misdirecting the attentional capacities away from the color dimension.

Training and Automaticity Development

In addition to Stroop's (1935) manipulation of color-naming practice, a more recent investigation of the effects of practice on Stroop stimuli has also supported the ability of training to influence the pattern of Stroop interference. MacLeod and Dunbar (1988) developed a variation of the Stroop task which used colored geometric shapes instead of color-words. Subjects were taught to refer to the various shapes using color names. Their "Stroop stimuli" therefore represented shapes displayed in hues which did not correspond to the same color as the shapes indicated. Initial task performance showed that the presence of the incongruent colors interfered with the ability to identify the shapes with their assigned color names. Subjects were then trained for increasing periods of time on the shape identification task. The extensive shape-naming training eventually led to a reversal in the asymmetrical interference pattern. That is, the conflicting shape interfered with color naming abilities, but the conflicting color did not significantly affect the ability to name the shape by its color name.

These results indicate that the presence and type of interference found between conflicting responses to integrated stimuli can be a function of the amount of training. MacLeod and Dunbar (1988) attributed this finding to the development of an automatic process due to the repetition of the task. The observed evolution of the interference over the course of the investigation was taken as support for a *continuum of automaticity* model. The interference pattern reflects which of the two tasks is more automatic. The degree of automaticity lies somewhere along a continuum and is a function of the amount of training for each task. Through this relationship, training determines the interference between the conflicting tasks.

Other models have been presented recently which also promote automaticity as continuous in nature, the degree of which is based on repetitions of the task. Using principles of parallel distributed processing theory, Cohen, Dunbar, and McClelland (1990) were able to create a computational model which successfully simulated the primary characteristics of a Stroop effect based on a given pattern of learning. Asymmetrical interference is attributed to the different strengths of the pathways representing each process. The backpropagation learning algorithm provided a mechanism for increasing the strength along the pathway of one process relative to the other as a function of differential practice. Each time a process is executed the system calculates the difference between the response generated and the desired result. This information is propagated back to the network, and connection strengths are adjusted to reduce the error and more closely approximate the desired response. Therefore, each time a task is repeated the network representing that process is fine-tuned and the pathway strength is increased.

Responses are generated when one of the output units has accumulated a sufficient level of activation to exceed the response threshold. A stronger pathway leads to quicker response since each processing cycle produces a greater amount of activation at its output unit so that fewer cycles are required to exceed the threshold.

This process is similar to the accumulation of evidence in a composite decision process described by Logan (1980). Each dimension in a Stroop stimulus provides evidence at a constant rate which is accumulated over time until a threshold is exceeded. The degree to which two sources of evidence correspond or conflict through habitual associations or expectations determines the amount of evidence required to choose a response. A distinction between these two models lies in the description of the rates of accumulation. While Cohen et al.'s (1990) theory attributes this to the strength of the network pathway as function of the number of repetitions, the rate of evidence accumulation in Logan's (1980) model is determined by the magnitude of the attentional and automatic weights attached to the dimension. Attentional weights are seen as flexible and responsive to strategy. Automatic weights are assumed to be fixed in magnitude and sign (i.e., inhibitory or facilitory) across situations.

In simulating their model, Cohen et al. (1990) varied the relative number of trials the computational model was given to "learn" each of the two types of tasks. This generated highly differential pathway strengths in their network. When tested on Stroop stimuli, the network produced reaction times comparable to what has been found in empirical studies.

The establishment of practice effects on Stroop interference and the influence of task repetition on automaticity development has been made without specific reference as to the nature of the training. The present study focuses on two primary issues of training with regard to automaticity development and Stroop task interference. The first issue addresses the scheduling of the two tasks during the training period and its impact on automaticity development. The second centers on the integrated nature of the stimulus and investigates the effectiveness of separating the dimensions into two independent stimuli for part-task training.

Task Scheduling

The Stroop effect has consistently been described as a competition between two independent tasks, color versus word identification. In the experiments described, however, procedures have been directed at training on a single task in an effort to develop automaticity in a previously controlled process. As such, no research has investigated the training of one task in contrast to the second. The relative scheduling of the two conflicting tasks may influence the development of automaticity. Specifically, would automaticity development be impaired if the subject were forced to constantly switch back and forth between training on the word identification and on the color identification tasks?

As mentioned, the question of scheduling is only relevant if there is more than one training task to schedule. The traditional Stroop task requires a verbal response for identification. Since the automaticity explanation assumes that a verbal reading response is already highly automatic for literate adults, training on this task would not be expected to change performance. However, if a new non-verbal response were used, both color and word identification tasks would have to be trained. Variable scheduling could thus be investigated. Based on this rationale, the current study employed a motor button-push response. Colors were identified by selecting a button in the appropriate position. The novelty of this task required that subjects be trained to use the buttons for identifying both word-originated and hue-originated colors. The effects of the amount of switching between these two types of training could thus be examined.

Practice on the two tasks was either alternated or blocked. It was predicted that subjects who were forced to alternate back and forth would perform worse overall than those who were allowed to practice all of the sessions for one task together before switching to the other task. This would indicate that the constant interruption of task switching impedes automaticity development. Although subjects in both training schedules would have completed the same overall number of trials, those forced to alternate might suffer a setback each time they change to the other task. As such, these subjects might progress in a stepwise manner rather than producing a smooth learning curve. A slight decline in performance may also be observed at the beginning of each session following the switch. If the expected finding is observed, this would indicate that automaticity development on multiple tasks is facilitated by clustering practice into large homogeneous chunks rather than dividing it into smaller sessions which are constantly varied.

Training Stimuli

A second aspect of the training procedure which might influence interference effects is the nature of the training stimuli. In Stroop's (1935) study on practice effects, subjects were trained on the controlled processing task using only integrated versions of the stimuli. This approach does not provide the most direct test of response competition accounts of the interference which describe the processing of the two stimulus dimensions as occurring independently. According to this model, it should be possible to train each of the two tasks separately in a part-task paradigm, then transfer the acquired skills into the integrated whole-task version. In other words, it should be possible to develop automaticity within each of the tasks using only non-integrated color and word stimuli and successfully transfer these skills into an integrated color-word version of the task. If, on the other hand, processing the stimuli also involves the ability to disentangle the integrated components or otherwise attentionally filter the stimulus information, then subjects should perform better only when trained on the whole task using the integrated stimuli. This question can be examined by training some of the subjects using unambiguous control stimuli while training the others with the integrated color-words. Any difference between these two training approaches will become evident when they are tested on the two tasks using Stroop color-words.

It was predicted that subjects trained on non-integrated controls would still exhibit interference when tested on the color-word stimuli. Those who were trained using the integrated color-words, however, were expected to show a lower degree of interference, if any, when tested on either control or Stroop stimuli. This result would suggest that the interference found with Stroop stimuli is not merely the result of competition between two independent subtasks. Rather, there is some attentional element involved in effectively processing the complex stimulus. If subjects trained on the integrated stimuli were able to demonstrate a lower degree of interference, this would indicate that, in addition to the motor response, they were able to learn some type of attentional filtering ability, i.e., they were trained to ignore the irrelevant dimension. Subjects trained on control stimuli would not have an opportunity to acquire this attentional function. As a result, the control stimulus group should have more difficulty when asked to do the tasks with the Stroop color-words.

The composition of the training stimuli, however, might also have a direct impact on the development of task automaticity. The control stimulus condition used two distinct stimuli to elicit the two types of responses. Each stimulus was consistently mapped to its response. In the integrated condition, on the other hand, subjects were asked to perform two different operations on identical stimuli, making the mapping between the stimulus and the response more difficult. Since the same stimulus was used to elicit to two different responses, the integrated stimulus properties may overstep the boundaries of consistent mapping. In this case, automaticity is not expected to develop (Shiffrin & Schneider, 1977; Shiffrin & Dumais, 1981; Shiffrin, Dumais, & Schneider, 1981). Whether or not the integrated condition falls within the consistently mapped training category may depend on the subject's ability to selectively filter out the irrelevant stimulus dimension. If attention could be focused on only one aspect of the stimulus, then it would be possible to consistently map each dimension to the appropriate response.

The ability to develop attentional focusing in the integrated training condition may depend on the scheduling of the two tasks. Similar to Zajano and Gorman's (1986) hypothesis that the presence of congruency disrupted the small degree of attentional focusing subjects were attempting to maintain, continual switching between tasks could also disrupt the ability to focus on a single dimension. The color-word task also shows a much stronger resemblance to a variably-mapped condition in the switching condition. On some trials the words correspond to the target which should be attended to while the colors represent the distractors to be ignored. In the intervening sessions, these roles switch, reversing the response pattern. In the blocked schedule, colors and words also represent both target and distractor stimuli over the course of training; however, these roles only reverse a single time allowing the subjects time to adjust their response pattern. In accordance with these factors, it was predicted that the blocked practice schedule would be more likely to cultivate selective attention with regard to the appropriate stimulus dimension and to demonstrate a higher level of automaticity and lower interference.

This study, therefore, is designed to investigate two primary hypotheses regarding the training of conflicting automatic responses. First, a high degree of switching between tasks during training impedes the development of automaticity. Secondly, part-task training on the component tasks using unambiguous control stimuli is not sufficient to avoid interference when transferred to the integrated color-word condition. In addition, the interaction between the two training manipulations will provide information on the influence of task switching on the development of selective attention.

Method

Subjects

Sixty-four subjects, ages 18 or older, were recruited from the research subject pool in the Psychology Department of San Jose State University. All potential subjects were screened for normal color vision using two pseudo-isochromatic plates, one testing for red-green color blindness and the other for blue-yellow. All subjects volunteering for the study demonstrated normal color vision. Each subject participated in only one of the training conditions. There were eight training conditions with eight subjects in each group. All subjects performed all four test conditions.

Apparatus

All stimuli for both the training and test phases of the experiment were presented on an HD Personal Computer 486-33 microcomputer with a Helm Engineering Corporation CM1448M Impression Plus 13 inch super VGA color monitor. The control colors and color-word stimuli were displayed in red, green, blue, and yellow characters on a black background. The control words were presented in white characters on a black background. Graphic fonts were used to present upper case block characters which were approximately 3 cm high on the screen. The words spelled out the names of the four hues being used. All color-word combinations were incongruent. Asterisk strings of the same font style and size were used to display the colors in the control condition.

Subjects identified the color or word for each stimulus using the "V" "B" "N" and "M" keys on the bottom row of the keyboard. The keys were labeled in black writing on a white background with the numbers 1 through 4, corresponding to the response instructions given verbally by the experimenter. Four different response sets were created according to a Latin square so that each of the four button positions was used for each of the four colors. Reaction times were recorded by the computer. Times reflected the interval between the stimulus display onset and the keystroke. The computer also recorded the response chosen as well as errors in identification. All data were stored in binary computer data files which were then converted to ASCII for statistical analysis.

Design

The experiment was a mixed factorial design involving three between-subjects training factors and three within-subjects test factors (see Figure 3). The response time for each trial in the test phase was the dependent variable. Two experimental manipulations and one control factor defined the training conditions. The training schedule represented the first between-subjects factor. Subjects were randomly assigned to either the alternating or blocked training condition. All subjects completed ten sessions of color identification and ten sessions of word identification training. A session consisted of 24 trials. Therefore, subjects performed 240 trials of each task, for a total of 480 training trials. Subjects assigned to the alternating condition switched back and forth between color identification and word identification training sessions, switching between the two tasks a total of nineteen times during the training phase. In the blocked condition, sessions were clustered together so that the subjects received all ten sessions of one task and then all ten sessions of the other, switching only once.

