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The Attentional Blink in Audition and Vision: An Early Selection

Model of Selective Attention Revisited

By

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Abstract

The current study investigated older and younger adults' performance in two rapid serial presentation tasks using simple stimuli: one auditory task (tones) and one visual task (lines). An attentional blink (AB) was found for both age groups in both tasks, however, the magnitude of the ABs was greater for older adults. Because the Inhibitory Deficit Hypothesis (Hasher & Zacks, 1988) predicts better performance on AB tasks for older adults, this hypothesis was not supported. Results are interpreted within an early selection model of attention.

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This thesis is dedicated to my parents, Lou and Joan Goddard.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Negotiating the environment is a dynamic enterprise for all living organisms. Our everyday world presents us with stimuli that are so rapid, complex, and numerous that we cannot analyze them all to completion. Instead, in an attempt to manage this vast array of information, we selectively attend to particular aspects of input, usually to the exclusion of other aspects. For example, a driver becomes attentive to the sound of a siren as it grows nearer and ignores the music that is playing on the radio. Of interest to the present inquiry is the fate of such attended-to stimuli and its immediate cognitive consequences. Will the processing of a selected stimulus impact the processing of a subsequent one? Will our driver be less likely to hear a car horn in the instant after she notices the siren, or will the detection of the second sound proceed unaffected?

The foregoing speaks to the question of the temporal nature of selective attention and specifically, what happens when it becomes necessary to attend to two objects or events that occur in close temporal proximity. This study will attempt to answer this question by employing an auditory and a visual rapid serial presentation task and additionally, will examine whether age differences exist in these tasks.

In selective attention research, the consequences of attention are often investigated with secondary probe paradigms, for example, rapid serial presentation techniques. There is a fairly extensive body of research in the visual domain using these techniques, with the majority of the findings suggesting that when two stimuli are presented in close temporal proximity, the ability to attend to the second stimulus is impaired (e.g., see Shapiro & Raymond, 1994; Chun & Potter, 1995). In this respect, two

major models have emerged to explain these results: a late selection model of selective attention (Raymond, Shapiro & Arnell, 1992b) and an early selection model of selective attention (Raymond, Shapiro & Arnell, 1992a), both of which will be discussed in more detail below. However, behavioral research in the auditory domain using rapid presentation techniques with a secondary probe are conspicuously absent and it is of interest to know if these second stimulus impairment effects are also observed in audition.

Selective attention research has also revealed that a critical dimension of efficient selection processes is the ability to ignore irrelevant information, or, the capacity for inhibition. Accordingly, this introduction will begin with a general overview of early and late selective attention theories, with particular emphasis on the role that cognitive inhibition may play in selection efficiency and whether these processes occur early or late. This will be followed by a review of relevant physiological research, which will examine the neurophysiological evidence for selective attention and cognitive inhibition. Finally, because declines in cognitive inhibition have been linked with age-related differences on cognitive tasks in general and selective attention tasks in particular, this discussion will also review the relevant literature on selective attention tasks with respect to the performance of both younger and older adults.

Overview of Selective Attention

In psychology, selective attention has frequently been studied by tracking the fate of unattended stimuli. For example, Cherry (1953) investigated attentional processes by examining the so-called cocktail party effect. In particular, Cherry was interested in how

it was that in a noisy environment like a cocktail party, people were able to focus on a single conservation. He speculated that selective auditory attention was the mechanism by which people were able to achieve this goal, namely, the perception of a weak speech signal in a noisy environment.

To test this hypothesis, Cherry designed a dichotic listening task, where people were asked to attend to and verbally shadow a train of speech in one ear while simultaneously ignoring speech in the other ear. He discovered that when shadowing the speech in one ear, people could not remember the details of the speech in the unattended ear. Cherry (1953) concluded that attention to one ear resulted in better encoding of the inputs to the attended ear.

Subsequent research supports Cherry's simple initial conclusion that attention acts to enhance a selected stimulus' processing. In visual-spatial investigations, individuals respond faster and more accurately to stimuli presented at attended locations than to stimuli presented at unattended locations (e.g. Posner, Snyder & Davidson, 1980). Further, signal detection experiments have demonstrated that focused spatial attention enhances perceptual sensitivity (Bashinski & Bacharach, 1980; Downing, 1988; Muller & Findlay, 1987). Similarly, auditory-spatial investigations that employ lateralized auditory cues influence the speed of correct detection responses and valid cues increase the probability of correct stimulus identification (Buchtel, Butter & Ayvasik, 1996).

Early versus Late Selection

Two centrally related questions are raised by Cherry's (1953) cocktail party experiment. The first has to do with the stage(s) of stimulus processing at which

incoming signals can be selected or rejected by attentional processes. Indeed, this level-of-selection issue, or *early versus late selection* debate has become one of the most contentious and continuing controversies in cognitive psychology (Houghton & Tipper, 1994). Implicit within any stage view of attentional processes is the notion that the system itself has limited capacity and that performance suffers when the system is overloaded with multiple inputs. In fact, it has been stated that attentive behavior is the result of limitations in the capacity of any realizable perceptual system (Tsotsos, 1997). Because of capacity limitations, decisions about what or how much to process next, the core of selection, must be made.

Capacity limitations are often conceptualized in the form of a "bottleneck" (see Broadbent, 1954, 1962) which exist to control the amount of information that can be attended to and processed by the system. The early versus late selection debate is centered on the location of that bottleneck. Early selection refers to the idea that a stimulus need not be completely perceptually analyzed and encoded as either semantic or categorical information before it can either be selected for further processing or rejected as irrelevant. Early selection models of attention suggest that it is possible to select inputs prior to a full analysis of a stimulus' elementary features, such as luminance, color or pitch. In these models (e.g. Broadbent, 1962), attention can thus potentially alter our perceptions by gating ignored inputs at an early point in stimulus processing. Early selection theories place the bottleneck at the perceptual stage of analysis, before stimuli have been fully identified and hence, attention is said to operate precategorically.

Late selection in contrast, refers to the idea that both attended and unattended inputs are processed equivalently by the perceptual system and reach a stage of semantic encoding and analyses. Selection takes place at higher stages of information processing after stimuli have already been identified, and involve decisions about whether stimuli should gain access to conscious awareness, be encoded in memory, or initiate a response. A late selection model of attention (e.g. Deutsch & Deutsch, 1963, 1967) claims that attentional processes do not alter the way that stimuli are processed by the sensory-perceptual system. Bottlenecks in late selection theories occur after objects have been identified or categorized, either at a decision stage or a response execution stage and, consequently, attention is believed to operate postcategorically. As will emerge throughout the course of this discussion, there is behavioral evidence to support both of these views.

Cognitive Inhibition

A second question prompted by both the early versus late selection controversy and the cocktail party phenomenon has to do with what happens to unattended inputs. Are they actively suppressed or do they merely decay away? This question, in turn, raises the possibility that inhibitory processes may exist within the system, potentially, for the purposes of actively suppressing inputs which are not attended to or are not relevant to an individual's current goals.

Inhibition is ubiquitous in the nervous system and exerts its influence at every level of it. Physiological inhibition however, has historically been difficult to relate directly to cognitive processes and, thus, the notion of cognitive inhibition has been privy

to a somewhat checkered history in psychological research (Dempster, 1991, 1992).

Klein and Taylor (1994) point out, however, that cognitive inhibition is a hypothetical

construct whose effects within the information-processing stream are inferred to exist on

the basis of observable behavior. Accordingly, there appears to be a growing

appreciation for the role of cognitive inhibition in human information processing systems,

as well as an emerging view that inhibitory processes are a vital part of skilled

performance and adaptive behavior (Rafal & Henik, 1994). McDowd (1997) notes that

inhibition is best conceptualized as a family of processes, which can be distinguished by

the domains in which they operate, but united in sharing a common operating

characteristic of suppression.

Defining Cognitive Inhibition

Behavioral vs. Cognitive Inhibition

Although McDowd (1997) criticizes the lack of a precise theoretical definition

and empirical operationalization for the construct of cognitive inhibition, it has received

much interest in developmental psychology and has been invoked to explain a number of

age-related trends in a variety of developmental domains such as social-personality,

motor skills, and cognition. Bjorklund and Harnishfeger (1990) suggest that cognitive

inhibitory mechanisms can be distinguished according to what psychological constructs

they act on. They further suggest that behavioral inhibition (as distinct from the

behavioral measures used to assess inhibition) involves the control of global behavior and

includes such indices as resisting temptation, delay of gratification, motor inhibition, and

impulse control. In contrast, cognitive inhibition involves the control of cognitive

contents or processes and thus encompasses a range of levels at which inhibition can operate on. Examples include thought suppression, directed forgetting, gating of information from working memory, and inhibiting attention to irrelevant stimuli (McDowd, 1997; Hasher & Zacks, 1988).

Although behavioral and cognitive inhibition are clearly related in that cognitive inhibition may facilitate behavioral inhibition, evidence that the two are dissociated comes from the finding that performance is correlated within each category but not across both categories. For example, Olson (1989) tested children aged 4 to 6 years on a number of inhibitory measures which included a cognitive inhibition measure (a delayed match-to-sample test), a motor inhibition measure (the ability to inhibit both gross and fine motor movements in response to situational demands), and a delay of gratification measure. Using factor-analytic techniques, Olson (1989) found that inhibitory control did indeed load onto three higher order factors: ability to delay gratification, motor inhibition, and cognitive inhibition. Controlling for age and IQ, Olson found a significant correlation between motor inhibition and delay of gratification but the correlations between these behavioral inhibition factors and measures of cognitive inhibition were not significant.

Cognitive Inhibition in Selective Attention

The construct of inhibition has recently been extended to include a role in selective attention (Hasher & Zacks, 1988; Neumann & Deschepper, 1991, 1992; Tipper, 1985; Tipper & Cranston, 1985). Thus, in addition to Cherry's notion of the enhanced processing that attended inputs receive, attentional efficiency is further aided by

supplementing it with an inhibitory component that acts to suppress competing or irrelevant information. Houghton and Tipper (1994) argue that even on theoretical grounds, there is good reason for the inclusion of a cognitive inhibitory component. According to these authors, while this dual-process in selective attention lacks parsimony at first glance, it is adaptive for two reasons. First, any gain control (i.e., amplification) mechanisms implemented in biological systems have finite limits and the degree to which one signal can be amplified with respect to another has some upper boundary. A parallel dual mechanism can boost a target signal while suppressing a distractor, effectively doubling the "distance" between the two. Second, and by extension, in the case where a signal and a distractor are both at high levels, an amplification-only system may fail to produce enough of a gain to effectively discriminate the two signals. An additional inhibitory component would clearly be advantageous in this situation. Similarly, in the case where a signal and a distractor are both at low levels, an inhibitory-only system may fail to produce enough suppression to discriminate the two signals. Again, an additional amplification component would be advantageous. Ultimately, a dual-process system would be much more effective over the entire dynamic range and particularly so in the cases of low signal-to-noise situations.

Interference vs. Inhibition

Consistent with the idea of cognitive inhibition, Neumann and Deschepper (1992) suggest that the more proficient one is at inhibiting irrelevant signals or information, the better one should be at detecting or identifying relevant information from irrelevant information. The logical extension of this suggestion is that less proficient 'inhibitors'

might be more susceptible to interference from irrelevant information. This presupposes a relationship between interference and inhibition and consequently, the terms 'inhibition' and 'interference' have often been used interchangeably in the literature (e.g., see Sugg & McDonald, 1994). However, as Neill (1977) and Neill and Westbury (1987) emphasize, cognitive inhibition is not synonymous with susceptibility to interference. Inhibition, whether intentional or unintentional, refers to an active suppression process which, for example, can keep task irrelevant information from entering working memory. Interference is generally understood to refer to the susceptibility to the performance decrements under conditions of multiple distracting stimuli such as visual search tasks, dual task performance situations such as divided attention tasks, and/or some selective attention tasks such as the Stroop task (Klein & Taylor, 1994; Broadbent & Broadbent, 1987). Even though some studies find strong correlations between increased interference and decreased inhibitory efficiency (e.g., Salthouse & Meinz, 1995), others have found no clear relationship between the two (e.g., Stoltzfuz, Hasher, Zacks, Ulivi & Goldstein, 1993). Further, although some experimental tasks used in the laboratory appear to tap both inhibition and interference (e.g., the Stroop task), other tasks suggest that the two can be dissociated (e.g., negative priming tasks). Finally, although decreases in the ability to inhibit irrelevant information could, in principle, manifest itself as an increase in interference, interference does not necessarily involve active suppression of cognitive thoughts or processes (Bjorklund & Harnishfeger, 1990). Interference without inhibition is readily apparent in divided attention tasks (e.g. see Craik & Salthouse, 1992).

Tipper and Baylis (1987) investigated the relationship between inhibition and interference in selective attention by examining whether efficient 'selectors' would employ active inhibition of distractors to a greater extent than less efficient 'selectors' through the use of the Cognitive Failures Questionnaire (CFQ) and a negative priming paradigm. The CFQ is a self-report measure that addresses selection efficiency in everyday activities by asking questions such as "Do you find you forget why you went from one part of the house to another?" and "Do you read something and find you haven't been thinking about it and must read it again?" Tipper and Baylis (1987) were interested in whether selection efficiency as measured by CFQ scores, would predict performance on interference and negative priming (inhibition) tasks.

In their first experiment Tipper and Baylis (1987) chose an interference task that consisted of a central target with distractor words or a row of XXX's (control condition) above or below the target word. Distractor words were semantically unrelated to the target words and the participant's task was to respond as quickly as possible to the superordinate category of the target word (e.g. dog – animal). It had been predicted that individuals with low CFQ scores (good selection efficiency) would show less interference effects from the distractor words, as measured by reaction time. The results demonstrated a significant correlation between interference effects and CFQ scores. That is, individuals who were more efficient selectors were less susceptible to interference from distractors.

In their second experiment, Tipper and Baylis (1987) investigated whether low scorers on the CFQ were better selectors due to more efficient inhibitory mechanisms.

Their inhibition task consisted of a negative priming task embedded in their original interference task. Participants again viewed the target and distractor words as above, but this time, the original (prime) display was followed by a similar secondary (probe) display and the participants were required to respond as quickly as possible to the category of the probe target and then recall the category of the prime target. The relationship between the probe target and the prime target was manipulated such that the probe target was either the prime distractor from the previous prime display, the prime target from the prime display or neither. Of most interest to these authors was the condition where the probe target had been the distractor from the prime display. In this condition, reaction times were increased relative to the conditions where there was no relationship between targets and distractors in the prime and probe displays, a phenomenon known as negative priming (Tipper, 1985). Further, while both high and low CFQ scorers demonstrated *positive* priming (i.e., facilitory effects, as inferred from the decrease in reaction times when the target is the same in both the prime and the probe displays), only the low CFQ scorers showed a significant *negative* priming effect. Tipper and Baylis (1987) concluded that the increased inhibition of the distractors might lead to an enhanced ability in selecting targets from distractors for the low CFQ scorers.

Stoltzfus et al. (1993) also investigated the relationship between inhibition and interference. In their study, they employed three different measures of interference along with a measure of inhibition. The interference measures included: 1) a letter naming task in which reaction times were compared for responding to a letter alone with a response to a letter when another letter of a different color was presented; 2) a classic Stroop color

naming task; and, 3) a reading task in which participants were required to read text that contained distracting text within it. The inhibition measure included a letter-naming negative priming task.

Stoltzfus et al. (1993) predicted that there would be strong positive correlations between the measures of interference as well as negative correlations between the measures of interference and inhibition. Their results indicated interference on all three tasks as well as inhibition on the negative priming task. Correlational analyses revealed that the only significant correlations were between the Stroop interference measure and the letter naming interference measure.

Based on their results, Stoltzfus et al (1993) concluded that there appeared to be no clear relationship between their measures of interference and inhibition and, also, given that only two of their interference measures were correlated, they speculated that interference effects might arise from different sources. Finally, based on the finding that individuals can demonstrate negative priming (which is presumed to reflect inhibitory processes) and still show interference effects, they concluded that interference is not always the product of inefficient inhibitory mechanisms.