The second between-subjects manipulation was the training stimulus. Conditions from the two factors were crossed so that half of the subjects in each of the two schedule

Training Groups				
			Training Stimulus	
		Counterbalance Order	Integrated	Non-Integrated
Training Schedule	Alternating	Color First	s = 8	s = 8
		Word First	s = 8	s = 8
	Blocked	Color First	s = 8	s = 8
		Word First	s = 8	s = 8

Test Sessions			
		Test Condition	
		Stroop	Control
Identification Task	Color	trials = 24	trials = 24
	Word	trials = 24	trials = 24

n = 64

Figure 3. Diagram of the design factors.

groups were in each of the two stimulus groups. Those in the non-integrated group were trained using control versions of the color and word stimuli (colored asterisk strings and white word displays). The other half of the subjects were trained using the integrated color-word stimuli.

The order of training on the two tasks was counterbalanced across groups, representing the final between-subjects training factor. Half of the subjects in each group were trained on word identification first; the other half were trained on color identification first. All three factors were fully crossed yielding eight different training groups.

The test phase of the experiment was represented by three within-subjects factors. Following the training phase, all subjects completed the same four test sessions. Test conditions were represented by crossing two factors: (1) the type of identification task each subject was instructed to perform, color or word; and (2) the two test stimulus conditions used, Stroop color-word stimuli or unambiguous control stimuli. Each test session consisted of 24 trials, yielding a total of 96 test trials. The 24 trials in each test session were analyzed for replication effects, the final within-subjects factor. The order of the four test sessions for each of the eight subjects in a training group was assigned according to a balanced Latin square design. The reaction times from each of the 96 test trials was analyzed as the dependent measure. The analysis focused on whether subjects from each of the eight training groups varied in the time they required for identifying either words or colors using either Stroop or control test stimuli.

<u>Procedure</u>

Each subject was seated in the experimental booth approximately two feet in front of the monitor and directly in front of the keyboard on the table. The experimenter explained that a series of color-related stimuli would be presented encompassing both hues and words. The experimenter orally identified the correct buttons on the keyboard the subject was to use for identifying each of the four colors, regardless of whether the origin was chromatic or lexical. Subjects had been randomly assigned to one of the four response button sets so that each response set was used twice for each training group.

Subjects were given two familiarization sessions using non-integrated stimuli. One session involved word identification, the other color identification. The order of the two practice sessions was counterbalanced across subjects. Subjects were asked to respond as quickly as possible without making mistakes. If the subject responded incorrectly on a trial, the computer sounded a 400 Hz tone for 250 ms indicating the error, and that stimulus was presented again later. Once subjects were able to select the correct button twice for each color and each word stimulus, they moved on to the training phase.

The experimenter described the general format of the remainder of the training phase, instructing the subjects on how to proceed through the training sessions. If the subject was participating in the integrated training condition, the experimenter explained that the training stimuli would differ from those experienced in the practice phase. A verbal example of what to expect was described, and the correct response specified. If the subject was participating in the non-integrated training condition, the experimenter indicated that the subject would simply continue training on the same tasks they had just completed in the practice phase. All subjects were instructed to respond as quickly as possible without making mistakes. They were asked to try to increase their reaction times over the course of training without sacrificing their response accuracy.

Once the experimenter left the room, subjects proceeded sequentially through all 24 trials within a session. Before the start of each new session, the screen displayed a message instructing the subject to identify either the word or the color of the stimuli in the next session. The subject then pressed the 'space bar' on the keyboard to begin the session. During each trial the stimulus was displayed until a button was selected, or up to a maximum of five seconds. A 500 ms pause occurred between the end of the previous trial and the start of the next during which the screen remained blank. Identification errors were again indicated by the tone; however, error trials were not re-run. Following the 24th trial, the screen displayed a message for 250 ms indicating that the session was over. This was followed by the instruction screen for the next training session. To proceed with the next session, the subject pressed the 'space bar' when ready.

Following completion of the final training session, subjects entered the test phase. Subjects in all conditions were given the same four test sessions, counterbalanced across subjects. Each subject performed both the word and color identification tasks using control stimuli and also using Stroop stimuli. At the beginning of the test phase, the experimenter re-entered the room and described the four tasks to be performed. A sample stimulus from each of the four conditions was presented on the screen, and the experimenter verbally indicated what the correct response would be. No motor response was given by the subject until the test sessions began. Once the subject indicated an understanding of the tasks, the experimenter left the room, and the test phase proceeded.

Prior to the start of each test session, a message appeared on the screen instructing the subjects to identify either the color or word dimension, but no indication of the stimulus type was given. Sessions proceeded serially in a manner similar to the training phase. Following completion of the fourth test session, subjects were debriefed as to the purpose of the study and the conditions used, and any questions to the experimenter were answered.

Results

Reaction Time Data

A six-way mixed Analysis of Variance was conducted on the trial reaction times from each of the four test sessions. Prior to the analysis, the error trials were identified, and the reaction times in these instances were replaced by the session mean for that subject. There were three between- and three within-subjects factors. The *F*-ratios and *p*-values of the omnibus ANOVA are summarized in Appendix B. All probabilities which exceeded alpha (α =.05) were examined, and it was determined that the reduced error variance resulting from the replaced reaction times on the error trials was not sufficient to alter any of the findings which are discussed below. The mean reaction times and standard deviations for the four training manipulation groups in each of the four test sessions are presented in Table 1.

Replication Effects. There was a significant main effect of replication across the 24 trials in each of the test sessions [$F(23,1288) = 35.31, p < .001$]. This factor interacted significantly with the two test conditions, Stroop and control [$F(23,1288) = 3.24, p < .001$]. Together these factors interacted with the training stimulus, integrated versus non-integrated [$F(23,1288) = 1.56, p < .05$].

As can be seen in Figure 4, the reaction times decreased substantially over the first several trials in all cases. In the control condition, the response times leveled-off fairly quickly and were relatively stable after the third trial. This was true for both training stimulus groups. In the Stroop test condition, the reaction times did not decrease as much as in the control condition, and the learning curves varied across the two training groups. The group trained on integrated color-word stimuli showed a pattern similar to that observed for the control test condition, leveling-off after the fourth trial, although at a higher point. Reactions times for the group trained on non-integrated control stimuli,

Table 1

Means and Standard Deviations of the Test Session Reaction Times (ms) for Each Training Manipulation Group

Training Group		Test Session			
		Stroop Condition		Control Condition	
		Color ID	Word ID	Color ID	Word ID
Alternating	Integrated Stimuli	925.58 (168.14)	874.55 (217.86)	837.42 (191.48)	801.76 (174.06)
Alternating	Non-Integrated Stimuli	1087.86 (295.68)	895.82 (329.74)	755.82 (206.21)	765.80 (146.79)
Blocked	Integrated Stimuli	833.09 (223.75)	846.12 (258.20)	693.45 (121.28)	700.52 (113.86)
Blocked	Non-Integrated Stimuli	955.65 (184.21)	833.23 (142.01)	658.38 (133.11)	697.82 (120.10)

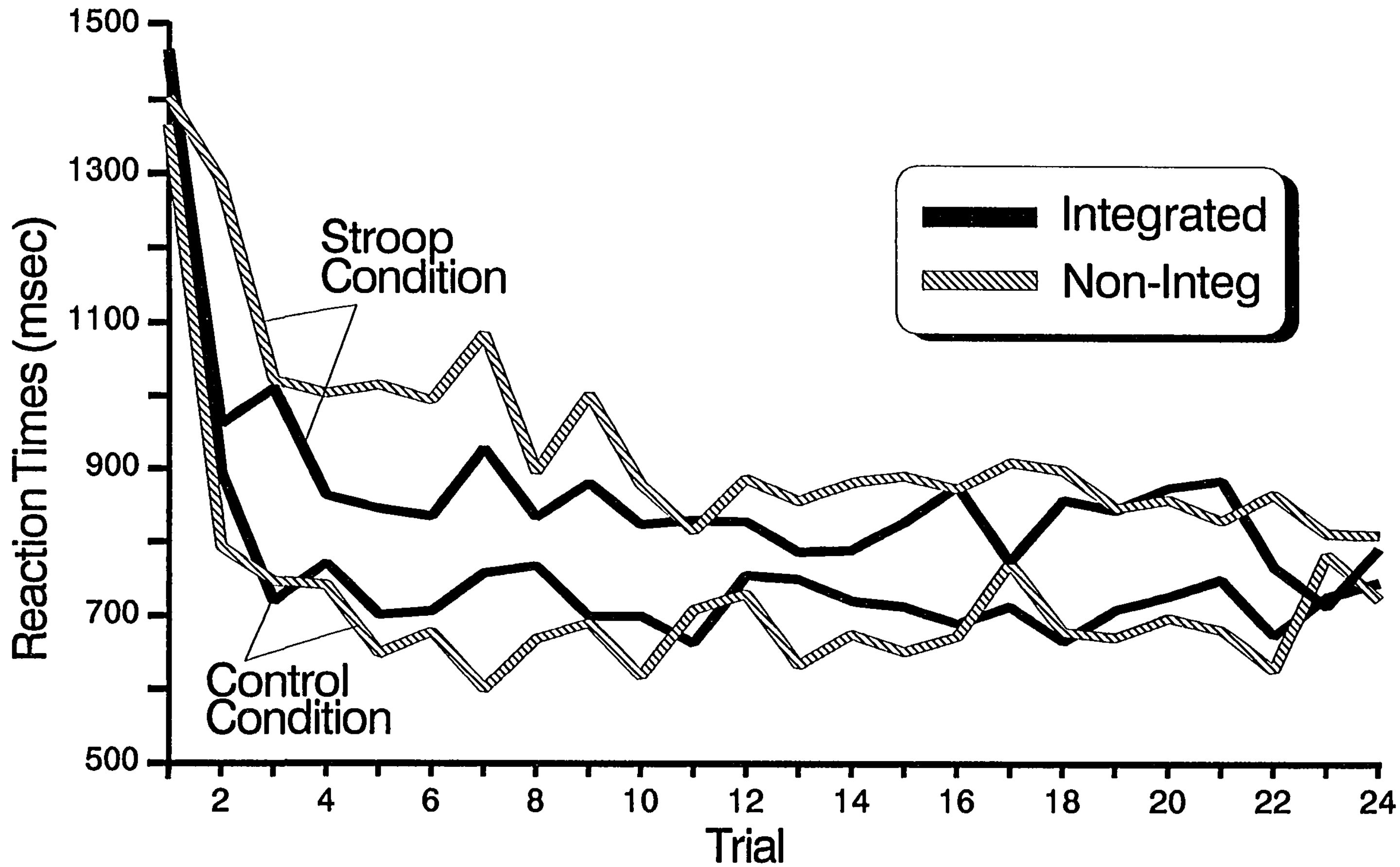

Figure 4. Mean reaction times (ms) of the training stimulus groups in Stroop and control test conditions across session trial

however, did not decrease as rapidly over the first several Stroop test trials. Following the initial drop, times continued to decline at a very slow rate until around the tenth trial before leveling-off. This pattern probably reflects the novelty of the Stroop task to this group. In each of the other cases, the high initial reaction times likely indicate that subjects were not fully focused on the task until after the first few trials had occurred.

Training Schedule Effects. The analysis also showed a reliable main effect of training schedule [$F(1,56) = 4.76, p < .05$] which is depicted in Figure 5. This factor did not interact with any other factor in the design. This indicates that in all cases, subjects who were forced to constantly switch back and forth between the two training tasks produced longer reaction times under all test conditions than those who practiced all of the trials for one task together before switching to the other training task.

Training Stimulus Effects. The training stimulus factor did not by itself produce a significant main effect. Rather, the results of this manipulation can be found in relation to the four test sessions as represented by crossing the test condition and identification task factors.

The test condition factor produced a reliable main effect [$F(1,56) = 109.14, p < .001$] which reflects the slower reaction times produced in the Stroop than in the control test sessions. This is consistent with what appears in the interaction described earlier between the replication and test condition factors. The relationship between the two levels of this factor remains consistent for all other cases in the design as well.

The main effect for identification task [$F(1,56) = 8.86, p < .01$] and the interaction between test condition and identification task [$F(1,56) = 9.54, p < .01$], however, both indicate effects which are not maintained within the interaction between the training stimulus, test condition, and identification task factors [$F(1,56) = 8.23, p < .01$]. This higher order interaction is illustrated in Figure 6.

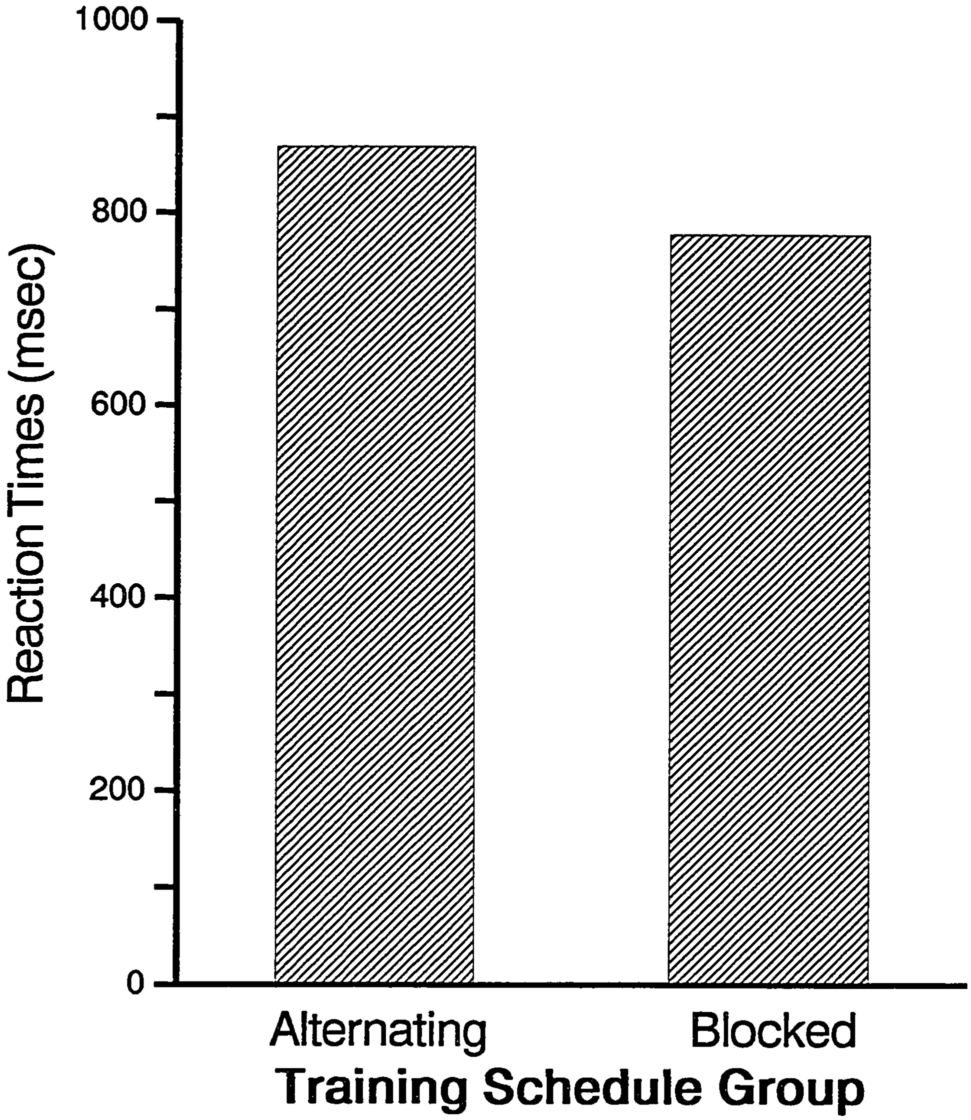

Figure 5. Mean test reaction times (ms) of the training schedule groups.

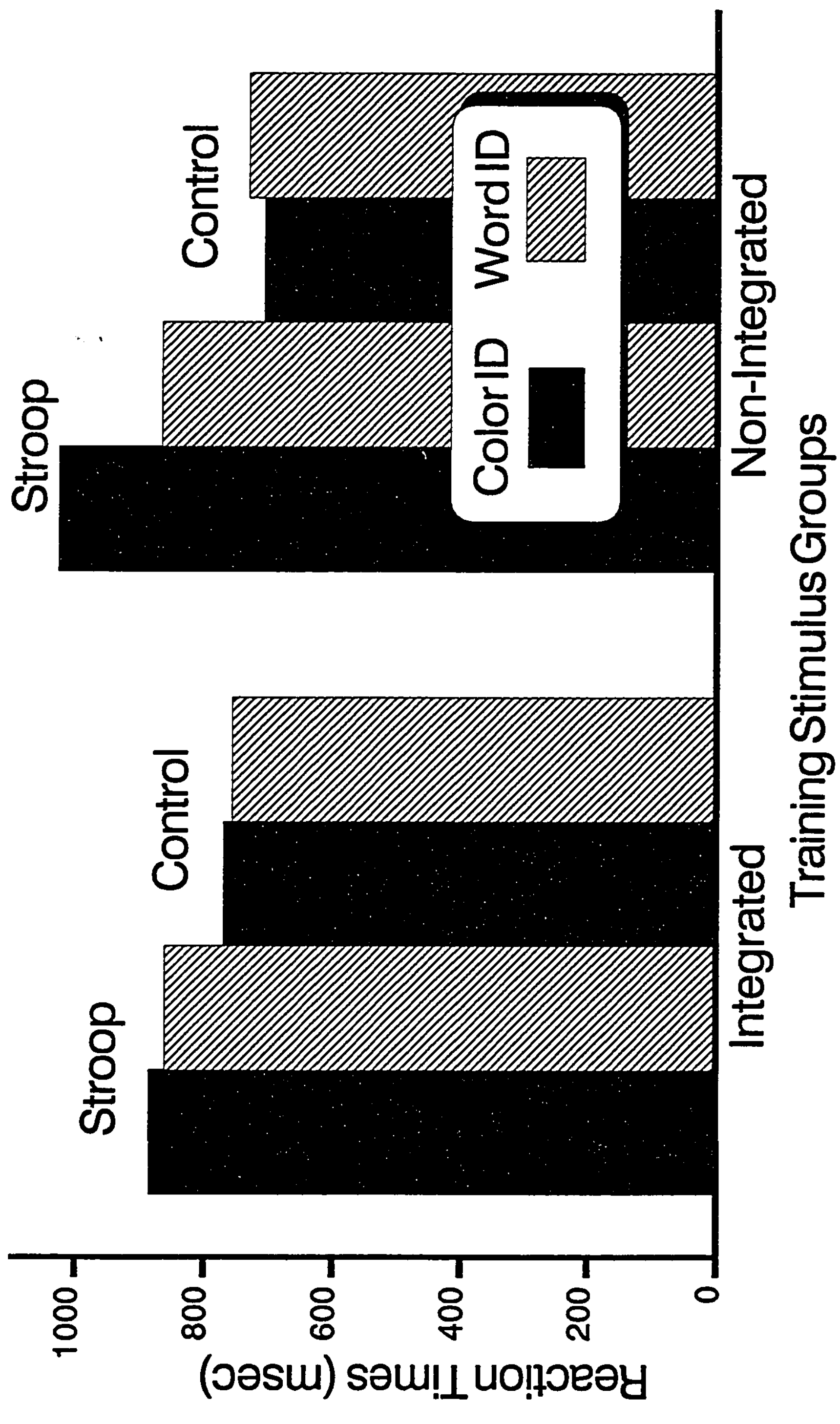

Figure 6. Mean Reaction time (ms) of the training stimulus groups across the four test sessions.

Evaluation of the figure reveals that, while performance on the control test sessions is roughly the same for both training groups, the integrated training group performed better in the Stroop test condition than did the non-integrated training group. This substantiates the interaction between the training stimulus and test condition factors [$F(1,56) = 11.93, p < .01$]. The advantage of training on the integrated stimuli, however, resides primarily with the color identification task in the Stroop test condition since the mean Stroop word identification times for the two training groups differ by only 4.2 ms. In other words, subjects who trained using the integrated color-words performed better on the Stroop color identification task than did the subjects who trained on unambiguous controls. Performance on the other three test sessions appears to be very similar between the two groups.

An additional series of ANOVAs was conducted to delineate the exact nature of this interaction. When the data from the two training groups were analyzed separately, it was found that the integrated training stimulus group only showed a reliable effect of test condition [$F(1,31) = 24.58, p < .001$]. Reaction times were significantly longer in the Stroop condition than in the control condition. The lack of either a significant main effect or interaction involving the identification task indicates that the reaction times for the color and word identification tasks were not statistically different in either test condition.

In contrast, the analysis of the non-integrated training group produced statistically reliable main effects for the test condition [$F(1,31) = 90.33, p < .001$] and identification task [$F(1,31) = 7.85, p < .01$] factors, as well as an interaction between the two [$F(1,31) = 13.00, p < .001$]. The significant interaction indicates that this group did not perform the same on the two tasks in the Stroop condition as in the control condition. The performance measures for the two identification tasks were then compared within each test condition. The results support the relationship suggested by Figure 6. Reaction times for color and word identification were reliably different in the Stroop condition [$F(1,31) = 13.03, p < .001$] but not in the control condition.

Comparisons between the two training groups were also conducted within each test condition. There were no reliable differences between the two groups on either task in the control condition. A significant interaction between training stimulus and task for the Stroop condition [$F(1,62) = 6.88, p < .05$] indicated that the groups did not perform the same across the two Stroop tasks. Further comparison confirmed that the two groups differ in performance on the Stroop color identification task [$F(1,62) = 6.09, p < .05$] but not on the word task.

To summarize, this interaction shows that, although the Stroop tasks remain more difficult than the control tasks in all cases, performance across the two Stroop tasks varied according the training stimulus while performance on the control tasks did not. Those trained on the integrated color-word stimuli showed relatively equal interference in both the color and word identification tasks within each test condition. Those trained on the non-integrated control stimuli, on the other hand, produced an asymmetrical interference pattern. This pattern was similar to that which is typically found in a traditional Stroop task with subjects taking significantly longer to identify the color of each color-word stimulus than to identify the word.