Harnishfeger, Nicholson and Digby (cited in Neill, Valdes & Terry, 1995) also agree with the view that interference and inhibition are separate constructs because interference and inhibition show different developmental trajectories. They contrasted the performance of first, third, and fifth grade children with college students on a Stroop/embedded negative priming task. College students demonstrated both Stroop interference and negative priming effects. Children demonstrated Stroop interference

effects but not all age groups showed negative priming. Although their study indicated that the development of inhibition was erratic throughout the elementary school years, a key finding in the present context was that their first graders demonstrated Stroop interference but did not show inhibition from the negative priming task. The latter finding replicated Tipper, Bourque, Anderson and Brehaut's (1989) study with second graders, with both studies suggesting that interference and inhibition are separate constructs.

In sum, it may be that selection efficiency is simply a 'third variable' problem where selection efficiency is correlated with both inhibition and interference measures but inhibition and interference are not necessarily correlated with each other. Alternatively, as Neumann and DeSchepper (1991, 1992) and Tipper and Baylis (1987) suggest, it is also possible that selection efficiency is the result of *both* efficient inhibitory processes and resistance to interference. If so, then this would further underscore the notion that dissociation exists between interference and inhibition. Of note is that these ideas are not mutually exclusive but in any event, the relationship between the two needs further investigation.

<u>Neurophysiological Evidence for Selective Attention</u>

<u>Event Related Potentials</u>

Physiological studies and in particular, Event Related Potential (ERP) studies are becoming increasingly important in understanding the workings of the neural processes that underlie cognitive processes such as inhibition and selective attention. ERPs reflect changes in electrical currents that are elicited in response to a stimulus. As stimulus

information traverses the sensory pathways, the activation of successive relay nuclei and cortical areas generate a sequence of precisely timed evoked potentials that may be recorded from the surface of the head. A significant feature of these evoked responses is that they provide a temporal record of underlying neural activity within the one to 10 millisecond range of resolution (Naatanen, 1995). Further, when combined with neuroimaging methods, ERPs can be localized to particular brain areas (structures) that are time-locked to stimulus processing. Figure 1 shows the prototypical component structure of an auditory ERP. The logarithmic time base used allows visualization of the major voltage peaks that occur at specific latencies after stimulus onset. These components include early waves evoked from the auditory brainstem pathways (I – VI), early positive (P) and negative (N) components evoked from the cortex (Na, Pa, Nb, and P1), and the late cortical components (N1 and N2). Components that may vary as a function of the attentional and cognitive processing of the stimulus are shown in dotted and dashed lines and extend beyond the N2 to even later components such as the P3 and P4 (not shown).
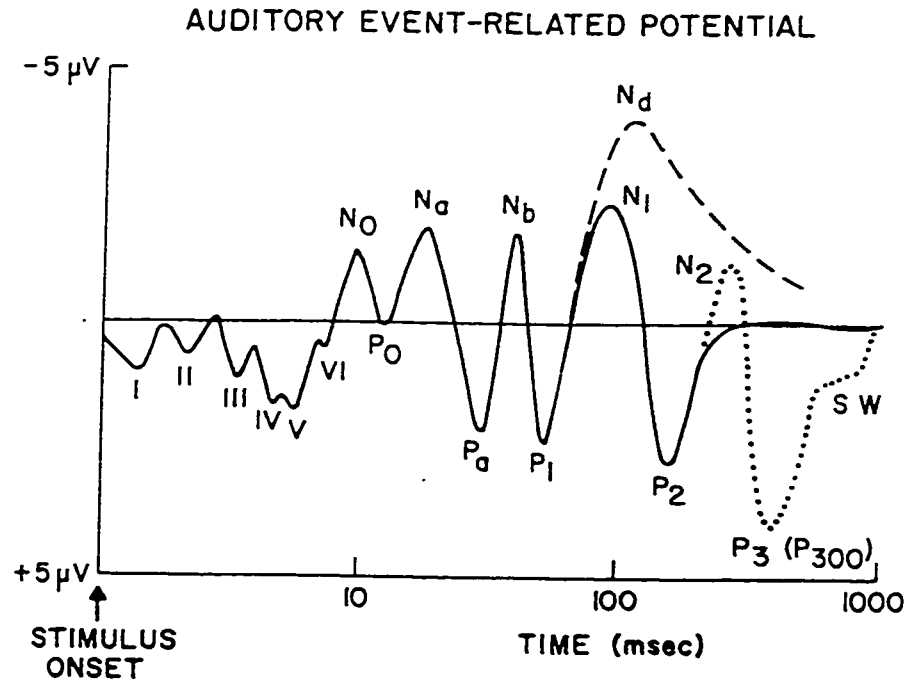
Figure 1. Example of an Auditory Event Related Potential

Because ERPs can provide a reasonable estimate of the time-course of information processing, they have become an important tool for research into human cognitive processes. ERP studies have been used extensively to investigate the temporal nature of auditory selective attention and to a growing degree, visual selective attention. In particular, the level-of-selection issue has been examined by employing ERP recordings in attentional paradigms, which permit strong inferences to be made about the level of processing, and the degree to which selectivity is imposed.

Auditory Selective Attention In the spirit of the cocktail party situation, ERPs have been recorded in several versions of a dichotic-like listening task (e.g., Alain & Woods, 1994; Schroeger, 1997; Woldorff & Hillyard, 1991). In one version, Woldorff and Hillyard

(1991) presented rapid sequences (6 tones/second) of standard tones to each ear. The sequences differed in pitch at each ear (e.g. 1700 Hz tones in one ear and 3400 Hz tones in the other) and some of the tones (targets) also differed in intensity. The task for the subject was to pay attention to the tones in one ear and to detect only the louder targets in that ear. The corresponding ERPs in their study indicated that tone targets in the attended ear elicited an enlarged negative ERP deflection that begins as early and 60 to 70 ms poststimulus and overlapped the major sensory-evoked negative component (N1), which peaked at approximately 100 ms. This enlarged negativity (termed negative difference (Nd) or processing negativity) was shown to consist of at least two phases: an early phase that overlaps the N100 and a later phase that persists for several hundred milliseconds beyond the N100.

Although some researchers disagree as to whether the early Nd attention effect reflects actual amplification of the N100 (see Hillyard, Hink, Schwent and Picton, 1973; Waldorff & Hillyard, 1991) or indicates separate, specialized processing of attended inputs (see Naatanen 1990, 1995), the majority of the ERP research employing cocktail party-like dichotic listening tasks have localized these early ERP attention-sensitive components to auditory cortex (e.g. see McEvoy, Levanen & Loveless, 1997). Further, even though the issue of whether attended inputs receive amplification or specialized processing has yet to be resolved, the localization of these components to auditory cortex in addition to their very short latencies, strongly suggests that selective attention to auditory inputs occurs at an early level, before perceptual processing is complete. This early selection conclusion has been reinforced by the subsequent finding that attended

stimuli elicit an enlarged ERP component (relative to unattended stimuli) as early as 20 to 50 ms after stimulus onset as well, which has also been localized to auditory cortex (Woldorff, Gallen, Hampson, Hillyard, Pantev, Sobel and Bloom, 1993). Woldorff et al. (1993) note that this finding accords nicely with the latencies of the earliest attention effects observed for neurons in primary auditory cortex of monkeys that Goldstein, Benson and Heinz (1982) found (cited in Woldorff et al., 1993).

ERPs have also been used to address the question of whether unattended inputs are actively suppressed. Auditory ERP recordings can contain a component known as mismatch negativity (MMN) which is specifically elicited by any type of physically deviant stimulus in a repetitive sequence of sounds. The MMN typically peaks between 150 and 200 ms poststimulus and can be elicited by deviations in a variety of auditory dimensions including pitch, intensity, duration, location and timing (See Naatanen, 1990 for a review). Because MMNs are generated in the absence of attention, many authors (e.g. Ahlo, Sams, Paavilainen, Reinikainen and Naatanen, 1989; Alho, Woods & Algazi, 1994; Naatanen, 1990) initially concluded that the MMN reflects strongly automatic feature encoding, memory trace formation and automatic mismatch-detection processes that operate independently of attention. Naatanen (1990) further concluded that physical features of auditory stimuli are automatically analyzed and stored in short-term memory whether or not they are attended. Although Naatanen (1990) does not explicitly advocate a late selection position, it is the logical extension of his conclusions.

Subsequent research however, has demonstrated that the MMN is affected by attentional manipulations. For example, Waldorff, Hackley and Hillyard, (1991) found

that the negative deflection elicited between 130 – 280 ms by intensity deviations in a tonal sequence was substantially reduced (by 70 to 90%) for tones in the unattended relative to the attended ear. Several researchers have replicated this finding, notably, Naatanen, Paavilainen, Tiitenen, Jiang & Ahlo (1993a) and Paavilainen, Tiitinen, Alho and Naatanen, (1993), leading Naatenen et al. (1993a, p445) to agree that the MMN to intensity deviants "appears to be vulnerable to attention". The significance of MMNs to the present discussion is that they have been localized to auditory cortex; specifically, the superior temporal plane (primary auditory cortex) which is believed to be the major generator of the MMN (e.g. Woldorff et al.1991; Naatanen et al, 1993a; Naatanen, 1995). This finding weighs heavily in favor of an early selection model of attention that amplifies attended inputs *and* suppresses unattended inputs at an early stage of perceptual processing.

Nevertheless, an aspect common to most if not all of the ERP results arising from these dichotic-like listening tasks, is that the stimuli used are very simple and consist primarily of tones which differ in frequency, intensity or location. It may be that these types of stimuli provide evidence for early selection theories of attention merely by virtue of their simplicity since their identity can only be defined by elementary features. In other words, it is difficult to conceive what a late selection mechanism of attention might operate upon (aside from a response decision) in these situations and consequently, early selection mechanisms may be invoked by "default".

This possibility has not been directly investigated; however, there are a small number of studies, which have recorded ERPs when using complex auditory stimuli for

different experimental purposes. For example, Klein, Kurtzberg, Battison, Kreuzer, Stappels, Dunn, Rapin and Vaughn (1995) recorded ERPs to both tones and speech sounds (phonemes) in a Verbal Auditory Agnostic (VAA; more commonly known as word deafness) group and compared them to a normal group in a effort to determine the locus of the VAA deficit. Klein et al (1995) found that both tones and phonemes exhibited the characteristic sequence of components (i.e. P1, N1, P2, N2, etc.) and that these components were similar in amplitude and onset latencies. However, these authors also found that in their control group, the P2s were smaller for target tones and target phonemes relative to their respective non-targets. They attributed the difference in amplitude to the presence of the underlying MMN, which suppresses non-targets and subsequently influences the P2. Most importantly, Klein et al's (1995) topographical analysis of the control group's (non-VAA individuals) data revealed a consistent spatiotemporal pattern of cortical activation that was similar for tones and phonemes. These findings imply that unattended speech sounds, like tones, are suppressed at early stages of stimulus processing.

In another study, Trejo, Ryan-Jones and Kramer (1995) investigated non-spatial auditory attention by using binaurally presented words and tones. Trejo et al. had his participants listen to a mixture of tones and narrative of which the targets were deviant tones (high or low pitch) and the word "and". They recorded ERPs while participants alternated between the conditions i.e., attend tones – ignore narrative and attend narrative – ignore tones. The results indicated that target tones (hit rate of 86.9%) and target words (hit rate of 91.5%) elicited enhanced DN1 and DN2 waveforms, where "D" refers to

difference waves. (Difference waves are calculated by subtracting a) the average ERP for standards from the average ERP of target deviants and b) the average ERP for standards from the average ERP for nontarget deviants.) Further, although the DN1 and DN2 amplitudes were greater for the tones than the words, maximum amplitude latencies for tones and words were virtually identical (e.g. 145.0 ms vs. 146.9 ms for tones and words respectively, for the DN1). Trejo et al. (1995) concluded that, in addition to the early selection by location (i.e. dichotic listening, where different streams of sounds arrive at each ear) that Woldorff & Hillyard (1991) demonstrated, selection in the auditory modality can also be based on complex spectral patterns such as speech, within a single spatial location (i.e. binaural listening, where different streams of sounds arrive at both ears).

One final point on auditory ERPs worth noting is that Polich, Eischen and Collins (1994) compared ERPs to attended tones in the prototypical auditory "oddball" paradigm (i.e. deviant targets in a stream of identical distractors), with those elicited by a single stimulus in isolation (no distractors present). Polich et al (1994) showed that the single-stimulus ERP components were virtually identical to those obtained from targets in an oddball paradigm. This finding strongly suggests that these amplitude-enhanced components are indicative of the "enhanced" processing that all attended-to, relevant, auditory signals receive rather than reflecting an artifact of a contrived experimental situation.

Visual Selective Attention

ERP recordings have also been employed in visual tasks in an attempt to address the

level-of-selection issue in vision. Visual attention has frequently been likened to a

"spotlight" (Posner, 1980; see also Treisman & Gelade, 1980) that can be focused on a

discrete spatial location, presumably for the purposes of enhancing the processing of

relevant stimuli. In this regard, ERPs provide compelling evidence for the well-

established observation that valid spatial cueing produces faster reaction times and better

accuracy judgements (e.g. Posner, 1980) for attended-to stimuli. Generally, ERP

recordings in spatial attention paradigms where voluntary covert attention is directed

toward rather than away from a stimulus show amplitude modulations as early as 70 to

90ms after stimulus onset (e.g., see Eason, 1981). More precisely, stimuli presented

within the focus of attention elicit an amplitude-enhanced P1 as recorded over the

ventrolateral extrastriate cortex regions of the scalp and an amplitude-enhanced N1 as

recorded over occipital-parietal cortex (Eason, 1981; Luck, Heinz, Mangun & Hillyard,

1990). Again, as with auditory selective attention, the localization of these components

to extrastriate cortex in addition to their short onset latencies suggests that selective

attention to visual-spatial inputs occurs before perceptual processing is complete.

One potentially confounding problem with the enhancement of P1 and N1 to

attended stimuli versus unattended stimuli in spatial location tasks is that the unattended,

non-target stimuli may fall outside of foveal vision and thus, be less discriminable to

begin with. However, while this may be so in some studies, ERP studies in visual

orienting seem to indicate that foveal vs. non-foveal vision is not the reason for the P1-

N1 enhancement.

In an effort to determine whether peripheral versus foveal vision effects were responsible for the P1-N1 enhancements, Luck, Hillyard, Mouloua, Woldorff, Clark and Hawkins (1994) recorded ERPs during a threshold-level luminance detection experiment. In this task, participants were required to maintain fixation at a central location and detect faint masked targets presented at one of four equidistant, possible locations. An arrow cue indicated the most likely target location, while in neutral trials, arrows pointed to all four locations. Target detectibility was highest on valid trials, lowest on invalid trials and intermediate on neutral trials. The corresponding ERPs indicated amplitude-enhanced N1 and P1 components over the lateral occipital scalp for the valid trials relative to the invalid trials. However, an interesting pattern was observed when comparisons were made between valid, neutral and invalid trials. The N1 component was enhanced on valid trials compared to neutral trials but was not suppressed on the invalid trials. In contrast, the P1 component was reduced on invalid trials compared to neutral trials, but was not enhanced on valid trials. When considered together, Luck et al (1994) concluded that the N1 and P1 components reflect two qualitatively different attentional mechanisms: one which enhanced attended signals within the focus of attention (N1) and one that suppressed signals that fall outside the focus of attention (P1).

Earlier ERP studies (e.g. Luck et al, 1990) have also suggested that the N1 and P1 components reflect two different attentional mechanisms. Wijers, Lange, Mulder and Mulder (1997) refer to an earlier study by Mangun, Hillyard and Luck in 1993 in which current source density analyses had indicated that the P1 and N1 components are generated in the extrastriate brain areas belonging to the ventral (the "what" pathway)

and dorsal "the "where" pathway) projection routes respectively. Wijers et al (1997) further investigated this claim using isoluminant letter stimuli. They reasoned that since the dorsal route derives its input mainly from the magnocellular pathway that is sensitive to luminance but not color, then the ERP deflections corresponding to the dorsal pathway should be most influenced by the manipulation of isoluminance. The ventral pathway on the other hand, is sensitive to color in addition to being specialized for object identification. Experimentally, random letters were presented equidistantly at either the right or left from a central fixation point. Participants were requested to attend to either the right or the left location and to determine if a target letter (either E or F) was present in a given trial. ERPs were recorded to all trials in conditions of both luminance (green letter on dark background) and isoluminance (green letters on an isoluminant gray background). Wijers et al. (1997) predicted that the difference between the N1 in the isoluminant condition and the N1 in the luminant condition would be greater that the differences between the P1 in the isoluminant condition versus the luminant condition.