<u>Order Effects</u>. The reaction time data also generated a significant interaction between the counterbalance orders and the training stimulus [$F(1,56) = 4.22, p < .05$]. Together these two factors also interacted with the test condition [$F(1,56) = 4.45, p < .05$]. This interaction is depicted in Figure 7. As can be seen in the figure, the integrated stimulus group which trained on color identification first performed worse than the group which trained on word identification first. In the non-integrated stimulus

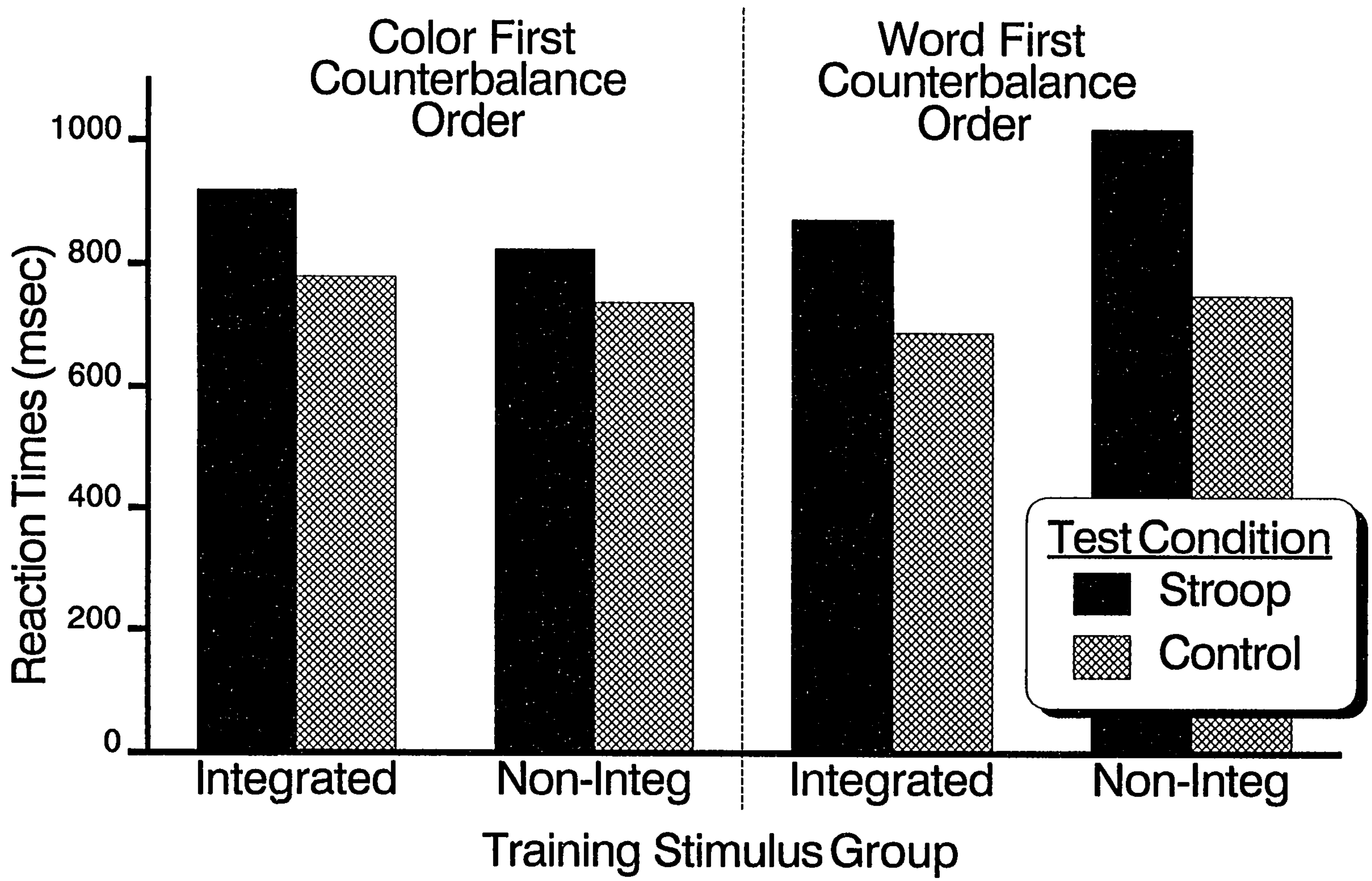

Figure 7. Mean reaction times (ms) of the trianing stimulus groups in each counterbalance order for Stroop and control test sessions.

group the reverse occurred; the color-first group performed better than did the word-first group.

Further analysis of this interaction found that these four groups did not differ in their performance on the control test sessions [$F(1,60) = 1.83, p > .05$]. A significant interaction, however, indicated differences in Stroop task performance across the two order groups within each training stimulus condition [$F(1,60) = 5.47, p < .05$]. While the Stroop performance of word-first integrated stimulus group was statistically worse than its non-integrated stimulus counterpart [$F(1,30) = 7.05, p < .05$], the performance of the two groups which began the training with the color identification task did not differ.

While there is no obvious explanation for the difference between the two order groups across the training stimulus conditions, this interaction does not compromise any of the findings discussed earlier. As indicated by the lack of an interaction with the identification task variable, the pattern of results illustrated in Figure 6 is maintained within both order groups for each training stimulus condition. In both of the integrated training order groups, the difference between the two identification tasks is relatively small, indicating symmetrical interference. Both of the non-integrated training groups, on the other hand, produced longer times for Stroop color identification than for Stroop word identification, demonstrating asymmetrical interference. So while the color first, non-integrated training group did not take any longer on average to respond in the Stroop condition than did the groups trained on integrated stimuli, their performance on the Stroop color task was still significantly worse than on the Stroop word task.

<u>Error Data</u>

Evaluation of the percentage of errors was conducted to determine if these data were consistent with the reaction time data or if task performance was subject to a speed/accuracy trade-off. The overall percentage of errors across all subjects ranged from 0% to 25% of the trials in a single test session (0 to 6 errors). The mean percentage of errors for all test sessions was 2.88%. This rate varied dramatically across the four test sessions, however, and the mean percentages for each session are summarized in Table 2.

The Stroop color identification task produced the greatest number of errors, with a mean of 5.27%. The Stroop word identification task resulted in the next highest number of errors, averaging 3.26%. Error rates in both of the control tasks were relatively low, with color identification producing 1.43% and word identification 1.56%. The pattern of these error rates is consistent with the reaction time performance data, maintaining the ordinal relationship of the four tasks. The task which generated the largest number of errors also took the longest to perform, while the task with the lowest number of errors produced the shortest mean reaction time.

The error rate data is also consistent with the interaction between the training stimulus, test condition, and identification task factors previously discussed. As can be seen by looking at the pattern of error rates presented in Figure 8, this pattern is consistent with that displayed in Figure 6. The non-integrated stimulus training group produced the greatest number of errors in the Stroop color identification test session. Error rates are much lower for the Stroop word task. The integrated training group, on the other hand, shows a relatively similar number of errors for both Stroop test sessions. Error rates for the control condition also show very little difference across either tasks or training stimulus groups.

Evaluation of the error data, therefore, failed to indicate that the faster reaction times observed for the control tasks and for the integrated training Stroop performance was the result of a speed/accuracy trade-off. In addition, the differential pattern of Stroop task interference demonstrated by the two training stimulus groups cannot be

Table 2

Mean Percentage of Errors in Each Test Session for the Entire Sample

Test Condition	Identification Task **Color**	 **Word**
Stroop	5.27%	3.26%
Control	1.43%	1.56%

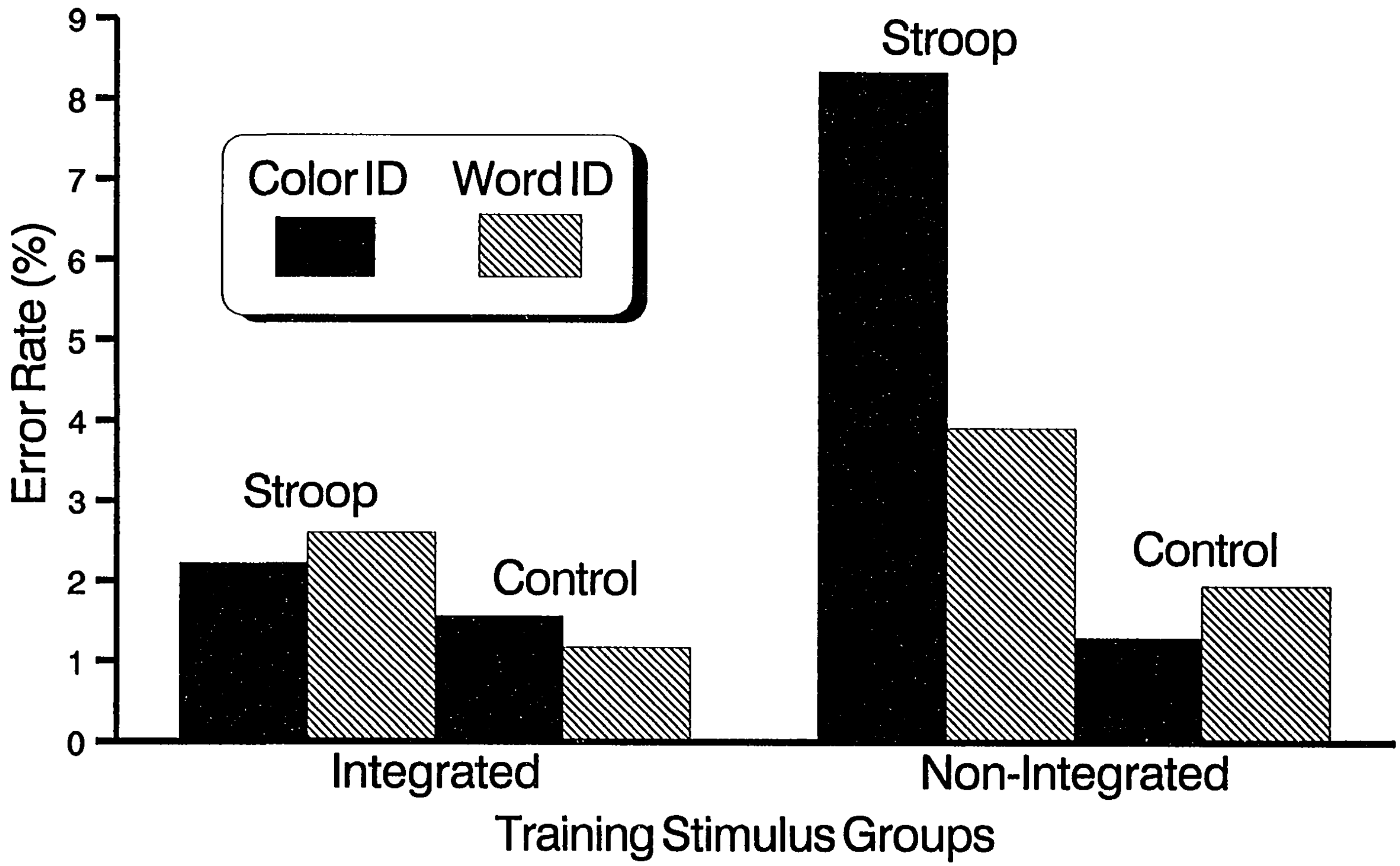

Figure 8. Mean percentage of errors for the training stimulus groups across the fours test sessions.

viewed as an artifact of increased caution on the part of the subjects from the non-integrated group in the context of an unfamiliar task.