Wijers et al's (1997) study generated a number of findings. First, their results only partially supported their hypothesis; the N1 was only slightly different than the P1 (the P1 was smaller). They concluded that the N1 reflects activity from both the dorsal and the ventral pathways in the form of early "bottom-up" processes. Secondly, both N1 and P1 components were enhanced for attended vs. unattended stimuli, confirming that spatial selectivity modulates early perceptual processing as found in Luck et al, (1994), but not compellingly providing evidence that the P1 is actually suppressed (there are multiple variables in this study though). Of note is that the duration of the N1 extended

to between 400 and 450 ms. Third, Wijers et al (1997) found that the N2 was smaller for unattended letters versus attended letters and that the P3 (P300), which is triggered when task-relevant events have been recognized and classified (Kenemans, Kok and Smulders, 1993; Wijers, Mulder, Okita & Mulder, 1989) was completely absent for unattended targets. Based on the different peak latencies and scalp topographies for the N1 (187ms; lateral occipital temporal cortex) and the N2 (280 ms; inferior temporal cortex), Wijers et al (1997) argued that the N2, in part, reflects early object identification processes independent of the spatial filtering of distractors.

In further consideration of non-spatial visual attention, Luck et al (1994) note that ERPs indicate very different patterns when stimuli are selected on the basis of features such as color, size and shape as opposed to location. One prominent difference is that ERPs in general have longer latency components (in the 150 – 350 ms range) with corresponding scalp topographies that that depend of the specific feature being selected.

Smid, Jakob and Heinz (1997) recorded ERPs in a multidimensional selection task based on color and shape. Participants were required to detect targets in serially presented stimuli of various shape and color configurations to a prespecified target containing the designated relevant features (e.g. a red circle (color and global shape) with an opening to the left (local shape)) presented at the beginning of each block of trials. Waveforms were assessed by subtracting ERPs elicited by stimuli with a nontarget (irrelevant) value on a dimension (e.g. blue) from ERPs elicited by stimuli with the target (relevant, cued) across the time frame of 120 to 350 ms. This results in a difference potential known as the selection negativity (SN), somewhat analogous to the difference

waves in audition. Smid et al (1997) states that the onset latencies of SNs reflect the target value of the attribute from the non-target value of the attribute and thus indicate: 1) that the attribute was identified and 2) that the stimulus with the relevant value received more task-directed processing than the stimulus with the irrelevant value.

Smid et al's (1997) results indicated that stimuli with a relevant second dimension produced significantly enhanced SNs compared to when the second dimension was irrelevant. These SN enhancement effects occurred independently of which dimension was relevant and which was irrelevant. In terms of specifics, the SN effect of color occurred at 196 ms and the SN effect of global shape occurred at 204 ms and thus, color and global shape effects occur at approximately the same time. Local shape SN effects occurred later, at 276 ms. Feature conjunction processing became specific at 252 ms. It is interesting to note that feature conjunction processing began prior to local shape processing, perhaps suggesting a possible mechanism for perceptual interference effects based on featural similarity of stimuli. Van der Stelt, Kok, Smulders, Snel and Boudewijn-Gunning (1998) also observed similar SN effects to color.

In the context of the present discussion, Smid et al's (1997) study does not speak directly to the late vs. early selection issue. Instead, this study provides an estimate of the time it takes to select particular features in a given object and then, to initiate subsequent conjunction processing. It is with these general time figures in mind that we can evaluate claims that individual, multidimensional complex objects or colored letters and words are identified in 100 ms, for example – as Raymond, Shapiro and Arnell (1992a) claim - a point which will be discussed later.

In sum, both auditory and visual ERP studies provide reasonably strong support for early selection theories of attention. In audition, the enhancement of attended-to stimuli at validly cued locations is corroborated by corresponding ERPs showing PI and N1 waveform enhancements relative to unattended locations. Similarly, attentional manipulations of the MMN suggest that unattended channels (locations) are actively suppressed (Woldorff et al, 1994). Further, the Trejo et al. (1995) study demonstrated that attentional selectivity is not limited to different locations or streams of sounds, but occurs within a single location. Taken together, auditory selective attention can selectively enhance attended-to inputs and suppress ignored inputs whether they are spatially separate (i.e. located in two different channels as in the dichotic listening task) or spatially contiguous (i.e. located in the same channel as in the binaural listening task). Further, this selectivity holds not only for stimuli such as pure tones that differ on basic attributes like intensity, but for the more complex spectral patterns seen in speech signals.

Early attentional selectivity also operates in vision. For visual-spatial attention, there is a suggestion that the processing of signals is enhanced at attended locations and suppressed at unattended locations, as evidenced by increased N1 amplitudes and decreased P1 amplitudes respectively, in the Luck et al. (1994) study. Attention further appears to be able to operate within a single location – as in audition - with the processing of attended targets or relevant features being enhanced, relative to unattended targets or irrelevant features as in the Smid et al. (1997) study. The issue of active suppression (inhibition) though, does not appear to be as definitive in vision, as indicated by the Wijers et al.(1997) study, as it does in audition. Finally, it is important to note that

even when the suppression of ERP components is demonstrated, this suppression is never total.

<div align="center">Behavioral Tasks Employed to Measure Selective Attention</div>

Stroop Task

The Stroop task is a well-known and widely used task in a variety of research domains including selective attention (Dulaney & Rogers, 1994). The primary phenomenon is the lengthening of reaction time (commonly referred to as the Stroop interference effect) when participants are asked to name (i.e. attend to) the ink color of a printed word and ignore the meaning of the word, compared to the condition where participants are asked to name to printed word and ignore the color it is printed in (Stroop asymmetry effect) or the appropriate control conditions. For example, ink naming color is slower when the word GREEN is presented in red ink (incongruent) compared to when nonwords are presented in green ink (neutral). A secondary phenomenon (often referred to as the Stroop facilitation effect) is the shortening of reaction time when the color word is the same as the ink color (e.g. GREEN in *green* ink). The Stroop interference effect is a robust one and occurs with a number of different control stimuli manipulations (e.g. a color patch, rows of XXX's) and has even been found when the two dimensions are not integrated, but presented spatially or temporally separated (MacLeod, 1991) or when the stimuli occur are presented in different modalities (Driver & Baylis, 1993).

In a recent comprehensive review of the Stroop literature, MacLeod (1991) notes that explanations for the Stroop asymmetry effect fall into five general categories: 1) a relative speed of processing account 2) an automaticity account 3) a perceptual encoding

explanation 4) a parallel model (e.g. Logan, 1980, in MacLeod, 1991) and 5) parallel

distributed models (e.g. Cohen, Dunbar & McClelland, 1990, in MacLeod, 1991). Of

these five categories, only the perceptual encoding explanation is an unambiguous early

selection explanation. MacLeod (1991) subsequently points out that this explanation

cannot account for the asymmetry effect and thus, is not prominent in the literature.

The case for late selection in the Stroop interference effect is reasonable. Words

are clearly processed to a semantic level and the color is processed to a semantic level as

well (Schooler, Neumann, Caplan & Roberts, 1997). Similarly, although the featural

aspect of color contributes to the facilitation effect and this effect occurs at a perceptual

level initially, color would also prime associative words, of which the word "Green" (as

in the above example) would be a highly probable candidate. Inhibition then, also occurs

at the "semantic" level and involves suppressing the response to the meaning of the word

(i.e., reading the word) in favor of the response to the color of the word (i.e. color

naming).

Stroop tasks are used as tests of both interference and inhibition because in this

task, interference and inhibition are directly related. Failures to inhibit word-reading

responses produce increased interference for color naming, as measured by reaction

times. To the extent that late versus early selection is an issue in the Stroop task,

observed reaction times, which are usually in the order of 600 to 700 ms or more (e.g. see

Lowe, 1985) tend to provide additional support for a late selection interpretation. In

contrast, reaction times to simple featural discriminations such as luminance or intensity

thresholds are about 200 to 300 ms less (Grice, Nullmeyer & Schnizlein, 1979). The

purpose in including the Stroop task in the present discussion was not present a

comprehensive review, but rather, to point out that the Stroop interference effect appears

to have generated considerable consensus for late selection explanations (MacLeod,

1991).

Negative Priming Tasks

The negative priming task has been a recurring theme through the course of this

introduction and as alluded to throughout, has been used extensively to study selective

attention processes and in particular, whether ignored or unattended stimuli (distractors)

are actively suppressed. Empirically, this has taken the form of behaviorally

distinguishing between the facilatory effects of attended stimuli and the inhibitory effects

(if any) of unattended stimuli. In the negative priming paradigm (e.g. Tipper, 1985), it is

assumed that if inhibitory effects for unattended stimuli exist, then they operate over a

finite temporal window. Further, if the internal representation of the to-be-ignored object

is associated with inhibition during selection and execution of the responses to the target

object, the processing of a subsequent stimulus that requires the inhibited representation

to be "reinstated", should be impaired. In other words, if a distractor is inhibited because

attention has been allocated to the processing of a target and if the distractor appears on a

subsequent trial and must be responded to as the target, then its processing must

overcome the persistence of previous inhibition, relative to a "neutral" target.

On the other hand, if distractors are not actively suppressed and any initial

activation merely dissipates over time, then two direct predictions would follow when the

distractor becomes the new target: First, if the distractor activation effects have not

completely dissipated, then its processing relative to a neutral target should be enhanced

(primed), at least in terms of reaction time. Second, if the distractor effects have already

dissipated, then its processing relative to a neutral target should not differ.

Neumann and DeSchepper (1991) directly tested these assumptions in an effort to

explore the role of inhibition in selective attention. They presented simultaneous pairs of

letter stimuli, slightly overlapping one another and both in different colors (see Figure 2).
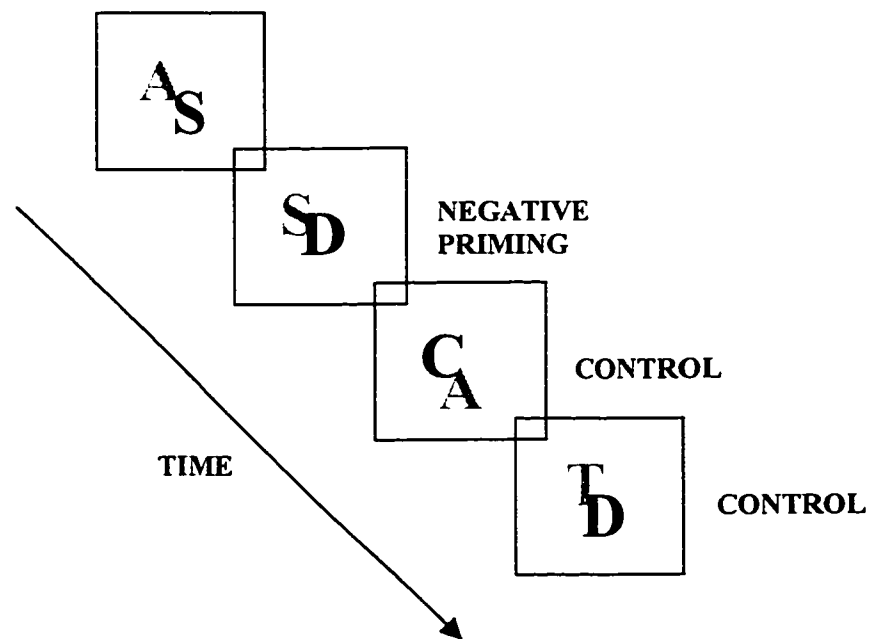
Figure 2. Example of negative priming stimuli

Participants were asked to name the letters in one color (targets), and ignore the letters in the other color at the beginning of a block of trials (e.g. trial n). N+1 or probe trials consisted of targets that had a) been ignored on the previous trial, b) were the same as the target on the previous trial, or c) neither i.e., were unrelated. Reaction times were faster for probes that had just previously been targets (facilitation or positive priming) and slower for probes that had been previously ignored distractors (inhibition or negative priming), both relative to the unrelated letters. Neumann and DeSchepper (1991) concluded that inhibition and facilitation play mutual roles in selective attention and that inhibition is just as powerful as excitation or facilitation since the degree of priming did not differ as a function of whether it was positive or negative.

This pattern of results in which subjects are slower and/or less accurate in responding to stimuli that were recently ignored has been observed in numerous experiments that have employed ignored distractor conditions (e.g., Tipper, 1985; Tipper & Cranston, 1985). Negative priming has also been demonstrated across a variety of experimental situations (e.g. location tasks (Tipper, Brehaut & Driver, 1990), perceptual tasks (Neill, Lissner & Beck, 1990; Treisman & DeSchepper, 1994), semantic tasks (Tipper, 1985; Yee, 1991), auditory tasks (Greenwald, 1972; Banks, Roberts & Ciranni, 1995) and cross-modal tasks (Driver & Baylis, 1993)) as well as with a variety of experimental stimuli (e.g. words (Banks, Roberts & Ciranni, 1995; Yee, 1991), letters (Hasher, Stoltzfus, Zacks & Rympa, 1991), pictures (Tipper, 1985) and random shapes (Treisman & DeSchepper, 1994). Moreover, negative priming occurs across response

requirements such as detection and identification or manual motor responses, whether the same or different (e.g. name vocally if "X", press key if "Y").

An interesting finding that has emerged from a few negative priming studies is that negative priming appears to be sensitive to Stimulus Onset Asynchrony (SOA); that is, the interval from the onset of the first (target) stimulus to the onset of the second target (probe) stimulus. In one experiment, Lowe (1985) had participants "attend" to the color of a Stroop word presented for 50 ms and then, asked them to identify the color of a probe Stroop word presented at an SOA of 50, 100, 200 or 400 ms. Again, probe trials were arranged such that probe targets were either related (color congruent or color incongruent with the previous prime trial) or unrelated. Lowe found no negative priming at the 50 ms SOA, but negative priming occurred at all other SOAs. Lowe further demonstrated that the lack of negative priming at the 50 ms SOA was not due to sensory masking since color-congruent probe trials (e.g. GREEN in *yellow* ink followed by BLUE in *yellow* ink) produced positive priming relative to the unrelated trials (e.g. GREEN in *yellow* ink followed by BLUE in *red* ink). Thus, the lack of negative priming at the 50 ms SOA could not be attributed to the fact that participants were unable to "see" the color.

Yee (1991) also demonstrated SOA effects. In her experiment, geometric figures were flanked by distractors, where the distractors were a single word, a pair of unrelated words or a single word paired with a string of nonlinguistic symbols. Participants' responses were signaled by a question mark at either 500 ms or 600 ms that they should respond to the figure on some trials, and on others, they received a word or a nonword for

a lexical judgement decision, i.e. a word/nonword decision. On the lexical judgement trials, words acted as probes and were either semantically related or unrelated to the just-ignored distractors. Yee found positive priming at 500 ms for the semantically related probe words, which reversed to negative priming at 600 ms.

Neill, Valdes and Terry (1995) argue that the inhibition seen in negative priming studies develops over time from the onset of the distractor stimulus. Thus, the inhibition of any distractor is preceded by an initial period of time in which the distractor is activated and can therefore interfere with target processing, as happens in the Stroop task. Further, it could be expected that when the distractor is compatible with the target, as in the color congruent Stroop task conditions, then facilitation might be initially observed. However, in a general review of negative priming studies, Neill et al. (1995) suggest that the large differences in the development of negative priming (i.e. 100 ms vs. 600 ms) between Yee's (1991) study and Lowe's (1985) study can probably be attributed to procedural differences such as degree from fixation of targets and distractors, and/or the size of the stimulus sets. Neill et al (1995) also note that they have been unable to replicate Yee's findings.

An alternate view however, is that Yee's (1991) study reflects a late selection inhibitory mechanism (based on inhibiting the semantic meaning of the distractor) whereas Lowe's study reflects an early selection inhibitory mechanism (based on inhibiting the perceptual feature of distractor color), at least initially. Further, if inhibitory mechanisms – whether early or late – have properties in common, then it is plausible that early inhibitory mechanisms, like their late counterparts, would also take

time to develop. Given this then, early selection processes may explain why no negative priming was observed at the 50 ms SOA in Lowe's study but positive priming was. Similarly, Yee's (1991) shows this same pattern of positive priming followed by negative priming. In fact, the observation that ignored distractors showed any kind of priming led Yee (1991) to conclude that her study supported a late selection model of attention. However, since Lowe did not include a baseline condition such as letter strings or nonwords in different colors, the case for early selection based on inhibiting the perceptual feature of color cannot be made conclusively in his study.

However, other studies, as mentioned previously, have found negative priming at the perceptual level. The most compelling of these studies is Treisman and DeSchepper (1994), who presented novel geometric shapes and asked for same/different judgements. Negative priming was found and presumably, inhibition was based on the perceptual feature of shape since the novel shapes would not have any preexisting cognitive representations. Also, Neill and Westbury (1987) conducted an experiment similar to Lowe's (1985) but included a baseline condition with strings of "O"s in the various colors. Equivalent negative priming was found for both conflict (e.g. GREEN in *yellow* ink followed by RED in *green* ink) and non-conflict (e.g. GREEN in *yellow* ink followed by OOOOO in *green* ink), suggesting that inhibition does occur at the perceptual level, even with complex stimuli such as words.

However, the fact that negative priming appears to be a phenomenon of broad generality generates some interpretive problems; most notably, the question of exactly what is inhibited across these different types of studies. Given that negative priming

exists across levels of representation, across response requirements and across modalities would seem to suggest that no single mechanism will be able to account for such diversity. Furthermore, no systematic study that manipulates both the complexity of the stimuli used with SOAs has been conducted. What can be safely concluded however, is that the inhibition observed from negative priming studies can result from either early or late selection mechanisms, and possibly, both.

Prepulse Inhibition Paradigms

The startle eyeblink is an automatic, involuntary brain-stem mediated reflex that is elicited by relatively strong stimuli (e.g. noise bursts, air puffs) with abrupt onsets. Prepulse inhibition (PPI) of the startle reflex occurs when a weak, nonstartling stimulus precedes the onset of the startle-eliciting stimulus by an interval of approximately 500 ms or less. In such cases, the magnitude of the startle reflex is reduced and depending on the characteristics of the prepulse, is sometimes even completely suppressed (Graham, 1975; Hoffman & Ison, 1980). Graham (1975) proposes that PPI acts to protect early processing of the desired stimulus (the prepulse) by initiating a gating process which acts to buffer other sensory stimulation until the processing of the prepulse has been completed.

Inhibition of the startle eyeblink is viewed as an index of automatic sensory gating in that it reflects a basic inhibitory process that regulates sensory input to the brain, filters out irrelevant information and allows the early stages of processing to proceed without disruption (Braff & Geyer, 1990 in McDowd & Filion, 1992). Sensory gating then, allows selective stimulus processing and prevents sensory overload. The automatic nature of PPI would seen to suggest that inhibition of the startle reflex should be

invariantly expressed, independent of the "cognitive" state of the recipient. However, the view that involuntary processes cannot be affected by strategic or voluntary control has been resoundingly criticized (Rafal & Henik, 1994). Accordingly, several researchers (e.g. Jennings, Schell, Filion & Dawson, 1996; Lipp, Arnold, Siddle & Dawson, 1994; McDowd & Filion, 1992; McDowd & Oseas-Kreger, 1991) have found that inhibition of the startle reflex is sensitive to attentional demands.

Filion and McDowd (1992) examined PPI and attentional modulation in an attention-to-prepulse paradigm. They had participants attend to (count) either high or low pitch tones and ignore the other in an intermixed series while they presented a startle eliciting air puff under the chin. They predicted that the attended to tones should increase protection of processing of that class of tones whereas instructions to ignore should result in less protection of processing. The results showed significantly greater PPI (i.e. less startle reflex) to the attended than to the ignored prepulse. They interpreted their results as reflecting greater protection of processing of attended to stimuli via inhibition of the startle response relative to the level of inhibition observed during a to-be-ignored prepulse.

In a subsequent study, Filion, Dawson and Schell (1996) charted the time course of PPI. Again, they presented participants with intermixed series of high and low pitched tones with instruction to attend to one class and ignore the other. They further presented bursts of white noise (startle stimulus) at intervals of 60, 120, 240 and 2000 ms following prepulse onset. Both attended-to and ignored tones produced significant eyeblink modification (inhibition) at 60, 120 and 240 ms intervals with eyeblink facilitation at

2000 ms. Further, attended-to tones produced even more PPI at 120 ms and more

facilitation at 2000 ms, compared to the unattended tones, both which were significantly

correlated with a skin-orienting measure also taken. Although the explanation for the late

facilitation processes is unclear, Filion et al (1996) suggested that initial PPI (i.e. less

than 240 ms) in an attention-to-prepulse paradigm reflects early stages of information

processing. It is interesting to note that the magnitude and the duration of PPI in this

study correspond very closely to the Woldorff et al (1991) MMN study where the MMN

was suppressed between 130 and 280 ms, with peak suppression occurring at 130 ms.

Filion et al (1996) do not explicitly make reference to an early selection theory; however

the attenuation of the startle response implies that the startle stimulus was suppressed at

an early stage of stimulus processing.

Rapid Serial Visual Presentation Tasks

In vision research, Rapid Serial Visual Presentation (RSVP) has become a useful

tool for investigating the cognitive consequences of items that have been selected for

further processing. In this procedure, items such as letters, digits, pictures and words are

presented briefly in rapid succession. Item presentation rates vary from 6 items/second to

20 items/second, and various combinations of stimulus duration and Inter-Stimulus

Intervals (ISI) have been reported (see Shapiro & Raymond, 1994), with the majority of

the studies using presentation rates of 10 to 11 .

In most visual experiments, RSVP procedures usually consist of 15 to 20 items in

a sequence, of which all items are different. Typically, there are two major approaches:

single task RSVP and multiple task RSVP studies. Single task RSVP studies consist of a

stream of visual items in which one is differentiated in some way (e.g., presented in a

different color) from all other items. The participant's task is to identify or detect the

target. The importance of these experiments lies in the finding that, although visual

masking of the target item by the immediately following item (+1 item) limits

performance to a small extent, visual attentional mechanisms account for most of the

performance limitations (Shapiro & Raymond, 1994). Multiple task RSVP studies

attempt to elucidate the temporal nature of events succeeding selection of a single target.

Typically, these experiments involve identifying both the primary target and a secondary

target (probe) where the temporal interval (SOA) between the two is manipulated (see

Figure 3).
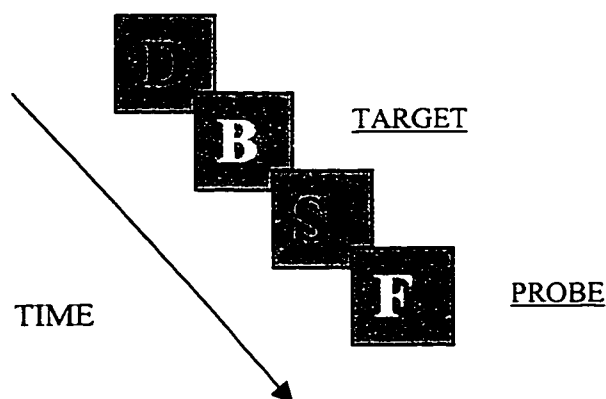
Figure 3. Example of rapid serial visual presentation stimuli, where the target is a white

letter and the probe is a red letter.

These experiments demonstrate that as the temporal proximity of the target and

probe decrease, the probability of correctly identifying the probe increases. Specifically,

the general literature suggests that if a probe is presented between 100 ms and 450 ms

after target onset, participants are unable to correctly identify it (e.g. Shapiro &

Raymond, 1994). Moreover, they frequently report being unaware that it had been

embedded in the stimulus stream. After 450 ms, correct identification increased steadily,

reaching an asymptote at approximately 720 ms post-target. This apparent post-target

processing deficit has come to be known as the Attentional Blink (AB) (Raymond,

Shapiro & Arnell, 1992a; Shapiro & Raymond, 1994) and Figure 4 demonstrates the

pattern of probe identification accuracy as a function the interval between the target and

probe in a typical RSVP task.
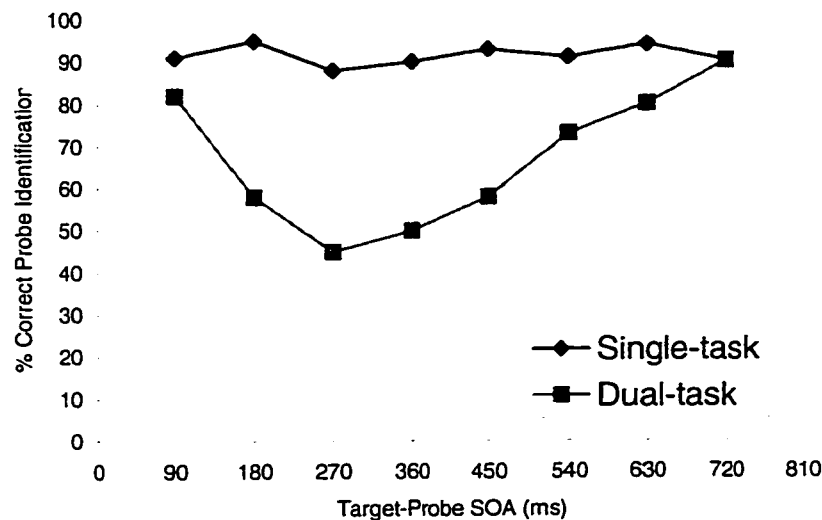
Figure 4. Example of a typical visual attentional blink pattern of results (e.g. Raymond et al., 1992a)

Raymond, Shapiro and Arnell (1992a; 1992b) have proposed two models for the AB: an inhibition model and an interference model. The inhibition model (Raymond, Shapiro & Arnell, 1992a) suggests that the blink occurs when subsequent processing is suppressed during target identification in order to limit "confusion". Confusion results because the immediate post-target item (t+1) appears before target identification processing is complete. The attentional system notes the confusion and further suppresses visual processing for a short time. If the probe appears during this temporal window, it will not be processed. The inhibition model is classified as an early selection model because suppression is thought to begin before target identification is complete, i.e. at approximately 180 ms from target onset. The model is supported by the finding that no blink occurs when the t+1 item is eliminated (Raymond et al, 1992a). However, the finding that the AB appears during detection-only tasks (i.e. participants are required only to detect the presence of a white target letter, for example) casts some doubt on the fundamental assumption of this model, namely, that target identification is critical in instigating the blink.

Interference, the second model (Shapiro & Raymond, 1994), claims that the AB results from competition among items in visual short term memory (VSTM) for retrieval and report. In RSVP (i.e. presentation rates of 6 to 11 items/second), the critical items entering VSTM are the target, probe and, due to close temporal proximity, the t+1 item as well as the probe +1 item. Entry of the +1 items is thought to result from the slowness with which the attentional filter closes after target selection (Botella and Erikson, 1991, 1992; in Shapiro & Raymond, 1994). Although these items are weighted differently for

representation (based on how well they match internal templates), temporal order loses its significance once items have entered VSTM (Shapiro & Raymond, 1994). This means that representational weighting is the sole criteria for report. However, VSTM items are subject to decay with time. Therefore, when the target-probe SOA is less than 450 ms, the target and the t+1 item may not have decayed from VSTM. Consequently, all four items must compete for report and retrieval as the probe. Such competition reduces probe accuracy and hence the blink effect results. With SOAs of greater than 450 ms, the target and t+1 items have begun to decay from VSTM, increasing probe report accuracy.

Two direct predictions follow from the interference model: 1) Processing does occur during the blink and 2) All four critical items are fully identified and represented in memory. Empirical evidence supports both predictions (Isaak, Martin & Shapiro, 1995; 1998). Additionally, and of particular interest, are three recent studies (Maki, Frigen & Paulson, 1993, 1997; Shapiro, Driver, Ward & Sorenson, 1995) which all found that words presented during the blink were able to semantically prime subsequent related words. These studies strongly support the interference hypothesis that processing does occur during the blink and it is conceptual in nature.

Interference interpretations are, at first glance, remarkably elegant and compelling when accounting for probe detection accuracy in RSVP paradigms. In particular, performance does indeed appear to be a function of VSTM load; this has also been tested empirically (see Isaak, Martin & Shapiro, 1998). One problem however, with a late selection explanation is that it appears somewhat inconsistent with what has been observed from the time course of information processing from ERP studies. For

example, Raymond et al (1992a, 1992b) found that the same pattern of probe detection or identification accuracy results whether the stimuli are letters, digits or complex patterns, where targets and probes are usually distinguished from each other and from non-target stimuli by color. Smid et al (1997) showed that feature conjunction (color and global shape) specific processing only began at approximately 250 ms, so it is unclear at present, how targets and their +1 counterparts can all be fully identified and competing for a response or a decision "channel" at the typical SOAs observed in RSVP paradigms. Indeed, in an analyses of target identification errors, Shapiro & Raymond (1994) note that on a significant number of trials, participants responded with the identity of the t+1 item, suggesting that an erroneous conjunction of the t+1 letter identity and the target letter color had occurred. Chun and Potter (1995) found similar conjunction errors for probes, and considered together, the conjunction errors in both studies suggest perceptual processing (conjunction processing) is still in progress, and that a consolidated target (or probe) identity has not yet been formed. One might speculate that the prolonged SNs and Nds in the ERP research are unlikely to be of the durations observed (between 200 and 450 ms; e.g. Smid et al, 1997) were targets able to be fully identified in 100 ms or less.

A second, somewhat subtler methodological problem stems from when the target and probe report measures are taken. In RSVP paradigms, participants are asked to report the identity of targets and probes at the end of every RSVP stream, some two to three seconds later. Clearly by this time, target stimuli have had enough time to be fully identified, and it is not surprising that they are. However, it does not necessarily follow that stimuli are identified in 100 ms or less, as Raymond et al. (1992a) and Chun & Potter

(1995) claim. A rhetorical question that suggests itself - were Raymond et al. (1992a) and Chun and Potter's (1995) claim to be true – would be, why then, would attentional inhibition be needed at all?

Essentially, a late selection model claims that probe identification impairments are the results of interference and that inhibition does not play a role in attentional processes. One implication of this claim might be that when the four critical items are in VSTM, probe responses must wait until target responses have been executed and thus, reaction times to the probe might be expected to decrease as a function of the temporal distance between targets and probes. That is, probe responses should be faster as the target-probe SOA increases. However, Van Selst and Jolicouer (1997) found that probe reactions times were unchanged across SOAs, suggesting that a "response bottleneck" may not be the underlying reason for the AB. In any event, the interference model needs clarification as it stands, and ultimately, the inhibition model may prove to be a better explanation of AB phenomenon.

Relationship Between Selective Attention, Inhibitory Processes and Aging

The Inhibitory Model of Age-related Cognitive Decline

In 1988, Hasher and Zacks proposed a conceptual framework for understanding age differences in working memory span that incorporated the notion of reduced inhibitory efficiency in older adults. In their view, the functional capacity of working memory is reduced with aging because less efficient inhibitory processes fail to prevent irrelevant information from entering or being maintained in working memory. They further claim that reduced inhibitory efficiency explains a wide range of cognitive

declines falling outside the domain of working memory such as discourse comprehension, speech production, episodic memory and selective attention (see Zacks and Hasher, 1994). In accordance with dual component model of selective attention (e.g. Houghton & Tipper, 1994; Neumann & DeSchepper, 1991; 1992) where both excitatory and inhibitory processes operate together to regulate attention, it is the inhibitory components which are differentially affected in selective attention for older adults (Zacks and Hasher, 1997)

Hasher and Zacks (1988) further argue that attention, memory and language are all interrelated in that they are generally "on-line" processes which additionally, often follow from the selective attention. Consequently, factors that affect the efficiency of selective attention will also affect other domains such as working memory and language comprehension and production – which rely (at least initially) on the integrity of the selective attention system. Specifically, if selection efficiency depends on both the activation or facilitation of relevant stimulus processing *and* inhibition of irrelevant stimulus processing, then deficient inhibitory processes should result in a decreased ability to ignore irrelevant stimuli. In some selective attention tasks such as the negative priming task and PPI, inhibitory deficits result in, paradoxically, *better* performance (Klein & Taylor, 1994; McDowd, Oseas-Kreger & Filion, 1995), while in other tasks such as the Stroop task, inhibitory deficits produce worse performance, as measured by an increase in interference.