Transfer of Training

Stroop Task Transfer. While it is apparent that the integrated stimulus group performed better on the Stroop tasks than did the non-integrated group following training, there remains a question as to whether the training experienced by the non-integrated group had any positive transfer to the Stroop condition. In order to determine this, the mean reaction times for the first Stroop task sessions encountered by each subject were compared. In the case of subjects from the non-integrated stimulus condition, this is represented by the color and word identification test sessions, since these subjects had no experience with the Stroop stimuli until reaching the test phase. For the integrated stimulus group, the data were taken from the training phase of the experiment and represented the first color identification and the first word identification sessions for each subject.

Due to an excessive amount of errors in the first task sessions, the data for two of the subjects from the integrated training group were dropped. In order to equate the number of observations, two subjects from the non-integrated group were randomly selected and their data were also dropped from the analysis. As a result, each training stimulus group was represented by 30 subjects.

A 2x2 mixed Analysis of Variance was performed on the session means comparing the performance of the two training stimulus groups across the two Stroop tasks. The analysis indicated a significant main effect of training group [$F(1,58) = 6.34$, $p < .05$] and of identification task [$F(1,58) = 20.01$, $p < .001$]. These results are depicted in Figure 9. The absence of an interaction indicates that the difference between the two groups is consistent across the two tasks. As can be seen in the figure, the word task

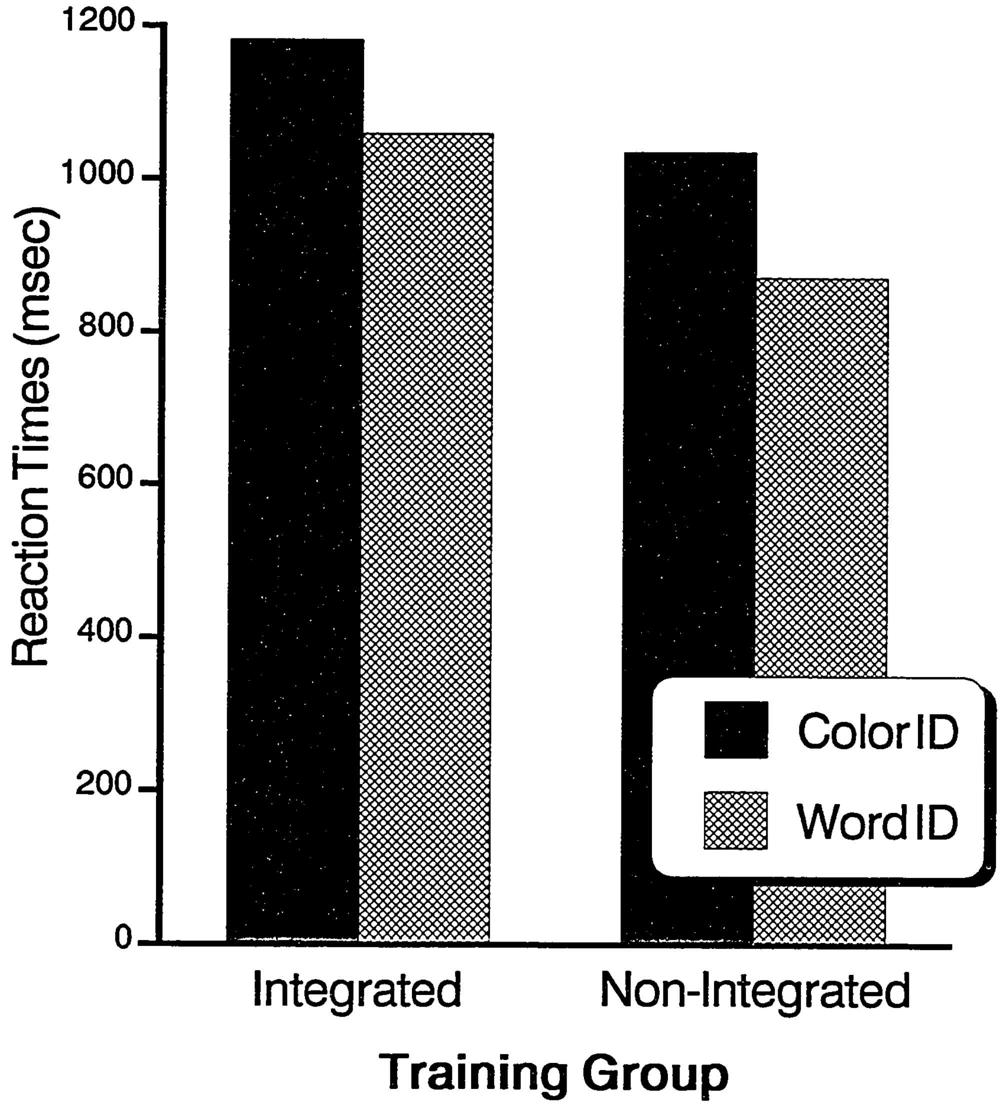

Figure 9. Mean reaction times (ms) of the training stimulus groups on their first session of the two Stroop tasks.

was considerably faster than the color task. Of greater importance is the fact that the non-integrated stimulus group performed better than did the integrated group on their first encounter with the Stroop stimulus in both color and word identification. This argues that training on the non-integrated control stimuli does develop some skills which positively transfer to the Stroop stimulus condition for both tasks.

Control Task Transfer. The lack of any effects for the control test sessions shows that the integrated group responded to the unambiguous stimuli as rapidly as did thegroup trained on them, indicating transfer. However, in order to gain a more complete understanding of skill transfer under both conditions, the same analysis was performed on the data from the first control task sessions for both training stimulus groups. In contrast to the previous analysis, error rates for the control sessions were relatively low, allowing data from all 64 subjects to be used.

Surprisingly, the analysis revealed no statistically reliable effects, indicating that reaction times were statistically equivalent for the first training sessions of the non-integrated group and the control test sessions of the integrated group. A within-subjects comparison of the mean reaction times for the first training phase and test phase sessions for those in the non-integrated training stimulus group confirmed that there was no difference in the speed of response between the first and last sessions or between the two types of tasks.

In an effort to understand this apparent lack of learning, the error rate data were then analyzed. A within-subjects analysis of variance was conducted on the number of correct responses from the first training session for each task and the two control sessions from the test phase for the 32 subjects in the non-integrated training group. The results indicated a statistically reliable difference in accuracy between the training and test phase sessions [$F(1,31) = 6.12$, $p < .001$]; however, there was no effect involving a difference between the two tasks. Contrary to the data which were gathered solely from the test phase of the experiment, this pattern of results suggests that subjects initially sacrificed some degree of accuracy in order to respond more quickly to the stimuli. As training progressed, reaction times did not increase significantly, but subjects did become more accurate in their responses.

Since learning in this case appears to be reflected in response accuracy rather than speed, the transfer of training analysis was re-run using the number of correct responses as the dependent variable. The performance on the first control task sessions of the two training stimulus groups was therefore compared based on accuracy. Results from this analysis showed that subjects trained on the integrated color-words were more accurate on the two tasks in the test phase than the non-integrated subjects were on their first training sessions [$F(1,62) = 6.96, p < .05$]. Again, no effects involving the identification task were significant. Table 3 displays the mean percentage of correct responses in each of the two tasks for the non-integrated training group during their first training session and for both training groups during the test sessions.

These analyses show that both training stimulus groups were able to exhibit some degree of learning which positively transferred to a stimulus condition on which they were not trained. Subjects who were only exposed to the non-integrated stimuli during training still responded faster on their first encounter with the color-word stimuli than had the integrated group at the beginning of training. However, the amount of task interference exhibited by both groups was the same. The group trained on color-words, on the other hand, performed with a greater level of accuracy during the test phase than the non-integrated training group had initially produced in training. The integrated training group in fact demonstrated the same level of speed and accuracy on their first encounter with the control tasks as had been achieved by the other group following

Table 3

Mean Percentage Correct for Each Training Stimulus Group on the First Training and Test Sessions of the Two Control Tasks

Training Stimulus Group *Control Session*	Identification Task **Color**	 **Word**
Non-Integrated Training *Training Session 1*	96.75%	96.35%
Non-Integrated Training *Test Session*	98.71%	98.04%
Integrated Training *Test Session*	98.44%	98.83%

training. Results also indicated that no relative change between the two identification tasks occurred as a result of training.

Discussion

The results of this experiment demonstrate that the subjects successfully learned to use the novel motor response for both word and color identification. The consistent lack of either training or task effects in the control condition shows that all groups learned to do the two tasks equally well and there was no advantage of one task over the other. When presented in an unambiguous format, subjects took the same amount of time to generate the correct motor response to identify color stimuli as to identify word stimuli. The scope of the present design does not empirically establish the two tasks as categorically automatic. However, if the continuum model of automaticity is adopted, rather than the two-process model, both tasks can be viewed as having achieved the same degree of automaticity since both tasks were subject to equal amounts of practice which resulted in similar response times. Since the current paradigm was successfully able to create motor responses of relative equivalence, it is appropriate to examine the effects of the experimental manipulations on the concurrent interference of the two tasks in the integrated color-word conditions.

Three primary effects of the training variables were found which address the two experimental hypotheses. First, the scheduling of task training produced an overall effect on performance which appeared for all groups in all test conditions but did not interact with any of the other factors in the design. Second, the nature of the training stimulus also influenced performance, but this manipulation primarily affected the pattern of Stroop task interference. Finally, training on the identification tasks, even with non-integrated control stimuli, did provide some positive transfer of skills to the integrated Stroop test condition, despite the fact that Stroop interference remained.

In addition to the experimental factors, the counterbalancing control factor did exhibit a statistically reliable interaction with the training stimulus factor across the test stimulus conditions. This issue was addressed earlier and found not to compromise any of the findings related to the experimental manipulations. As a result, this effect will not be further discussed.

Training Schedule Manipulation

The reliable effect of the scheduling manipulation showed that alternating back and forth between the two tasks results in slower task performance than does practicing all of the trials for each task together and switching only once. This finding supports the first hypothesis addressed by this study which predicted that a high amount of switching between two training tasks would inhibit the development of an automatic response. This outcome indicates an advantage of clustering training on individual tasks into larger blocks rather than interspersing different tasks, thus leading to interruptions of automaticity development. In addition to the disruptions to task learning, the constantly changing task requirements in the alternating schedule also produced an environment in which the encoding context was highly variable. This high degree of encoding variability may have also impeded the development of automaticity in the alternating group.

The lack of the anticipated interaction between the schedule manipulation and the type of training stimulus indicates that blocked practice is equally advantageous for both simple identification and Stroop task training. Despite the fact that the role of the two dimensions of the color-word stimuli in the alternating condition was constantly switched from target to distractor, relative test performance was no worse for this group than for those who switched constantly between looking at colored asterisks and neutral color names. This finding suggests that the subjects were able to successfully switch their attentional focus such that the task did not significantly impair the automaticity development. This was true in spite of the fact that the constant switching back and forth between target and distractor appears to be analogous to the variable mapping condition used by Shiffrin and Schneider (1977).