Age Effects in Negative Priming and Prepulse Inhibition

Negative Priming

Within the negative priming paradigm, as stated earlier, it is possible to separate the effects of facilitation and inhibition. Thus, the inhibitory deficit model of Hasher and Zacks (1988) would predict that facilitatory processes (i.e. positive priming) would be relatively unaffected by age and consequently, should not be significantly different than the facilitory processes of younger adults. In contrast, inhibitory processes would be sensitive to aging and should manifest themselves as decreases in negative priming.

McDowd and Oseas-Kreger (1991) investigated negative priming in a sample of older and younger adults. Using Tipper and Cranston's (1985) overlapping letter stimuli, they compared reaction times from three different types of trials. One block of trials consisted of the presentation of single letters to which participants responded to the identity of the letter. The second type of trial consisted of the overlapping letters where distractors had no relationship to the target letters. The third type of trial was a negative priming type trial where the target on every trial was the distractor from the previous trial. Their results indicated that while younger adults demonstrated a significant negative priming effect, the older adults did not. Furthermore, the older adults appeared less able to ignore distracting letters compared to younger adults, even when the distractor was a constant letter throughout (based on the difference in reaction times between the no-distractor trials and the trials in which a distractor was present but not a negative priming trial.

McDowd and Oseas-Kreger's (1991) results are consistent with those of several

other studies that have looked at negative priming in older adults (e.g., Hasher, Stoltzfus,

Zacks & Rympa, 1991; Stoltzfus et al, 1993; Tipper, 1991). Moreover, these inhibitory

deficits do not appear to be the result of a delay in the initiation of inhibition (McDowd &

Oseas-Kreger, 1991; Stoltzfus et al., 1993) as would be suggested by a simple age-related

slowing hypothesis (Salthouse, 1985; Salthouse & Meinze, 1995), nor do they appear to

be the result of an inhibitory mechanism that diminishes at a faster rate for older adults

(Stoltzfus et al, 1993). Finally, Kane, Hasher, Stoltzfus, Zacks and Connolly (1994)

demonstrated that the apparent inhibitory deficit as observed in negative priming studies

is not the result of insufficient stimulus duration (temporal integration). In this study,

Kane et al. increased the stimulus durations to 500 ms but still did not obtain a significant

effect of negative priming for older adults. Of note is that Kane et al (1994) also

observed equivalent positive priming in younger and older adults.

Not all studies have found a lack of negative priming in older adults however. In

contrast to Tipper's (1991) study, which used pictures as stimuli, Sullivan and Faust

(1993) found equal magnitudes of negative priming for older and younger adults, using

superimposed line drawings not dissimilar to Tipper's stimuli. Sullivan, Faust and Balota

(1995) further compared the performance of younger adults, older adults and older adults

with Alzheimer's in another negative priming study. Their 1995 results replicated their

1993 results with equivalent negative priming for older and younger adults; a lack of

negative priming was only observed for the older adults with Alzheimer's. Kramer,

Humphrey, Larish, Logan and Strayer (1994) also observed equivalent negative priming

for younger and older adults in a letters task. Thus, while the balance of studies appear to support decreased inhibitory efficiency with age, there are enough studies supporting the opposite result to warrant caution when categorically assuming the former.

Prepulse Inhibition

With respect to prepulse inhibition, age effects on sensory gating were first examined by Harbin and Berg (1983). Younger and older adults were presented with trials consisting of either a brief air puff to the eye alone or a weak tone (prepulse) followed by the air puff shortly after stimulus onset. The results indicated that the air puff alone elicited large startle eyeblinks, that the non-startling prepulse produced significant inhibition of the eyeblink response and that there were no age differences in the magnitude of these effects.

Although there has been extensive research of PPI in animals (e.g. see Swerdlow, Lipska, Weinberger & Braff, Jaskiw & Geyer, 1995) none of these animal studies have looked at PPI as a function of aging. In the human aging domain, McDowd and Filion (1992) investigated whether attention in an attention-to-prepulse paradigm would modulate the blink reflex and if the effects were sensitive to age. They found that in contrast to the younger adults who showed greater PPI (reduced startle response) to the attended tones relative to the ignored tones, older adults showed equivalent PPI to both prepulse types. Thus, in comparison to younger adults, older adults showed reduced PPI (increased startle response) to the attended tones but not to the unattended tones. McDowd and Filion (1992) concluded that older adults were less able to mobilize

volitional attentional processes and thereby increase the level of protection provided to the processing of the task-relevant stimuli.

In a second study, McDowd, Filion, Harris and Braff (1993) investigated PPI in late-life schizophrenics compared to older age-matched controls and younger adults. They also included a measure of negative priming. Their results indicated that the magnitudes of PPI and negative priming were positively correlated for older and schizophrenic participants and that for both measures, older adults and late-life schizophrenics showed an inhibitory deficit relative to young controls, with the deficit being more pronounced in the older schizophrenic population. They concluded that the older schizophrenic patients suffer a more pronounced deficit resulting from the combined effects of schizophrenia and aging.

Age Effects in Stroop and Rapid Serial Visual Presentation

Stroop Tasks

Age effects in selective attention tasks are abundantly documented. (e.g. see Plude & Doussard-Roosevelt, 1989) and these effects extend to the Stroop task as well. Cohn, Dustman and Bradford (1984) report several other important findings in addition to the increase in Stroop interference for older adults. First, increased reaction times are not due to decreased reading speed because there was no difference between the groups on simple reading tasks. Second, the increased interference in not due to age-related changed in color discriminibility. Cohn et al. (1984) investigated the errors according to the different color patterns and found no difference between the age groups. Lastly, they ruled out the possibility that the effect was due to an increased cautiousness on the part of

older adults. They examined the speed-accuracy trade-off by looking at the number of errors made and found that only one group of their four older age groups has significantly fewer errors than the rest. After eliminating all the above potential confounding variables, they suggested that the increased interference effect could be due to a deficit in the ability to inhibit one stimulus aspect (the word) while attending to the other (the color).

Dulaney and Rogers (1994) further investigated the notion of inhibition by examining whether practice would reduce Stroop interference. They found that both younger and older adults developed decreases in reaction time and interference with practice, which they speculated might be due to the development of a reading suppression response. However, they noted that this effect dissipated much quicker in the older adults. Dulaney and Rogers (1994) then manipulated task factors so that a reading suppression response could not be developed through inconsistent practice with Stroop stimuli. Under these conditions, there was still a reduction in Stroop interference however, Dulaney and Rogers (1994) were able to attribute this reduction to practice with general task factors alone. The improvement for younger adults was attributed to both general task factors as well as the development of a reading suppression response since their reading suppression effect did not dissipate as the older adults' did. Dulaney and Rogers (1994) concluded that older individuals have reduced inhibitory abilities in selective attention tasks; specifically, they had difficulty in inhibiting distracting, irrelevant information, but also in the ability to inhibit previously well-learned automatic processes.

RSVP Tasks

Only two studies have investigated potential age effects in a RSVP paradigm, both unpublished. Zacks, Henderson, Mangun and Hasher (1994) report an equivalent visual letter AB for both age groups. That is, both younger and older adults demonstrated a similar probe accuracy deficit following the target in the dual-task condition, relative to the single task condition. Interestingly, Zacks et al. (1994) concluded that the RSVP paradigm might be a useful tool to measure preserved cognitive abilities in older adults.

McArthur (1996) also investigated age effects in RSVP tasks. In contrast to Zacks et al. (1994) however, she reported a significant decrease in probe detection accuracy in the dual-task condition, relative to the younger adults, using similar letter stimuli to Zacks et al (1994). She also included a Stroop task and a negative priming task in her study and found increased Stroop interference for her older adults, but no decreases in negative priming. Considering all three results together, she concluded that the older adults did manifest some "form of attentional deficit" (p69) but it was not an inhibitory deficit, as predicted by the Inhibitory Deficit Model (Hasher & Zacks, 1988).

In sum, what negative priming, PPI and RSVP studies share in common is that they direct attention to an initial stimulus and measure – either directly or indirectly – the impact on a second stimulus. Across these different paradigms, it has been shown that the processing of the second stimulus is impaired. Further, with the exception of the late selection account of the AB in RSVP tasks, there is a general consensus that this impairment is presumed to reflect the operation of cognitive, or more precisely,

attentional inhibition. Attentional inhibition in turn, appears to have accumulated a reasonable amount of support in the physiological ERP studies.

However, while most of these behavioral paradigms that have attempted to track the time course of inhibition have found evidence of early attentional inhibition, the duration of such inhibition is highly variable across the paradigms (e.g. contrast PPI that dissipates by 240 ms with RSVP inhibition that dissipates by 500 ms). Of note though, is that all these studies differ widely in the type of stimuli used (again, contrast the tones used in PPI with the letters, pictures and words used in negative priming and RSVP studies). It was with this consideration in mind, that led, in part, to the choice of both simple visual and auditory stimuli used in the present experiment.

The Present Experiment

The goals of the present study are threefold. First, while single task (i.e. auditory analogue RSVP) studies have been conducted in the auditory domain (e.g. Watson, Lehman & Kelly, 1981; Watson, Wroton, Kelly & Benbosset, 1975), dual-task studies are rare. Consequently, auditory AB effects are not well elucidated. For example, Duncan, Martens and Ward (1997) found both auditory and visual as did Shulman and Hsieh (1995), but Potter and Chun (1995) report auditory ABs only when target and probe tasks differed. Potter and Chun (1995) argued therefore, that the auditory effect was not a "true" AB, but simply a task-switching phenomenon instead. Furthermore, these existing auditory studies have used spoken names of letters or digits as auditory stimuli. Because spoken letter and digit names correspond to highly familiar graphemes, it is possible that the presentation of the auditory stimulus would trigger the development

of the corresponding visual representation. The effect of visual perception on auditory perception is compellingly demonstrated in the McGurk effect (McGurk & MacDonald, 1976). Thus, existing auditory and cross-modal studies are potentially ambiguous with respect to what the findings actually reflect. Therefore, the first goal in this experiment is to establish the existence of an auditory attentional blink using pure tone stimuli differing in frequency, for which it is assumed that no visual representations exist.

A second goal of the present study is to determine whether the auditory AB supports an early or late selection model of attention. That an early or late selection controversy exists is reflected in the two existing models of the attentional blink, with one being an interference-based or late selection account and the other model being an inhibition based or early selection account. Although based on the RSVP literature, most authors endorse a late selection interpretation of the AB (e.g., Raymond et al, 1992b, Shapiro & Raymond, 1994; Shapiro, Driver, Ward & Sorenson, 1997; Van Seldt and Jolicouer, 1995), a review of the ERP literature presented here suggests that a late selection model may be in need of clarification, if not revision. This study will address this question by employing rapid serial presentation techniques using simple stimuli and measuring target and probe detection accuracy. It will be of interest to examine whether the same overall pattern of target-probe accuracy deficits emerge when using this simple stimuli, compared to other studies which have used complex stimuli (e.g. see Figure 4).

The third goal of this study is to examine whether age differences exist in the auditory and visual ABs. Age effects in AB tasks are equivocal to date and further, assess the AB only in the visual domain. Further, *assuming* an inhibitory deficit in older

adults, the inclusion of this population may shed some light on the current AB models, since each model makes specific predictions about the performance of older adults. Specifically, an inhibition account of the AB predicts "better" performance for older adults, while an interference account predicts poorer performance.

METHOD

<u>Participants</u>

Young participants were 21 college age students (mean age = 21.2 yrs; 16

females, 5 males) enrolled in an undergraduate psychology course at the University of

Calgary, who received course credit for participation. Older participants were 11

community dwelling adults (mean age = 66.8 yrs; 7 females, 4 males) who responded to

ads placed in the local newspapers. They received a $20 honorarium for their

participation. Only older adults were screened for hearing impairment and their hearing

was within normal limits for the frequency range tested (500 – 3000 Hz). All participants

reported normal or corrected-to-normal vision as well as being in a state of good health.

All participants signed an informed consent form.

<u>Stimuli and Procedures</u>

     <u>Auditory Task</u>

Stimuli Stimuli consisted of 168 Rapid Auditory Presentation streams of 25 randomly

presented tones each, comprising the range of 1000 Hz to 2490 Hz in 10 Hz multiples.

Tones were generated using a SoundEdit 16 software program and all tones included a

constant 5ms rise and fall time to prevent spectral splatter. Tones of 1500 Hz, 2000 Hz,

and 2500 Hz were not stream items, being reserved for the target and probe. Tones were

adjusted to equal loudness, producing streams at an approximate intensity of 40 dB SPL

and were presented in free field. Targets and probes were further increased in intensity

by approximately 10 dB SPL over and above the stream items. As such, targets and

probes were subjectively speaking, clearly louder. All tones, including target, probe and

stream items were 85 ms in duration, separated by a silent 5 ms Interstimulus Interval

(ISI). The stimulus duration plus the ISI resulted in a presentation rate of 11

tones/second.

Design   Participants were first trained on a frequency identification task. Three

sequential tones were presented in free field: 1500Hz, 2000Hz, and 2500Hz and

participants were asked to identify these three tones according to a low, medium or high

pitch. Training continued until proficiency was demonstrated and participants felt

comfortable with the task.

Experimental Condition (dual-task condition): Targets were presented equally

often at positions 5, 9, or 13 in the stream on 50% of the trials, the remaining 50%

constituting catch trials which enabled a measure of false alarms to be calculated. Probes

were presented on all trials, equally often at SOAs of 90, 180, 270, 360, 450, 540 and 630

ms. Targets and probes were never the same in any given stream and all possible target-

probe combinations were balanced across SOAs. Participants were asked to identify the

first loud tone according to pitch, and then, if a second loud tone was heard, it was also to

be identified according to pitch. Participants waited until the end of each stream to give

responses and the experimenter recorded the participants' answers (e.g. "high, low").

Control condition (single-task condition): The control condition was identical to

the experimental condition except that in the target present trials, targets were not louder.

Essentially, participants performed only the probe task, where the experimenter recorded

the participants' answers at the end of each stream.

Visual Task

Stimuli   Stimuli consisted of 168 RSVP streams of 25 randomly presented lines each,

consisting of orientations of 30, 60, 120, and 180 degrees. Lines of orientations 45, 90

and 135 degrees were not stream items being reserved for the target and probe. All lines

were 3 cm long and stream lines were of identical thickness. At a viewing distance of 30

cm, all line stimuli were 0.95 X 0.76 degrees visual angle. Targets and probes were

thicker lines, clearly discriminable from stream lines. All lines were displayed for 15 ms,

separated by a blank 75 ms Interstimulus Interval, (both of which was measured

independently) and a presentation rate of 11 lines/second. Lines were presented at the

center of the computer screen following a "READY?". At a viewing distance of 30 cm,

all line stimuli were 0.95 X 0.76 degrees visual angle.

Design   Participants were familiarized with the task prior to beginning each condition.

Experimental Condition (dual-task condition): Targets were presented equally

often at positions 5, 9, or 13 in the stream on 50% of the trials, the remaining 50%

constituting catch trials again, allowing for a measure of false alarms to be calculated.

Probes were presented on all trials, equally often at SOAs of 90, 180, 270, 360, 450, 540

and 630 ms. Targets and probes were never the same in any given stream and all target-

probe combinations were balanced across SOAs. Participants were asked to identify the

first thick line according to orientations of left, right or vertical (i.e., 135, 45 or 90

degrees respectively), and then, if a second thick line was seen, it was also to be

identified according to orientation. The participants were instructed to give their

responses at the end of each stream and the experimenter recorded the participants' answers (e.g. "left, right").

Ignore Condition: The ignore condition was included in the visual task to obtain an estimate for the contribution of sensory masking to any observed dual-task performance decrements. The ignore condition was identical to the experimental condition in every respect and differed only in the instructions given to participants. Participants were informed that half of the trials would contain two thicker lines and in those trials, they were to ignore the first thicker line and only identify the second thicker line. If the trial had only one thicker line, they were asked merely to identify it. The participants were instructed to give their answers at the end of each stream and the experimenter recorded the participants' answers. Any effects of sensory masking of targets by probes or stream items will manifest itself in a significant difference between the Ignore-target condition and the single-task control condition.

Control condition (single-task condition): The control condition was identical to the experimental condition except that in the target present trials, targets were not thicker. Again, as with the auditory task, participants performed only the probe task. Participants were instructed to give their answers at the end of each stream and the experimenter recorded the participants' answers at the end of each stream.

General Procedures and Apparatus

All participants were tested individually and the testing session lasted approximately 1 - 1 ¾ hours for the young adults and 2 ½ hours for the older adults. 11 younger adults completed both the auditory task and the visual task (experimental and

control conditions). The remaining younger adults performed only the visual task (experimental and ignore conditions). Older adults (11 individuals) completed all tasks; specifically, the auditory task as well as all three conditions of the visual task (experimental, control and ignore). Order of tasks (auditory vs visual) as well as order of condition (control and/or ignore vs. experimental) were counterbalanced across participants. Participants were encouraged to take a five-minute break between the auditory and visual tasks.

The auditory task was completed in a dimly lit, acoustically shielded room. Tones were presented through a Power Mac Macintosh internal computer speaker and participants were seated approximately 60 cm from the computer speakers. Blocks of trials (streams) were initiated by the experimenter and consisted of 17 trials in each of 4 blocks plus 1 block of 16 trials, for a total of 84 trials in each condition (experimental and control). There was a 5 second intertrial interval for participants to give their responses.

For the visual tasks, participants sat approximately 60 cm from the screen and were asked to maintain fixation at the center of the screen, where all stimuli would appear. Visual stimuli were presented on a computer monitor from a Macintosh Quadra 800 computer. There were 6 blocks of trials, consisting of 14 trials (streams) in each block, for each condition. Each trial began with a "READY?" displayed in the center of the screen. Participants were instructed to press the space bar to initiate a trial. Participants were free to pace the trials (streams) themselves.

Scoring

In the auditory task, the dependent measure was target-detection accuracy (single-task condition) or target-probe detection accuracy (dual-task condition). However, identification responses were required in an effort to ensure strongly focused attention and "on-line" processing. Participants' responses were scored according to the number of loud tones correctly reported. For example, in the experimental condition, the correct reporting (detection) of two louder tones produced a score of one, as did the correct reporting (detection) of one louder tone. Thus, participants obtained a score of 1 for detecting the correct number of louder tones in a stream even though they may have mistakenly reported a high tone for a medium tone. Incorrect reporting (detection) - for example, reported one louder tone but two were present - were scored as zero. False alarms where two louder tones were reported but only one louder tone was present, were also scored as zero.

In the control condition, the correct reporting (detection) of one louder target tone was scored as one, as was the correct reporting (detection) of no louder tones. Incorrect reporting, where no louder tones were reported but one was present, was scored as zero. False alarms, where one louder tone was reported by none were present, were also scored as zero.

This procedure was chosen for two reasons: 1) the pilot study had indicated that correct identification accuracy performance was only at chance levels and 2) when participants were asked only to detect the presence of louder tones in the streams,

detection accuracy performance was near ceiling levels. Thus, the term "detection accuracy" in the auditory task is defined as the number of louder tones correctly reported.

Because auditory dual-task performance was going to be compared to visual dual-task performance, target-probe detection accuracy was also used as one of the dependent measures on the visual task. As with the auditory task, identification responses were also required in the visual task and scoring was as above. The term "detection accuracy" is again, understood to be defined as the number of thicker lines correctly reported.

In addition and in contrast to the auditory task, pilot data indicated that participants were able to identify the thicker lines with respect to their orientation. Consequently, it was further possible to obtain a measure of correct identification in the visual task by re-scoring the data according to whether or not targets and probes were accurately identified. When target-probe identification accuracy was used as the dependent measure, a score of one required that both target and probe be accurately identified, otherwise the score was zero. Similarly, in the Ignore Target-Identify Probe condition, a score of one required that the probe be accurately identified. In all future references to dependent measures, comparisons between auditory and visual tasks will always use target-probe detection accuracy. Comparisons between the visual conditions will use both target-probe identification accuracy and target-probe detection accuracy, depending on the comparisons being made.

Data Analyses

The Statistical Package for the Social Sciences (SPSS) 8.0 was implemented for all analyses of variance (ANOVAs) and simple effects. An alpha level of $p < .05$ was

adopted for all tests of statistical significance. Because older adults participated in this study, a generous *a priori* criterion for inclusion of individual data in the analyses was set at an accuracy rate of 85% for target detection (e.g., see Zacks et al., 1994) and a false alarm rate of less than 10%.

For each participant, the target and target-probe detection accuracy scores were calculated as a proportion of correct detections from all target-present trials at each SOA, in both the experimental (dual-task) and the control (single-task) condition. These scores were subjected to an Age (young, old) x Condition (dual-task, single-task) x Target-probe SOA (SOA; 90, 180, 270, 360, 450, 540 and 630 ms) mixed ANOVA with Condition and SOA as repeated measures and Age as a between-subjects measure. Target-probe detection accuracy, expressed as percent correct, was the dependent variable in the dual-task condition while target detection accuracy (% correct) was the dependent variable in the single-task condition.

A three-way SOA x Condition by Age interaction was expected in both the auditory and the visual task. This interaction will be investigated by conducting separate two-way ANOVAs (Condition by SOA) for each age group. Attentional blink effects (i.e. Condition main effects and Condition x SOA interactions) will be investigated using multiple comparisons at every SOA for each age group and for each task (auditory and visual) separately. Finally, any age effects will be investigated by post hoc comparisons as suggested by the data.

RESULTS

Auditory Task

<u>False Alarms</u>

The false alarm requirement resulted in the exclusion of data from one younger

adult whose the false alarm rate was 33% and one older adult whose false alarm rate was

28%. The remaining younger adults' false alarm rates ranged from 0 to 9% with an

overall average of 2.3%. Older adults' false alarm rates also ranged from 0 to 9% with an

overall average of 1.8%. False alarm rates did not differ across age groups ($\underline{t}$ (138) = .84,

$\underline{p} > .05$)

<u>Analyses</u>

The three-way mixed ANOVA revealed a main effect of Age, $\underline{F}$ (1, 18) = 13.02,

$\underline{p} < .05$, a main effect of Condition, $\underline{F}$ (1, 18) = 76.25, $\underline{p} < .05$, a main effect of SOA,

$\underline{F}$ (6, 13) = 17.59, $\underline{p} < .05$, a significant Condition x Age interaction, $\underline{F}$ (1, 18) = 6.35,

$\underline{p} < .05$, a significant Age x SOA interaction, $\underline{F}$ (6, 13) = 5.37, $\underline{p} < .05$, a Condition x SOA

interaction, $\underline{F}$ (6, 13) = 19.03, $\underline{p} < .05$, as well as a significant Age x Condition x SOA

interaction, $\underline{F}$ (6, 13) = 3.06, $\underline{p} < .05$. The three-way interaction was further investigated

by conducting separate two-way ANOVAs for each age group and these results are

presented below.

<u>Younger Adults</u>

The first 2 (single-, dual-task condition) X 7 (SOA; 90, 180, 270, 360, 450, 540,

and 630 ms) repeated measures ANOVA revealed a main effect of condition, $\underline{F}$ (1,126) =

43.23, $\underline{p} < .05$, a main effect of SOA, $\underline{F}$ (6,126) = 6.71, $\underline{p} < .05$ and a significant

Condition by SOA interaction, F (6, 126) = 6.40, p < .05 for younger adults. Collapsing % correct detection accuracy across all SOAs in each condition, younger adults demonstrated an overall impairment in the target-probe detection accuracy in the dual-task condition (M = 81.4%, SD = 26.5%), relative to the single-task condition (M = 97.8%, SD = 6.4%). The main effect of SOA as well as the significant SOA x Condition interaction was further investigated by examining percent correct detection accuracy in each of the conditions separately and these results are further described below.

<u>Target Detection Accuracy (Single-task condition)</u>

A single repeated measures ANOVA revealed that target-detection accuracy did not significantly differ as a function of SOA in the single-task condition, F (6, 63) = 1.11, p > .05. On average, younger adults correctly detected single targets 97.8% (SD = 6.4%) of the time.

<u>Target-Probe Detection Accuracy (Dual-Task Condition)</u>

Since detection accuracy was unaffected by SOA in the single-task condition, the main effect of SOA and the significant SOA x Condition interaction arises in the dual-task condition. With respect to the interaction, multiple planned comparisons revealed that correct target-probe detection accuracy was significantly lower at SOAs of 90 ms (t (9) = 4.87, p < .05), 180 ms (t (9) = 2.63, p < .05), 270 ms (t (9) = 1.86, p < .05), and 360 ms (t (9) = 2.22, p < .05), but not at SOAs of 450 ms (t (9) = .75, p > 05), 540 ms (t (9) = 1.02, p > .05) and 630 ms (t (9) = .83, p > .05), when compared to the corresponding SOAs in the single-task condition. This dual-task decrement in target-probe detection accuracy as a function of SOA relative to preserved target detection

accuracy in the single-task condition, indicates the presence of an auditory attentional blink-like effect for younger adults.

Older Adults

The second 2 (single-, dual-task condition) X 7 (SOA; 90, 180, 270, 360, 450, 540, and 630 md) repeated measures ANOVA for older adults revealed a main effect of Condition, F (1,126) = 152.87, p < .05, a main effect of SOA, F (6, 126) = 18.10, p < .05 as well as a significant SOA x Condition interaction, F (6, 126) = 19.31, p < .05. Collapsing % correct detection accuracy across all SOAs in each condition, older adults also demonstrated an overall impairment in dual-task performance (M = 61.9%, SD = 32.4%) relative to performance in the single task condition (M = 93.3%, SD = 10.3%). The main effect of SOA as well as the significant SOA x Condition interaction was further investigated by examining percent correct detection accuracy in each of the conditions separately and these results are further described below.

Target Detection (single-task condition)

A single repeated measures ANOVA revealed that target-detection accuracy did not significantly differ as a function of SOA in the single-task condition, F (6, 63) = 1.52, p > .05. On average, older adults correctly detected single targets 93.3% (SD = 10.3%) of the time.

Target-Probe Detection Accuracy (Dual-task Condition)

The lack of significant SOA effects in the single-task condition indicates that the main effect of SOA and the significant SOA x Condition interaction arises in the dual-task condition. The significant Condition x SOA interaction was investigated by using

multiple planned comparisons. Again, target-probe detection accuracy was significantly

less at SOAs of 90 ms ($\underline{t}$ (9) = 19.58, $\underline{p}$ < .05), 180 ms ($\underline{t}$ (9) = 6.60, $\underline{p}$ < .05), 270 ms

($\underline{t}$ (9) = 4.0, $\underline{p}$ < .05) and 360 ms ($\underline{t}$ (9) = 4.40, $\underline{p}$ < .05), when compared to the

corresponding SOAs in the single-task condition. In addition, target-probe detection

accuracy was also significantly impaired at 450 ms ($\underline{t}$ (9) = 2.62, $\underline{p}$<.05). Target-probe

detection accuracy was not significantly different than single task detection accuracy at

540 ms ($\underline{t}$ (9) = .33, $\underline{p}$ > .05) and 630 ms ($\underline{t}$ (9) = .69, $\underline{p}$ > .05). Similar to the younger

adults, these dual-task performance impairments as a function of SOA relative to

preserved target detection accuracy in the single-task condition, indicate the presence of

an auditory attentional blink-like phenomenon for older adults.

<u>Younger vs Older Adults</u>

<u>Target Detection Accuracy (Single-task Condition)</u>

While both age groups were very good at detecting a single louder tone in a

stream of distractors, the percent correct accuracy rate was significantly better

($\underline{t}$ (138) = 2.89, $\underline{p}$ < .05) for younger adults ($\underline{M}$ = 97.8%, $\underline{SD}$ = 6.4%) as compared to

older adults ($\underline{M}$ = 93.3%, $\underline{SD}$ = 10.3%).

<u>Target-Probe Detection Accuracy (Dual-task Condition)</u>

Figure 5 illustrates auditory percent correct detection accuracy for both younger

and older adults as a function of SOA in the experimental and control conditions. As

suggested by both statistical analyses and the graph, the older age group appears to show

poorer performance in the experimental condition relative to younger adults. To address

which of these differences were significant, 5 post hoc comparisons were conducted at a

Bonferonni adjusted alpha of .025 between the age groups at SOAs of 90, 180, 270, 360

and 450 ms. The differences were significant at 90 ms ($\underline{t}$ (18) = 3.91, $\underline{p}$ < .025), 180 ms

($\underline{t}$ (18) = 4.38, $\underline{p}$ < .025), 270 ms ($\underline{t}$ (18) = 2.08, $\underline{p}$ < .025), 360 ms ($\underline{t}$ (18) = 4.32, $\underline{p}$ < .025)

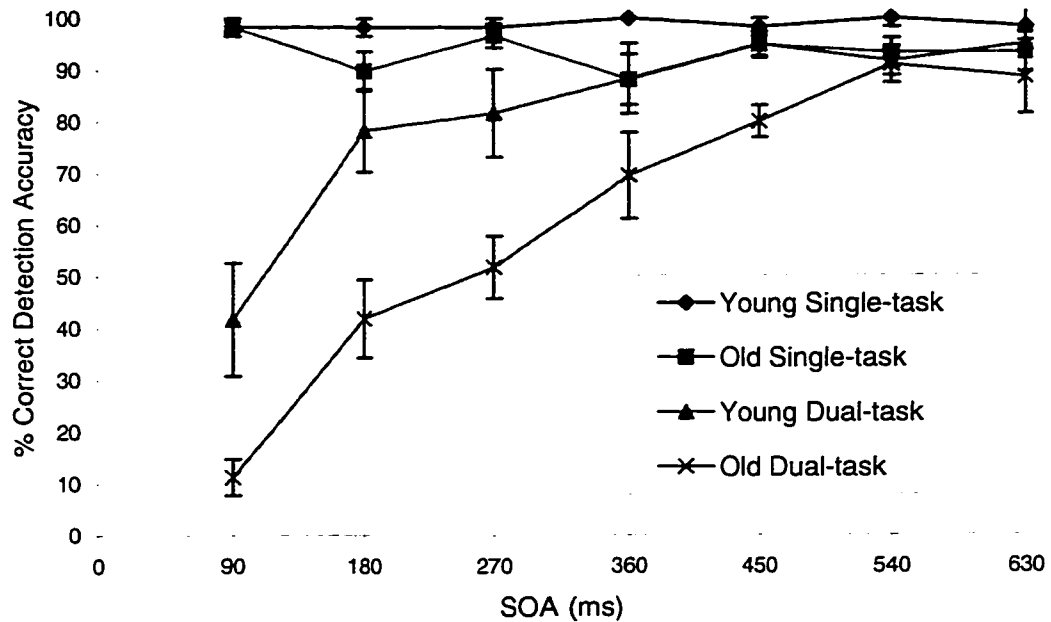and 450 ms ($\underline{t}$ (18) = 2.75, $\underline{p}$ < .025).

Figure 5. Auditory single- and dual-task detection accuracy as a function of SOA for older and younger adults (error bars indicate the standard error).

Visual Task

False Alarms

In the visual lines task, no data from either age group was excluded due to the

false alarm requirement. Younger adults' false alarm rates ranged from 0 to 2.4% with

an overall average of .48%. Older adults' false alarm rates ranged from 0 to 9%

resulting in an overall average of 1.0%. False alarms did not significantly differ between

older and younger adults (t (138) = .37, p > .05).

Analyses

The Age x Condition x SOA mixed ANOVA revealed a main effect of Age,

F (1, 18) = 11.41, p < .05, a main effect of Condition, F (1, 18) = 19.53, p < .05, a main

effect of SOA, F (6, 13) = 8.24, p < .05), a significant Age x SOA interaction,

F (6, 13) = 3.13, p < .05, as well as a significant Age x Condition x SOA interaction,

F (6, 13) = 3.28, p < .05. The Age x Condition interaction did not reach statistical

significance, F (1, 18) = .26, p > .05). The three-way interaction was further investigated

by conducting separate two-way ANOVAs for each age group and these results are

presented below.