One aspect of the present design which may have facilitated the development of attentional focusing is the predictability of the switching schedule. Since the alternating schedule involved switching on every other session, the pattern of task demands was easily established by the subjects after only a few sessions. As such, subjects in the alternating group always knew exactly what to expect in the following training sessions. It is possible that, if the switching schedule were varied in such a way that subjects would not necessarily be able to predict what the task for the next session would be in advance, attentional switching may become somewhat more difficult.

One method which could explore this possibility would be to control the number of task shifts and vary the specific number of practice sessions between each alternation. Rather than examining only the extremes, the experimenter could have a range of task switching increments, such as three, seven, eleven, and seventeen times. Schedules could then be constructed which would vary the number of sessions given on a particular task before each switch. There might be four sessions of the first task, then switch to only two sessions of the second task, then switch back to the first task again, and so forth. The total number of switches which occurred during training would still be fixed, and the number of training sessions for both tasks could still be kept equivalent. Since the number of task sessions occurring in a row would not follow a predictable pattern, the subject would not be able to anticipate when the shift to the other task would occur. If it were found that a higher number of alternations under these conditions still showed no effect on the pattern of interference, then it would support the conclusion that increasing the amount of switching for the relevant dimension of an integrated stimulus does not affect the development of attentional focusing.

Training Stimulus Manipulation

The type of stimulus used during training produced the most interesting effect on the performance of the two Stroop tasks. As mentioned earlier, the use of the color-word stimuli during the training phase essentially eliminated the asymmetry associated with a standard Stroop effect. This finding is consistent with the results reported by Stroop (1935, Experiment 3) and MacLeod and Dunbar (1988). When subjects are allowed to practice on the integrated version of the task stimuli, performance on the two tasks becomes more similar.

An important difference among these three paradigms is represented by the tasks being trained. In both of the earlier studies, practice was limited to the one task which initially demonstrated weaker performance. This strategy ultimately led to different results for the two studies. Despite the fact that Stroop applied a relatively intensive practice phase for the verbal color-naming task, lasting for eight consecutive days, interference was only shifted to a symmetrical pattern. This pattern reportedly lasted only a very short period of time before the asymmetrical pattern returned. MacLeod and Dunbar, on the other hand, were able to continue past symmetrical interference. Their subjects practiced to the point that a reversal of the asymmetrical pattern occurred.

It is interesting to note that the pattern of interference obtained in the current experiment is similar to that obtained by Stroop. The time required for identification of the stimuli in the control condition remains faster while the two dimensions of a color-word stimulus appear to produce equal interference on the ability to correctly identify one dimension and ignore the other. A key distinction, however, is the fact that the word identification task received as much training in the current experiment as did the color identification task.

It is true that the incorporation of a novel task in the current experiment was specifically designed to discourage the advantage of one of the two tasks over the other. The training strategy of the other two experiments was designed to compensate for just such a pre-existing discrepancy. Despite the novelty of both tasks in this study, however, the data clearly indicate that performance was initially worse for color identification in the color-word training condition. This indicates that, even when the response is switched to one which does not inherently conflict with either type of stimulus, Stroop stimuli initially tend to produce asymmetrical interference favoring word processing over color processing.

One possible explanation for the initial presence of the asymmetrical pattern in the absence of an overt response conflict is that subjects were verbally mediating their responses to the stimuli. If subjects were to sub-vocalize a verbal response when initially learning the correct buttons for the motor response, then a response conflict situation would be present for the color identification task. The observed asymmetry would then be expected. Such a finding would support a response competition explanation of these findings.

Data from the control conditions, however, contradict this hypothesis. In accordance with the observations described earlier involving naming responses (e.g., Cattel, cited in Jensen and Rohwer, 1966; Fraisse, 1969), verbal mediation should produce slower reaction times for color than for word stimuli. Performance measures for the two tasks in the unambiguous stimulus condition exhibit statistical equivalence for both groups in the test phase, and even at the very beginning of training. The relative uniformity of performance on these tasks, both in terms of speed and accuracy, provides no evidence of verbal mediation for the two responses.

One method which might be employed in a future experiment to test for verbal mediation would be the incorporation of a verbal secondary task at the end of training. Based on a multiple-resources model of processing limitations (Wickens, 1984; Navon & Gopher, 1979), if the primary task was not utilizing any verbal resources (i.e., was not being verbally mediated) then the addition of a concurrent verbal task should have a limited impact on the performance of the primary manual identification task. If, on the other hand, the addition of the secondary task significantly decremented performance on the identification task, this would suggest that, not only is the response being verbally mediated, but the processes are probably not sufficiently automatic since they would be exhibiting an effect of increased processing load.

Since the scope of the present design was not intended to examine the training manipulations in the context of a dual-task paradigm, conclusions concerning the equivalence of the two identification responses are based on the relative performance of the two control tasks. Since there was no evidence found in support of the predictions made in accord with the verbal naming studies, it is assumed that, in the current experiment, any verbalization which occurred during the tasks was functionally disintegrated from the response generation process and, at best, played only a peripheral role (see Figure 10).

Given that the two motor response processes were approximately equivalent, response competition theory predicts that response interference should also be equivalent. This prediction was not substantiated by the results from the non-integrated training stimulus group. Although their control task performance demonstrated equal

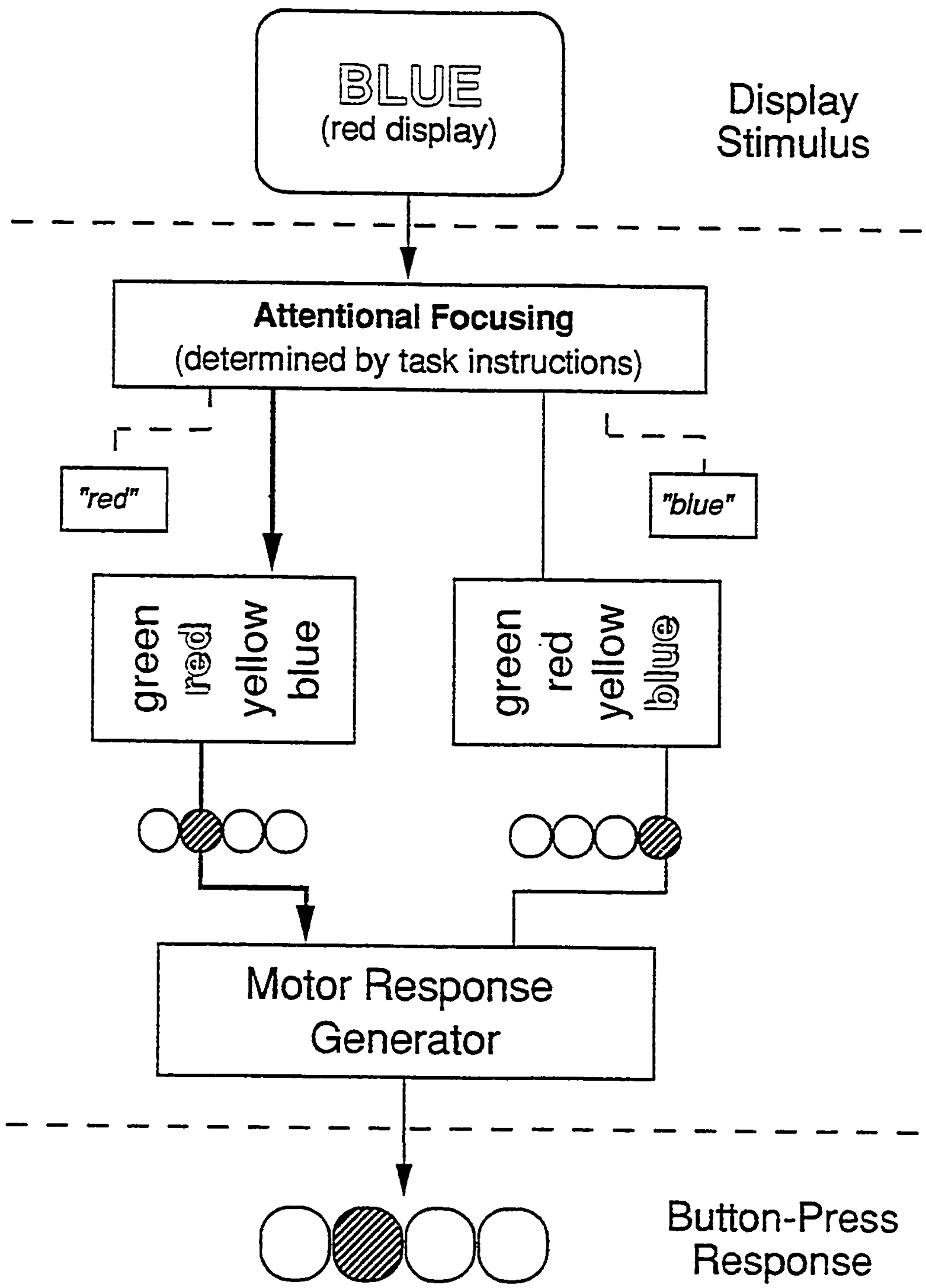

Figure 10. Schematic of a proposed model of the motor and verbal responses to a Stroop stimulus following training.

skill levels for the two identification tasks, the word dimension of the color-word stimulus still produced a much greater amount of interference on color identification.

In contrast, the other training stimulus group did produce equivalent response interference for the two tasks. Since they received exactly the same number of training trials for the two identification tasks, the difference in interference must be the result of the type of stimulus they were trained upon. This result argues that the contribution of practice to Stroop performance lies not in training the response, but rather in exposure to the complex stimulus. Experience with the multi-dimensional nature of the stimulus provides a context for the development of selective attentional skills. In other words, subjects who were trained on the integrated color-words were given the opportunity to learn how to focus their attention on the relevant dimension and to ignore the irrelevant one. Subjects who practiced only the motor response were never allowed an opportunity to learn attentional focusing until the test session. This pattern of results therefore supports the second hypothesis presented in this paper. Equivalent training on the two component response tasks was not sufficient to avoid asymmetrical interference in the integrated color-word Stroop condition.

Attentional Skills. The current findings demonstrate that the competition of concurrent responses cannot provide a fully adequate account of the presence or pattern of interference. Instead, they support the position that the processes of stimulus encoding and attentional control play a central role in Stroop asymmetry. The most influential factor in the present study for determining the pattern of interference between conflicting stimulus dimensions was prior experience with the integrated stimuli. In light of this, Stroop's (1935) results should be re-interpreted. The fact that subjects practiced on the integrated versions of the stimuli implies that the training sessions provided subjects with an opportunity to practice their attentional focusing, rather than merely their response generation skills.

The conclusion that subjects are able to learn attentional focusing skills as a result of training is in accordance with the conclusions of Harvey (1984) and Zajano and Gorman (1986) that subjects do possess the ability to exhibit some degree of attentional focusing. If this ability exists, then the question arises as to why this skill is so difficult to invoke under the circumstances found in the Stroop paradigm. One possible explanation for this grows out of the hypothesis posed by Navon (1977) that perceptual processing proceeds in a hierarchical manner in which the processing of certain properties precedes the processing of other properties.

This interpretation was derived from data concerning the interference generated by either the global or local properties of a stimulus. Letter stimuli containing both global and local dimensions were formed by aligning small letters into patterns which represented larger incongruent letters. Results showed that incongruent large letters (global features) interfered with performance on an auditory discrimination task while the smaller letters (local features) did not. Manual identification of either the large or small letters also produced an asymmetrical interference pattern analogous to what is found in a traditional Stroop task. Subjects took considerably longer to identify the small letters when they formed a conflicting large letter. On the other hand, identification of the large letter was virtually unaffected by the conflicting small letters which formed it. Based upon these findings, Navon postulated that the global properties of a visual stimulus take precedence over the local ones and are processed first.