Younger Adults

The first 2 (single-, dual-task) x 7 (SOA; 90, 180, 270, 360, 450, 540, and 630

ms) repeated measures ANOVA revealed a main effect of Condition, F (1, 126) = 22.58,

p < .05, a main effect of SOA, F (6, 126) = 2.75, p < .05, and a significant Condition x

SOA interaction, F (6, 126) = 3.24, p < .05. Collapsing % correct detection accuracy

across all the SOAs in each condition, younger adults demonstrated a slight overall

impairment in the dual task condition performance (M = 92.1%, SD = 16.2%) relative to

performance in the single task condition (M = 99.5%, SD = 2.8%). The main effect of

SOA as well as the significant SOA x Condition interaction was further investigated by

examining percent correct detection accuracy in each of the conditions separately and these results are further described below.

Target Detection Accuracy (Single-task Condition)

A single repeated measures ANOVA revealed that target-probe detection accuracy did not significantly differ as a function of SOA in the single-task condition, F (6, 63) = .83, p < .05. On average, younger adults correctly detected a single visual target with an accuracy rate of 99.5% (SD = 2.8%).

Target-Probe Detection Accuracy (Dual-task Condition)

The main effect of SOA and the significant SOA x Condition interaction was investigated with multiple planned comparisons which revealed that target-probe detection accuracy was significantly poorer at SOAs of 90 ms (t (9) = 2.26, p < .05), 180 ms (t (9) = 2.45, p < .05), 270 ms (t (9) = 1.96, p < .05), and 360 ms (t (9) = 2.24, p < 05), but not at 450 ms (t (9) = .61, p > .05), 540 ms (t (9) = .17, p > .05) or 630 ms (t (9) = .54, p > .05), when compared to the corresponding SOAs in the single-task condition. This dual-task decrement in target-probe detection accuracy as a function of SOA relative to preserved target detection accuracy in the single-task condition, indicates the presence of a visual attentional blink-like effect for younger adults.

Older Adults

The second 2 (single-, dual-task condition) X 7 (SOA; 90, 180, 270, 360, 450, 540, and 630 ms) repeated measures ANOVA for older adults revealed a main effect of condition, F (1,126) = 17.69, p < .05, a main effect of SOA, F (6,126) = 4.95, p < .05 as well as a significant Condition x SOA interaction, F (6,126) = 3.84, p < .05. Again,

collapsing % correct detection accuracy across all SOAs in each condition, older adults

demonstrated an overall impairment in dual task performance ($\underline{M}$ = 83.1%, $\underline{SD}$ = 22.3%)

relative to performance in the single task condition ($\underline{M}$ = 95.5%, $\underline{SD}$ = 7.6%). The main

effect of SOA as well as the significant SOA x Condition interaction was further

investigated by examining percent correct detection accuracy in each of the conditions

separately and these results are further described below.

Target-Detection Accuracy (Single-task Condition)

A single repeated measures ANOVA revealed that target-detection accuracy did

not significantly differ as a function of SOA in the single-task condition, $\underline{F}$ (6, 63) = .21,

$\underline{p}$ > .05. On average, older adults correctly detected single targets 95.5% ($\underline{SD}$ = 7.6%) of

the time.

Target-Probe Detection Accuracy (Dual-task Condition)

The main effect of Condition as well as the significant Condition x SOA

interaction was investigated by using multiple planned comparisons, which revealed that

correct target-probe detection accuracy was significantly poorer at SOAs of 90 ms

($\underline{t}$ (9) = 4.17, $\underline{p}$ < .05), 180 ms ($\underline{t}$ (9) = 1.94, $\underline{p}$ < .05), and 270 ms ($\underline{t}$ (9) = 1.91, $\underline{p}$ < .05),

but not at 360 ms ($\underline{t}$ (9) = 1.63, $\underline{p}$ > .05), 450 ms ($\underline{t}$ (9) = 1.64, $\underline{p}$ > .05), 540 ms

($\underline{t}$ (9) = .95, $\underline{p}$ > .05) or 630 ms ($\underline{t}$ (9) = 1.33, $\underline{p}$ > .05) when compared to the

corresponding SOAs in the single-task condition. These dual-task performance

decrements in target-probe detection accuracy in the dual-task condition with preserved

target detection accuracy in the single-task condition indicate the presence of a visual

attentional blink-like effect for older adults.

Younger vs. Older Adults

Target-detection Accuracy (Single-task Condition)

While both age groups were very good at detecting a single thicker line in a stream of thinner distractor lines, the percent correct accuracy rate was significantly better for younger adults as compared to older adults (t (138) = 4.52, p < .05).

Target-probe Detection Accuracy (dual-task Condition)

Figure 6 illustrates visual percent correct detection accuracy for both younger and older adults as a function of SOA in the experimental and control conditions. Again, as suggested by both the statistical analyses and the graph, the older age group appears to show poorer performance in the experimental condition relative to younger adults. To address whether these differences were significant, 3 post hoc comparisons were conducted at a Bonferonni-adjusted alpha level of .025 between the age groups at SOAs of 90, 180 and 270 ms. The differences were significant at SOAs of 90 ms (t (18) = 2.59, p < .025), 180 ms (t (18) = 2.60, p < .025) and 270 ms (t (18) = 2.56, p < .025).
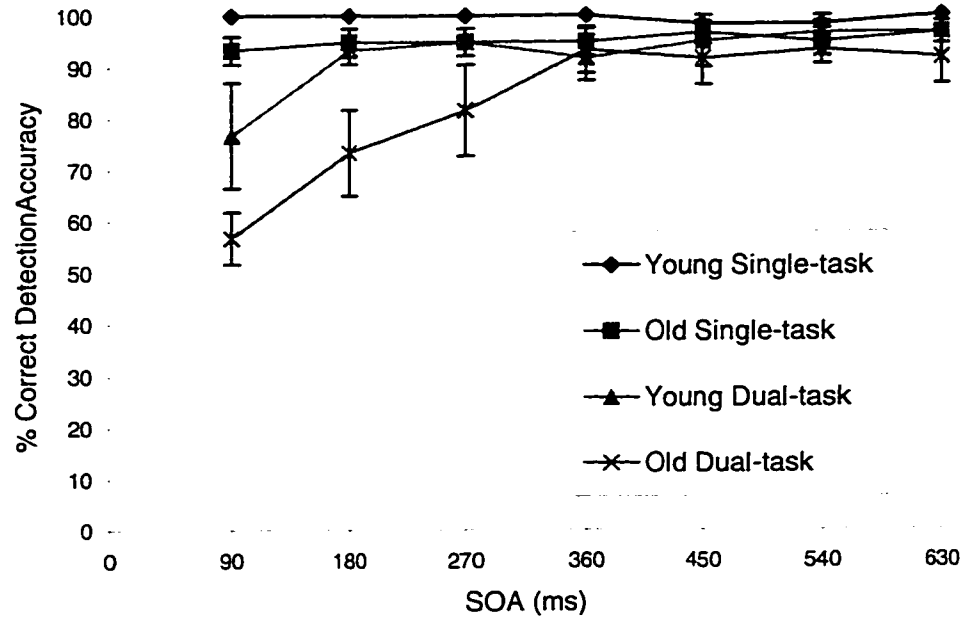
Figure 6. Visual single- and dual-task detection accuracy as a function of SOA for older and younger adults (error bars indicate standard error).

Attentional Blink Magnitudes

Given that differences emerged in the control conditions between younger and older adults, but that both age groups demonstrated an attentional blink in the visual and the auditory detection tasks, blink magnitude was calculated to determine the extent of the processing deficit. Blink magnitude was determined for each individual by averaging the difference in percent correct detection accuracy between the single and dual task conditions for the first four SOAs (90 ms, 180 ms, 270 ms, and 360 ms) in the auditory task. These SOAs were chosen since it was at these intervals that the younger adults

demonstrated significant differences in the dual task condition relative to the single-task

condition, in both audition and vision. For the auditory task, a t-test ($\underline{t}$ (78) = 3.50,

$\underline{p}$ < .05) revealed that the older adults ($\underline{M}$ = 51.7%, $\underline{SD}$ = 34.4%) demonstrated a

significantly "deeper' blink magnitude than the younger participants ($\underline{M}$ = 28.3%,

$\underline{SD}$ = 30.5%). For the visual task, a t-test ($\underline{t}$ (78) = 2.44, $\underline{p}$ < .05) revealed that the older

adults ($\underline{M}$ = 20.1%, $\underline{SD}$ = 25.6%) again demonstrated a significantly "deeper" blink

magnitude that the younger participants ($\underline{M}$ = 11.0%, $\underline{SD}$ = 21.0%). Between modality

comparisons indicated that the magnitude of the auditory AB was greater than the visual

AB for both younger ($\underline{t}$ (78) = 2.82, $\underline{p}$ < .025) and older ($\underline{t}$ (78) = 5.21, $\underline{p}$ < .025) adults.

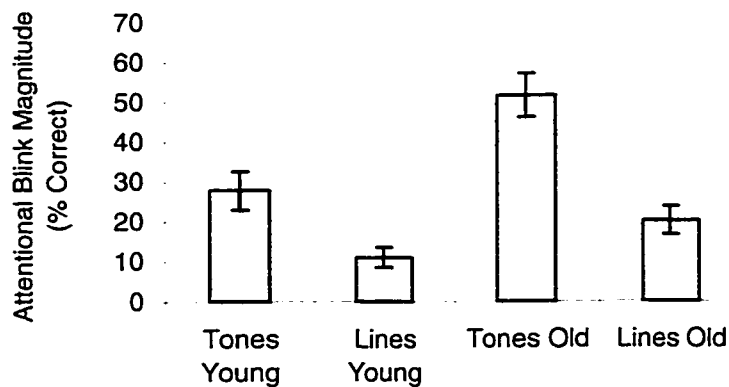Figure 7 illustrates these differences graphically for both the auditory and the visual task.

Figure 7. Attentional blink magnitudes for visual and auditory tasks as a function of age

group (error bars indicate standard error).

Correlational Analyses

Because an attentional blink emerged in both the auditory and the visual tasks,

correlational analyses were conducted for all individuals in each age group to determine

if AB magnitude on the auditory task was correlated with AB magnitude on the visual

task. The data used for the correlational analyses was the same data that was used to

calculate average blink magnitude. However, the Pearson rs revealed no significant

correlations for either age group. That is, AB magnitude on the auditory task did not

predict AB magnitude on the visual task for either younger or older adults. Specifically,

the correlation between the AB magnitudes on the visual task and the AB magnitudes on

the auditory task was r (18) = .136, p > .05, for younger adults and r (18) = .232, p > .05,

for older adults. At a critical value of r = .444, these correlations did not even approach

significance for an alpha of .05. Figures 8 and 9 display scatterplots of the individual

visual and auditory magnitudes for younger and older adults, respectively.
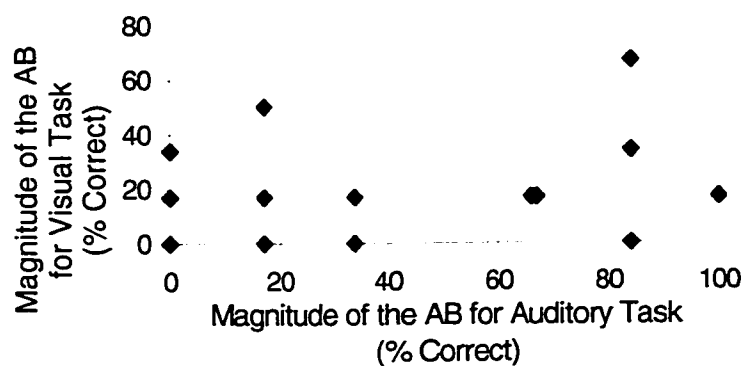

Figure 8. Scatterplot of individual AB magnitude as a function of modality for younger
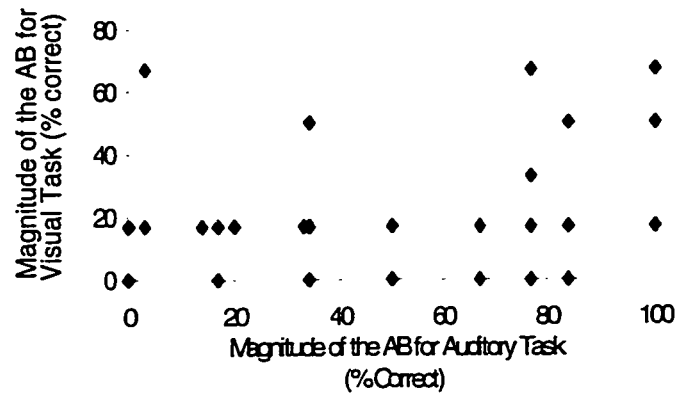
adults.

Figure 9. Scatterplot of individual AB magnitude as a function of modality for older adults.

The Contribution from Interference: Visual Task Identification Results

As mentioned previously, target-probe detection accuracy was scored according to a 0 – 1 method with a score of 1 indicating that both target and probe had been correctly detected and a score of 0 indicating that either the target or the probe had failed to be detected. In the visual lines task, an identification measure was also calculated from re-scored detection data, where a score of 1 indicated that both target and probe had been correctly identified. A score of 0 indicated that: a) either target or probe was misidentified, or b) either target or probe had failed to be detected. Thus, the difference between the average of the identification condition and the detection condition at each SOA should produce the average percent of trials where targets or probes were misidentified. Assuming that performance differed significantly as a function of whether participants detected or identified targets and probes, misidentification errors should yield a simple measure of interference.

Target Identification Accuracy (Single-task Condition)

When the target detection accuracy data was re-scored according to reflect

accurate identification and collapsed across all SOAs, younger adults correctly identified

targets 98.1% of the time ($\underline{SD}$ = 2.8%). A t-test ($\underline{t}$ (138) = .36, $\underline{p}$ > .05) revealed that

performance did not significantly differ compared to when data were scored according to

correct target detection accuracy (e.g., mean detection accuracy was 99.5. Older adults

correctly identified targets 93.3% (SD = 7.8%) of the time, and similarly, a t-test

($\underline{t}$ (138) = .58, $\underline{p}$ > .05) indicated that their performance also did not differ when

compared to target detection accuracy performance (e.g. mean detection accuracy was

95.5%).

Target-Probe Identification Accuracy (dual task)

When the target-probe detection accuracy data was re-scored according to

identification accuracy and collapsed across all SOAs, younger adults correctly identified

targets and probes 91.4% of the time ($\underline{SD}$ = 17.0%). A t-test ($\underline{t}$ (138) = .28, $\underline{p}$ > .05)

indicated that percent correct identification accuracy did not differ significantly when

compared to percent correct detection accuracy. Figure 10 compares performance (%

correct) when targets and probes were scored to reflect accurate identification for

younger adults as a function of SOA to performance when targets and probe were

accurately detected.

Older adults correctly detected targets and probes 82.7 % of the time

($\underline{SD}$ = 24.2%). A t-test ($\underline{t}$ (78) = 2.44, $\underline{p}$ < .05) indicated that percent correct identification

accuracy did not differ significantly when compared to percent correct detection

accuracy. Figure 11 compares performance (% correct) when targets and probes were

scored to reflect accurate identification for older adults as a function of SOA to

performance when targets and probe were accurately detected.
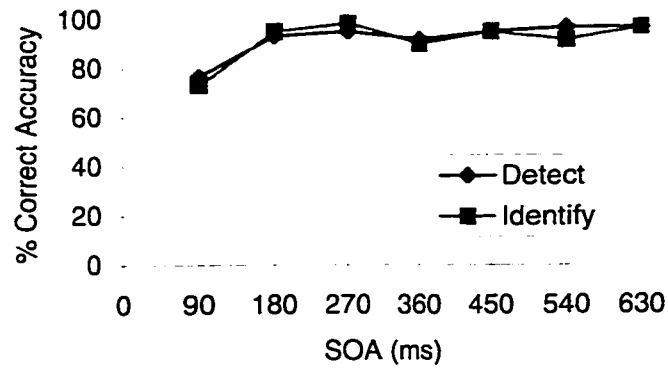
Figure 10. Younger adults' % correct target-probe accuracy as a function of detection

and identification.
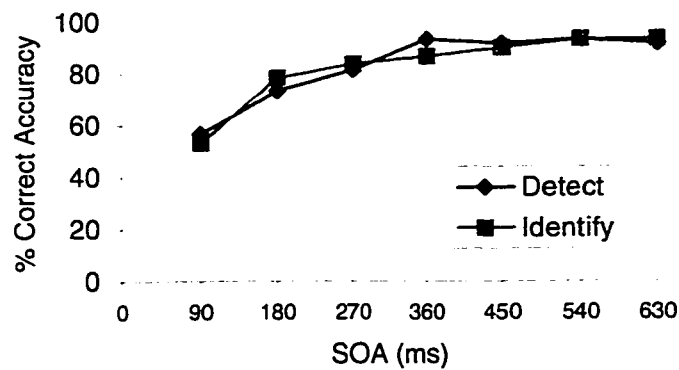
Figure 11. Older adults' % correct target-probe accuracy as a function of detection and

identification.