Regan (1981) also found a priority of global over local properties when examining English and Armenian letters. The unfamiliar Armenian letters showed a much stronger effect of increased processing load than the well-learned English letters, as would be predicted by automaticity theory. However, when the two types of letters were used to created composite letters similar to Navon's, incongruent large letters consistently delayed the time required for naming the small letters, regardless of which alphabet was being used. This finding supports the precedence of global over local properties. This occurs even when the interfering global properties are relatively unfamiliar and demonstrate high susceptibility to interference under other conditions, while the local properties are well-learned and demonstrate low effects of processing load.

If this theory of hierarchical processing were expanded to include relationships among other properties of perceived stimuli, it is possible to draw an analogy to the asymmetry of the Stroop stimuli. When presented with a complex stimulus which contains both lexical and chromatic qualities, the lexical information may take precedence over the chromatic information, and is therefore processed first. This theory still views the asymmetry as the result of differential processing of the two stimulus components. However, the advantage of words over colors is determined by the bottom-up nature in which the stimulus properties are perceived and processing is initiated.

Others (e.g., Kahneman & Treisman, 1984) have attributed this type of selective attention failure to the structure of the perceived stimulus. Garner (cited in Regan, 1981) has argued that experimenters may be defining certain stimulus properties as separate dimensions when subjects are actually processing them in a unitary manner. These stimulus properties are perceptually integrated in such a way that observers cannot selectively attend to one dimension without interference from the other. Garner has further described the concept of *asymmetrical integral stimuli* in which the failure to selectively attend occurs for one dimension but not for the other. In other words, subjects are able to perceive the word without attending to the color used to display it.

However, they are not able to see the color as independent of the form in which it is presented.

Regan (1981) suggests that the way in which the stimulus structure captures attention may be strongly influence by the type of spatial and temporal presentation. Modifications of stimulus presentation in the Stroop paradigm have supported this notion. As reported earlier, bilateral presentation of the non-integrated stimulus elements has been shown to produce reliable Stroop interference (Dyer, 1973a). In another approach using bilateral presentation, color-word stimuli were enclosed in geometric shapes which were simultaneously presented side-by-side. Subjects were then instructed to report the color of the word in one the two shapes and to ignore the other shape. The presence of an incongruent color name produced only minor interference on color identification if it was located in the shape which subjects were instructed not to attend to (Kahneman & Henik, 1981). The addition of information which facilitated the perception of the conflicting stimuli as belonging to two separate objects severely diminished the influence of the incompatible information.

If the way in which attention is allocated to the properties in a visual scene are predisposed according to the context, expectations, and other top-down influences present in the observer, then it should be possible to change attentional functioning by affecting these predispositions without modifying the stimuli. One mechanism which might result in changes to this system is experience. Gibson (1969) proposed a theory of perceptual development in which experience and practice in dealing with certain types of stimulation leads to improvements in an observer's ability to extract information from the environment. Gibson's theory is directed toward the ability to differentiate stimuli and is based on the concept of increased specificity. As individuals repeatedly encounter stimuli, they detect and respond to an increasing number of properties, patterns, distinctive features, and other stimulus attributes which they initially showed no response to. As the amount of information extracted from a stimulus increases, then the ability to differentiate it from other, similar stimuli is improved.

The mechanisms which are proposed to account for perceptual learning include abstraction, filtering, and peripheral attentional responses which involve sensory exploratory activities in the environment. Since the stimuli in the present experiment occupied the same perceptual space and involved only the visual system, the third mechanism is not relevant to this discussion. The concept of abstraction defines the ability of the observer to identify and use some invariant relation or feature of the stimulus in the context of other varying objects or events. Coexistent with the abstraction of relevant features is the ability to filter out the irrelevant varying stimulus features. In other words, as perceptual learning develops, the observer learns how to identify and attend to those relevant features of a stimulus situation which remain constant, while concurrently filtering out the variable aspects which are not relevant.

If these concepts are applied to the current findings, then the results of the color-word training may be viewed as affecting these two processes. The present task requires the subject to abstract and identify the relevant color feature from the context of varying, irrelevant lexical forms, or vice versa. At the beginning of training, subjects demonstrate a bias against filtering the word information, due possibly to either a precedence in processing or to the way in which the stimulus structure is represented. Through training, subjects learn to restructure their abstraction and filtering processes in order to more effectively meet the task demands. This may involve improving their color abstraction or word filtering processes in order to compensate for the dominance of word over color information, thus allowing the two dimensions more equal status. It could also indicate the development of the ability to parse the stimulus elements into two separate structures so that both processes are given the opportunity to operate (if there is only one object, there is nothing to be filtered). Through experience with the multi-dimensional stimuli, and in the context of the task demands, subjects in the integrated training condition were thus able to learn equal or compensatory levels of abstracting and filtering abilities for both dimensions of the stimulus. This allowed them to successfully attend to the relevant dimension and ignore the irrelevant dimension for the color as well as the word identification tasks, producing a symmetrical interference pattern.

Word-Reading Interference. One characteristic of the present data which differs from many of the reported results of the Stroop task is that word identification also showed some degree of interference in the presence of irrelevant colors. Not only was this true for both training stimulus groups, but the amount of interference appears to be the same for both groups. Most results report that performance on the word task is virtually unaffected by the presence of an incongruent color. An exception to this was found in the two training studies described (Stroop, 1935; MacLeod & Dunbar, 1988). In both cases, repeated training on the controlled task eventually let to interference on the initial automatic task. The fact that the non-integrated training group in the present study also showed interference, albeit unequal, in *both* dimensions implies that the extensive experience with the color stimuli may have affected the way in which subjects process color information in the future, as exhibited by the decrement in performance on the word task which occurred in the presence of conflicting colors.

Evidence that word reading is subject to attentional limitations has been previously reported with respect to filtering costs (Kahneman, Treisman, & Burkell, 1983). It was found that speeded choice reading or naming responses to a relevant stimulus were delayed by the simultaneous occurrence of other visual events. This occurred even when the irrelevant stimuli provide no sensory interference, discriminability problems, or response conflicts. The authors concluded that filtering costs represent a delay in the appropriate deployment of attention, whether this involved focusing on the target or excluding the distractors.

Another example of the effects of additional perceptual information is the dilution of Stroop effects (Kahneman & Chajczyk, 1983). When additional neutral words or non-lexical strings were added to a non-integrated Stroop color-word display, interference on naming the color presented in the display changed. A primary distinction of the dilution effect, however, is that the additional irrelevant stimulus had the effect of delaying responses in congruent color-word conditions and *accelerating* responses in conflicting conditions. This led to the proposal that the additional information introduced some form of attentional capture or sharing between the stimulus elements which influenced the processing of the irrelevant color-related word stimulus. Again, the increase in perceptual information was seen as affecting the processing of the lexical portion of the display.

Based on the conclusions of these two studies, word reading does appear to be subject to some types of attentional limitation. Since Stroop studies have historically shown no effect of the presence of incongruent colors on the ability to read color names, it seems reasonable to suggest that the training procedures have resulted in some change to this attentional pattern. In the training phase subjects experienced several hundred trials in which they responded to the color information. It appears that the presence of this information on the screen in the test session diverted some portion of their attentional resources, thus slowing the response. The strong asymmetry found with the non-integrated training group still argues for an advantage of filtering color information over filtering word information. However, following training, the presence of color information does appear to reduce attentional processing to some degree. This supports the suggestion of MacLeod and Dunbar (1988) that automatic responses are subject to attentional limitations when executed in the presence of a stimulus from a process which has an equal or greater level of automaticity. This interference may involve the automatic attention response described by Shiffrin and Schneider (1977).

The only way to test the proposal that the interference of incongruent colors on word reading is a result of the training would be to examine the pattern of interference between the Stroop and control tasks for subjects who had not received any training. Since there was no control group which was given the four test phase conditions without first completing training on both tasks, it is not possible for us to confirm this hypothesis using the data of the present study.

Transfer of Training

The primary finding with regard to the second experimental hypothesis is that training each of the two response tasks on non-integrated stimuli did not provide sufficient skills when subjects were transferred to the integrated Stroop color-word condition. Lack of transfer has been attributed to the need to develop certain attentional control skills which could not be trained using the control stimuli. A potential alternative explanation for the failure of transfer can be found in Logan's (1988) instance-based theory of automation. This theory is based on three main assumptions: (1) attention to a stimulus unavoidably results in encoding it into memory; (2) attending to a stimulus will simultaneously result in retrieving from memory whatever has been associated with it in the past; and (3) each encounter with a stimulus is encoded, stored, and retrieved *separately*. According to this theory, automaticity is conceptualized as a memory phenomenon. A process is automatic when it is based on the single-step direct-access retrieval of past solutions from memory. When novices are presented with a situation which has not previously been encountered, they are forced to use a general algorithm. As experience is gained, memories of successful solutions are accumulated, and retrieval of those memories will become more rapid, exemplifying automatic task performance.

According to this view, practice remains the primary mechanism for the development of automaticity. However, the instance-based approach interprets practice as the source of an increased number of memory instances available for retrieval. The more traditional view of automaticity is process-based and construes the effect of practice as making the underlying process more efficient by strengthening bonds, reducing resource demands, and eliminating processing steps.

Based on this difference, the instance-based model of automaticity makes a different prediction on the transferability of training in the current paradigm. Since automatization involves learning specific responses to specific stimuli, the transfer of skills to stimuli which differ from those used in training should be very poor. Despite whatever level of skill subjects had been able to acquire in the part-task paradigm, transfer to the color-word stimuli would leave them with no prior experiences to retrieve from memory, and they would be forced to revert to an algorithm-based approach. As such, the non-integrated training group would not be expected to perform much better than if they had no training on any portion of the task.

Consistent with this prediction is the fact that the non-integrated group's performance in the transfer condition shows they were unable to transfer the relative equivalence of the trained tasks. Instead, they produced a pattern similar to that generated by the other group at the beginning of training, as would be expected if both groups were using similar algorithms. However, examination of the transfer effects did produce several examples of transfer, to varying degrees, which would tend to contradict the broad-range predictions generated by a strict interpretation of this theory.

While the non-integrated training group was not able to effectively ignore the irrelevant word information when instructed to identify the color, they did exhibit some degree of positive transfer. Comparisons between the two training stimulus groups showed that the non-integrated group responded faster to the stimuli on their first encounter with the color-words in the test phase than had the integrated group on their first encounter in the training phase.

The most logical skill to be transferred from the non-integrated training experience is the ability to effectively use the button responses for identification. The slower reaction times from the training phase data reflect not only an unfamiliarity with the color-word stimuli, but an unfamiliarity with the motor response as well. Subjects who did not receive any Stroop trials until the test phase at least had the advantage of 480 trials to learn how to correctly select one of the four buttons to indicate their response. As is noted by Shiffrin et al. (1981), any specific task is likely composed of many sub-components which together produce a montage of automatic and controlled processes. While the untrained skill of disentangling the integrated stimulus components probably required a great deal of effort for the subjects to perform in order to generate the correct internal response, the overt button press response should have been executed with relative ease.

A problem related to this hypothesis is the fact that training on the unambiguous stimuli did not effectively increase reaction times, only accuracy. The fact that the integrated stimulus group also produced a high percentage of errors at the beginning of training argues against the possibility that one group was emphasizing speed and the other accuracy on their first encounter with the color-word stimuli. One possible explanation for the lack of any apparent learning curve for the reaction times in the non-integrated condition is a floor-effect. The unidimensional identification task may have been so simple that subjects could perform it as fast as they could push the buttons, even without training.

Another possible explanation for this effect can be found in the types of feedback which were used in the study. There was no summary feedback at the end of each session to inform the subjects on their progress in either speed or accuracy. However, accuracy feedback was provided on error trials in the form of an auditory beep. Subjects, therefore, had an objective measure of improving their accuracy, since the number of beeps decreased as they improved. Measures of improving speed, however, were entirely subjective. If reaction time feedback were included in the training phase, it is highly probable that the non-integrated training group would show improving performance in speed as well as accuracy. Since feedback conditions were the same for both training groups, it is likely that both groups would show greater reaction time decreases as a result of training. It is therefore unclear what effect this modification would have on the transfer effects currently observed.

In the present study, the lack of any training stimulus effects involving the control test sessions in either the reaction time or error data indicate that the integrated group was able to fully transfer their response skills to the unambiguous condition. Considering the simple nature of these stimuli, this is not surprising. However, this finding does contradict the predictions made by Logan's (1988) theory with regard to this paradigm and supports the notion of process-based learning. It is also noteworthy that the attention-focusing skills developed by these subjects was not at the expense of learning the motor task.

While the current findings failed to fully support the predictions based on Logan's model regarding the transfer of training, his theory does provide an interesting question regarding the transferability of the attentional focusing skill. If the ability to selectively focus on the relevant dimension and suppress the irrelevant information were a process-based skill, then subjects should be able to transfer that skill to a similar task with different stimuli. If subjects demonstrated that they learned to successfully ignore the irrelevant word information to the same degree as the color information on one set of color-words and hues, they should then be able to produce a similar symmetrical interference pattern with a different set of names and hues. The extent and limitations of such transfer could provide an interesting area of investigation.

Concluding Summary

The present findings support the ability of training to influence the pattern of Stroop task interference. Both the training schedule and training stimulus manipulations were found to influence task performance in the test phase, providing some support for the two experimental hypotheses.

The first hypothesis, that a high amount of switching between tasks during training would impede the development of task efficiency, was supported. The scheduling of the two tasks during the training period, however, did not have any specific effect on the pattern of interference between the two dimensions in the integrated test condition. Rather, the constant task switching diminished the overall effectiveness of the training, leading to poorer performance on all four tasks following the conclusion of practice.

The alternating condition also did not produce any differential effects across the two training stimulus groups. This demonstrates that, in the current experiment, switching stimulus elements between the roles of target and distractor did not appear to disproportionately diminish training effectiveness relative to training on control stimuli.

While this may be the result of the success the subjects had in selectively focusing on the two distinct types of stimulus dimensions, it may also reflect the predictability of the alternating schedule used in the current design.

The second hypothesis was also confirmed by the present results. Subjects trained strictly on the identification responses were not able to transfer these skills to the integrated color-word condition without exhibiting standard Stroop interference. Instead, the stimulus used for training proved to have the greatest influence on the pattern of interference. By having an opportunity to develop attentional focusing as a separate skill, subjects trained on the color-word stimuli were able to reduce the interference of conflicting words on color identification to the point that the interference was equivalent. In addition, the continued presence of Stroop interference for the non-integrated group contradicts a prediction made by response competition theories.

While the subjects from the non-integrated group were unable to transfer any skill which compensated for the interference of words on color identification, they did demonstrate some degree of response transfer as indicated by their overall faster reaction times. In addition, the integrated training group exhibited full transfer of response skills to the control test conditions. These findings imply that training on one task will transfer relevant components to a similar task. However, in this case, training on the independent responses does not compensate for the lack of training on the selective attention process.

The present finding support several ideas regarding the relationships between training, automaticity, attention, and Stroop interference. The development of automaticity through task repetition was found to create interference on a second automatic task, suggesting a limitation in our ability to concurrently process two closely-related, yet conflicting automatic tasks. The different interference patterns developed through training also support the position that attentional control is a critical element in the occurrence of standard Stroop interference. This suggests that the composition of similar multi-dimensional stimuli and their potential interaction with attentional control should be taken into consideration when employing part-task training. Finally, while it appears that these limitations in attentional control are initially biased against filtering out color information, the present data also appear to indicate that these skills are modifiable through experience. Thus, these finding suggest that the asymmetrical interference pattern characteristic of the Stroop effect reflects a bias in selective attention abilities, which may be a product of experience on the two tasks.

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Appendix A

Design and Analysis Committee and

Human Subjects Institutional Review Board Approvals

SJSU SAN JOSE STATE UNIVERSITY

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One Washington Square • San José, California 95192-0120 • 408/924-5600 • FAX 408/924-5605

October 11, 1991

TO: Susan Heers, MA candidate

FROM: Kevin Jordan, MA Coordinator

RE: Design and analysis review

Drs. Feist and Huntsman have read your thesis proposal for the Design and Analysis Committee. Their comments are enclosed. Based on their comments, the thesis proposal is approved. As you can see, however, both reviewers have some concerns which merit your careful consideration. Many of these concerns can be addressed in the final versions of your thesis. For example, much of your discussion of the hypotheses in the proposed analyses section might better be placed in the introduction. You should also be more exact in specifying your eight training groups. The comment from both reviewers that you must consider prior to conducting the experiment concerns subject fatigue given the number of proposed trials. Granted, automaticity presumably requires a good deal of prior experience as you describe in your introduction, but you might consider a more distributed prior experience (i.e., build in longer breaks).

Based on this committee's approval, the collection of data for your thesis is approved contingent on documentation of compliance with university policy regarding the use of human subjects in research. University policy requires approval of your project by the Human Subjects Institutional Review Board. Please provide me with a file copy documenting such approval as soon as you receive it. After that copy is part of your file, you may begin collecting data.

Congratulations on your progress to date! We look forward to the continuation of your fine performance in the program.

cc:
Cooper
Feist
Huntsman
Johnson (NASA-ARC; forward to Jordan)
Jordan
file

SAN JOSE STATE UNIVERSITY

Office of the Academic Vice President • *Associate Academic Vice President* • *Graduate Studies and Research*
One Washington Square • San Jose, California 95192-0025 • 408/924-2480

To: Susan T. Heers, Psychology
1628 Begen Avenue
Mountain View, CA 94040

From: Serena W. Stanford *Serena W. Stanford*
AAVP, Graduate Studies and Research

Date: October 18, 1991

The Human Subjects Institutional Review Board has approved your request to use human subjects in the study entitled:

"The Effects of Training Strategy on Stroop Color Word Interference"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The Board's approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Dr. Serena Stanford immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

Please also be advised that each subject needs to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have questions, please contact me at 408-924-2480.

CC: Kevin Jordan, Ph.D.
Ruth M. Jones, Psychology

Appendix B

Summary of Omnibus ANOVA *F*-ratios and *p*-values

SOURCE	F	p-value
Training Schedule	4.76	0.0333
Training Stimulus	0.16	0.6906
Counterbalance Order	0.16	0.6868
Schedule x Train. Stimulus	0	0.9764
Schedule x Order	0.24	0.6284
Train. Stimulus x Order	4.22	0.0445
Sched. x Train. Stimulus x Order	0.53	0.4716
Test Stimulus	109.14	0.0000
Test Stim. x Schedule	0.5	0.4829
Test Stim. x Train. Stimulus	11.93	0.0011
Test Stim. x Order	0.2	0.6571
Test Stim. x Sched. x Train. Stimulus	1.35	0.2500
Test Stim. x Sched. x Order	1.32	0.2556
Test Stim. x Train. Stimulus x Order	4.54	0.0376
Test Stim. x Sched. x Train. Stimlus x Order	0.1	0.7540
Identification Task	8.86	0.0043
ID Task x Schedule	3.47	0.0679
ID Task x Train. Stimulus	2.97	0.0901
ID Task x Order	1.62	0.2083
ID Task x Sched. x Train. Stimulus	0.01	0.9179
ID Task x Sched. x Order	0.29	0.5953
ID Task x Train. Stimulus x Order	0.9	0.3474
ID Task x Sched. x Train. Stimulus x Order	0.12	0.7256
Test Stimulus x ID Task	9.54	0.0031
Test Stim. x ID Task x Schedule	0.29	0.5938
Test Stim. x ID Task x Train. Stimulus	8.23	0.0058
Test Stim. x ID Task x Order	1.35	0.2495
Test Stim. x ID Task x Sched. x Train. Stimulus	0.01	0.9035
Test Stim. x ID Task x Sched. x Order	0.74	0.3943
Test Stim. x ID Task x Train. Stimulus x Order	0.46	0.5007
Test Stim. x ID Task x Sched. x Train. Stim. x Order	0.02	0.8767

SOURCE	F	p-value
Replication	35.31	0.0000
Replication x Schedule	0.69	0.8550
Replication x Train. Stimulus	1.01	0.4533
Replication x Order	0.64	0.9022
Replication x Sched. x Train. Stimulus	1.41	0.0957
Replication x Sched. x Order	0.63	0.9089
Replication x Train. Stimulus x Order	0.64	0.9062
Replication x Sched. x Train. Stimulus x Order	0.76	0.7828
Test Stim. x Replication	3.24	0.0000
Test Stim. x Rep. x Schedule	1.1	0.3383
Test Stim. x Rep. x Train. Stimulus	1.56	0.0434
Test Stim. x Rep. x Order	1.03	0.4269
Test Stim. x Rep. x Sched x Train. Stimulus	1.51	0.0571
Test Stim. x Rep. x Sched. x Order	1.38	0.1075
Test Stim. x Rep. x Train. Stimulus x Order	0.66	0.8887
Test Stim. x Rep. x Sched. x Train. Stimulus. x Order	0.88	0.6235
ID Task x Replication	1.22	0.2192
ID Task x Rep. x Schedule	0.88	0.6300
ID Task x Rep. x Train. Stimulus	0.85	0.6731
ID Task x Rep. x Order	0.51	0.9750
ID Task x Rep. x Sched x Train. Stimulus	0.87	0.6419
ID Task x Rep. x Sched. x Order	1.16	0.2729
ID Task x Rep. x Train. Stimulus x Order	1.07	0.3689
ID Task x Rep. x Sched x Train. Stimulus. x Order	0.9	0.5952
Test Stim. x ID Task x Replication	0.68	0.8722
Test Stim. x ID Task x Rep. x Schedule	0.78	0.7652
Test Stim. x ID Task x Rep. x Train. Stimulus	0.8	0.7328
Test Stim. x ID Task x Rep. x Order	0.86	0.6542
Test Stim. x ID Task x Rep. x Sched x Train. Stimulus	1.36	0.1167
Test Stim. x ID Task x Rep. x Sched. x Order	0.64	0.9062
Test Stim. x ID Task x Rep. x Train. Stimulus x Order	0.8	0.7395
Test Stim. x ID Task x Rep. x Sched. x Train. Stim. x Order	0.86	0.6579