Ignore Target-Probe Identification Accuracy

Younger adults ignored targets and subsequently identified visual probes with an average accuracy rate of 97.8% ($\underline{SD}$ = 3.1%). Younger adults' performance in this condition did not differ significantly from their performance in the single-task condition, where they were asked only to identify a single target (t-test with $\underline{t}$ (138) = 66, $\underline{p}$ > .05). Older adults ignored targets and subsequently identified probes with an accuracy rate of 93.1% ($\underline{SD}$ = 8.2%). Similarly, older adults' performance did not differ significantly in this condition when compared to their performance in the single-task condition ($\underline{t}$ (138) = 71, $\underline{p}$ > .05).

DISCUSSION

The Auditory and Visual Attentional Blink

As indicated in the introduction, the first goal of this study was to explore the existence of an auditory attentional blink. To date, investigations into attentional blink phenomena have found evidence of auditory ABs only with the use of compressed speech (e.g. Duncan et al, 1997), making it difficult to unambiguously attribute AB effects to the auditory modality. To address this issue, this study employed pure tones in a rapid auditory presentation paradigm. In this respect, the auditory tones task demonstrates a decrease in target-probe detection accuracy, relative to the single-task situation, for both older and younger adults. This impairment in the detection of both a target and a probe compared to the unimpaired detection of a target (or probe) alone (e.g. Broadbent & Broadbent, 1987) or the case where the target is ignored and the probe detected or identified (e.g. Raymond, Shapiro & Arnell, 1992a; 1992b), defines the attentional blink.

For the purposes of modality comparisons, this study also included a visual task in a rapid serial presentation paradigm, where an attempt was made to match visual stimuli with auditory stimuli in terms of stimulus complexity. This was accomplished by using lines that differed only in width and orientation for visual stimuli and tones that differed only in frequency and intensity. For the visual lines task, there is also a decrease in target-probe detection accuracy, relative to the single-task situation, for older and younger adults. Further, this decrease in dual-task performance is unchanged across both experimental and control condition manipulations. Specifically, for the control condition manipulations, dual-task performance did not change whether participants performed

only the single-task control condition or whether they ignored the target and identified the probe. Further, the lack of any significant difference between the Ignore-Target condition and the single-task condition suggests that sensory masking as an explanation for dual-task performance decrements can be eliminated. For the experimental condition "manipulations", dual task performance decrements remained the same whether the data were scored according to target-probe detection accuracy or target-probe identification accuracy. The impairment in target-probe detection accuracy in the dual-task condition with preserved target detection accuracy in the single-task condition, defines the presence of a visual attentional blink.

A point worth noting about the visual AB obtained in this study is that when this AB is compared to the Shapiro et al. (1992a) AB, there is no apparent "delay" in the initiation of inhibition. The reason for the lack of a delay in inhibition in this study is unclear at present. It is conceivable that the simple stimuli used in our visual task, which differed only on elementary features, are partially responsible for this effect. Tentative support for this speculation comes from two sources: First, the auditory AB in the present study shows a similar lack of delay in the initiation of inhibition. The auditory stimuli used here were also very simple, differing again, only on elementary features. Second, the time course or duration of the visual AB in this study is much shorter than Shapiro et al (1992a) visual AB, perhaps suggesting that the duration of inhibition is less for simple stimuli than for more complex stimuli such as letters or complex, patterned shapes. In this regard, it is notable that both the auditory AB and the visual AB in this study are of the same duration, at least for younger adults. However, a point that argues

against stimulus simplicity in accounting for a lack of delay in the onset of inhibition is that Shulman & Hsieh (1996) obtained a similar AB pattern to the present one using auditory spoken digits as stimuli with a presentation rate of 10 words/second.

When comparing the visual AB with the auditory AB, one readily apparent difference emerges. The magnitude of the auditory AB is greater (i.e. the auditory AB is more pronounced) in comparison to its visual counterpart. With respect to the visual AB for the young adults, target-probe detection impairment is at its worst at the 90 ms SOA with an accuracy of 76%. Detection accuracy increases rapidly after the 90 ms SOA and although significant dual- task processing deficits remain until approximately 360 ms. post-target, target-probe detection accuracy is already quite high (93%) by 180 ms SOA. With respect to the auditory AB, the target-probe detection impairment is, similarly, at its most pronounced at the 90 ms SOA. However, this 90 ms post-target processing deficit of 45% detection accuracy contrasts sharply with the visual AB post-target processing deficit of 76% detection accuracy at the same point. Further, when compared to visual AB, the auditory AB recovery pattern is much slower over time, with 76% and 84% detection accuracy at 180 and 270 ms SOA, respectively. Overall differences are more clearly depicted in AB magnitudes, where the younger adults' AB magnitude averaged for the first four SOAs (90 to 360 ms inclusive) are much greater in the auditory task relative to the visual task. These modality magnitude differences are particularly interesting in light of the ceiling effects seen in the single-task (target detection) performance for both tasks, which averaged 97.8% in audition for younger adults (93.3% for older adults) and 99.5% in vision (95.5% for older adults). Thus, these modality-

specific magnitude differences do not appear to reflect the differential discriminability of auditory versus visual targets. In any event, Ward, Duncan and Shapiro (1997) manipulated discriminability by degrading the quality of their visual stimuli and found that target discriminability did not affect the magnitude of the AB.

There are at least two explanations that suggest themselves in accounting for magnitude differences in the visual versus the auditory AB. First, most participants reported that the visual task was easier than the auditory task, and thus, the magnitude differences may simply reflect differential difficulty between the two tasks. Shapiro and Raymond (1994) argue however, that task difficulty does not significantly affect the magnitude of the visual AB because their studies have shown that simple detection tasks produce an AB that is little different from the AB produced by identification tasks. Perhaps somewhat consistent with this interpretation, the magnitude of the visual AB in this study did not change significantly whether target-probe detection accuracy was used as the dependent measure or whether target-probe identification accuracy was used. However, it is important to note that identification – not detection - was asked for in the present tasks and therefore, the Shapiro and Raymond (1994) identification/detection distinction is undoubtedly irrelevant here. Additionally, Eimer and Schroeger (1998) noted that detected targets are often processed to the point of identification anyway, even though identification is not required, further blurring the identification/detection distinction - and even disguising potential differences - by suggesting that detection measures (e.g. Shapiro & Raymond, 1994) may be contaminated by automatic identification processes. Eimer and Schoreger's claim has also been observed in our

laboratory in an RSVP letter paradigm where the target task is to detect the presence of a white letter and to identify (by letter name) a red probe. Participants frequently frame their answers as "There was a white R and a red M". In sum, while the ceiling effects in the single-task situation (discussed previously) would seem to suggest that participants experienced no more difficulty in performing the auditory task compared to the visual task, their subjective reports should not be ignored. A reaction time measure to responses in the dual-task condition for both tasks may shed some light on this matter.

Another more objective way of evaluating task difficulty may be to consider the temporal resolution in each modality. Temporal resolution refers to the minimum time interval that is required between two stimuli in order to be perceived as being two discrete objects or events. In vision, temporal resolution thresholds for simple stimuli (e.g., white circles on a dark background) are between 33 to 45 ms for younger adults (see Schieber & Kline, 1986; Corballis, 1996). In audition, temporal resolution thresholds for identical pure tone frequencies (e.g. 1000 Hz tones presented at suprathreshold levels) lie between 4 and 5 ms (see Viemeister & Plack, 1993). Without considering any other stimulus parameters, the visual task may have been easier in terms of temporal resolution given that all stimuli were separated by a 75 ms ISI, a duration equivalent to approximately 2 times the temporal resolution threshold. In contrast, auditory stimuli were separated by a 5 ms ISI, which is almost equivalent to auditory temporal resolution thresholds.

There are two factors that would seem to argue against using temporal resolution thresholds as an explanation for task difficulty and by extension, as an explanation for

differences in AB magnitudes. First, the threshold values quoted above for temporal resolution tasks were measured for identical stimuli. When stimuli differ on one dimension or attribute, thresholds decrease further (Grose & Hall, 1996). The target stimuli in the present experiment differ from probe stimuli in one attribute (frequency for auditory stimuli and orientation for visual stimuli) and they also differ from non-targets (stream items) by an additional attribute (intensity for auditory stimuli and width for visual stimuli). Second, targets and probes presented in isolation (not embedded in the streams) are clearly discriminable as two separate stimuli, even at the shortest target-probe SOA of 90 ms (which was an ISI of 5 ms for the auditory task and an ISI of 75 ms for the visual task) as determined by the pilot study.

A second explanation for AB magnitude differences is that separate attentional systems govern vision and audition and thus produce different AB magnitudes in each, where magnitude is an indication of the strength of attentional inhibition. Banks, Roberts and Ciranni (1995) argue that attentional inhibition should be more pronounced in audition than in vision and that these differences result from "structural constraints imposed by the nature of the perceptual apparatus in each case" (p.1355). They note that auditory attentional selection is not aided by any analogue of visual fixation which can foveate attended stimuli and place non-attended stimuli in areas of lower acuity than the target. Further, moving the eyes or turning the head may completely obscure a visual object, if desired. In contrast, although turning the head may result in the attenuation of rejected messages in audition, the effect in terms of a reduction in presentation levels is very small (a few decibels). Consequently, auditory attentional inhibition must operate

almost entirely by internal auditory processes. Some support for Banks et al. (1995)

claim comes from the observation that there are descending pathways from higher

auditory levels (e.g. auditory cortex, superior olivary complex) to the cochlea which can

modify auditory input, but there are no analogous descending pathways from primary

visual cortex to the retina (e.g., see Vander, Sherman & Luciano, 1994).

The results presented here support Banks et al. (1995) interpretation. As can be

seen, the auditory AB magnitude is almost 2 ½ times greater than the visual AB

magnitude. In addition, the results from the correlational analysis indicate that

performance on the auditory task was uncorrelated with performance on the visual task.

This further supports the dissociation between auditory and visual attentional inhibition

since presumably, if vision and audition were governed by a common attentional system,

then performance on the individual tasks should be, at least, modestly correlated.

The Early vs. Late Selection Model of the AB

The second goal of this study was to investigate whether the auditory and visual

ABs are better accounted for by an early or late selection model of attention. To reiterate,

late selection models of the visual AB attribute the dual-task performance decrements to

interference between the target and probe during retrieval of information out of visual

short-term memory. Selection then, occurs at the conceptual level and interference is the

key defining feature (Shapiro et al, 1992b; Van Seldt and Jolicouer, 1995). Early

selection models in contrast, attribute dual-task performance decrements to an inhibitory

mechanism that is initiated when a subsequent item is encountered during target

processing (Shapiro et al, 1992a).

With respect to the auditory AB, target-probe detection accuracy is poorest at the

90 ms SOA, or in other words, when the probe immediately followed the target.

Accuracy then improves as the temporal proximity between the target and probe

decreases and inhibition appears to decrease. At this point, it is worth noting again that

the dependent measure on this task was detection of *both* the target and the probe. Thus,

inaccurate detection (i.e. % incorrect) reflects a bona fide miss of either the target or the

probe. Although in the auditory task, it cannot be said for certain whether it was targets

or probes that failed to be detected, the results from the visual identification task show

that, during the duration of the AB, it was probes that were not detected. Thus,

participants did appear to follow instructions. To the extent that it can be assumed that

the same instructions were followed when performing the auditory task and participants

did fail to detect probes and not targets, this finding suggests an early selection model

where attention to the target results in inhibition of the processing of subsequent probes.

The present auditory AB findings are consistent with a growing body of auditory

ERP research that suggests selective attention acts upon the very early stages of

information processing and that selective attention also involves a process that suppresses

unattended stimuli. Of particular relevance to the current auditory task are the dichotic

listening ERP experiments of Woldorff et al. (1991) and Woldorff and Hillyard (1991).

These experiments demonstrated that even when targets were presented in the unattended

channel (perhaps analogous to the unpredictable probes in the unattended stream items in

AB tasks) the amplitude of the corresponding ERP waveform (i.e. the N1) was

significantly attenuated. Further, this suppression process was shown to peak between

140 and 280 ms after target onset. The behavioral measure of inhibition in the present study also peaked in this range, specifically, at the end of the 90 ms SOA, which is equivalent to180 ms after target onset. Similarly, the degree of inhibition for the auditory AB – while not as great as the 70 to 90 % reported for young participants by Woldorff and Hillyard (1991) - is still quite high at the 90 ms SOA, averaging 55% (100% - 45%) for young participants.

To completely rule out a late selection model though, interference should not contribute to dual-task performance decrements. To address this issue, it is useful to consider the visual AB. Similar to the auditory AB, it is evident that target-probe detection accuracy is also poorest at the 90 ms SOA, again suggesting inhibition, which also appears to decrease as the temporal distance between target and probe increases. That is, the contribution of interference, as determined by a comparison of target-probe identification vs. detection accuracy, did not significantly contribute to the visual AB effect. Thus, the contribution of interference to visual dual-task performance in this study is negligible.

In further consideration of the visual AB, the present results suggest inhibition in an overall pattern similar to that of the auditory AB, with differences in magnitude and duration. The suggestion of the presence of inhibition in both the auditory and the visual tasks here, is consistent with the inhibition observed in a wide variety of negative priming studies (e.g.Tipper, 1985; Banks et al., 1995; Treisman & DeSchepper, 1994), and as well, with PPI studies (e.g. McDowd & Filion, 1992). However, while there appears to be a reasonably high degree of consensus for the interpretation of inhibition across the

behavioral paradigms for both modalities and corroborating evidence for suppression or inhibition in auditory physiological paradigms such as ERP studies, physiological suppression visual ERP studies has been slower in forthcoming. To wit, while the Smid et al (1997) study unequivocally demonstrated SNs for attended features relative to their unattended counterparts, the Wijers et al (1997) study indicated only a small suppression of the P1. Perhaps the issue of active suppression of visual non-targets could be elucidated in an ERP study employing RSVP tasks.

It is notable that, while rapid presentation paradigms are commonplace in auditory ERP studies (i.e. the typical "oddball" task is a rapid presentation technique), these procedures are uncommon in visual ERP studies. To date, only one ERP study has been done with an RSVP task. Luck, Vogel and Shapiro (1996) recorded ERPs during a semantic RSVP task. Targets were same digit strings of numbers, distractors were random letter strings and probes were words. The task was to indicate whether the digit strings were odd or even, and then to determine whether the probe word was semantically related or unrelated to a context word which was presented for 1000 ms prior to the RSVP stream. Luck et al (1996) found no evidence of early attention component enhancements (i.e. N1, P1, N2, P2) and no evidence of suppression for the unattended stimuli. The only effects found were for semantically unrelated word as measured by differences in the N400 components between related and unrelated words. Consistent with Shapiro et al's (1992b) interpretation of the attentional blink as a late-selection phenomenon, Luck et al (1996) interpreted their overall ERP findings as reflecting a "postperceptual loss of information...that was not caused by a suppression in perceptual

processing" (p. 618). An important point worth mentioning is that Luck et al (1996) note

that their results are inconsistent with the results from spatial attention experiments and

these authors further suggested the independence of perceptual and postperceptual

attentional processes i.e., early and late selective attention processes.

The implication of Luck et al's (1996) suggestion is that inhibition may not be

expressed in semantic or late-selection phenomenon. This view is incompatible with the

negative priming literature that finds inhibition at the perceptual level (e.g. Treisman &

DeSchepper, 1994; Neill, 1991) *and* at the postperceptual or semantic level (e.g. Tipper,

1985; Yee, 1991). Moreover, the lack of amplitude enhancements in the early

components of the ERPs to the target digits in the Luck et al (1996) study, is inconsistent

with Wijers et al (1997) study who found N1 and P1 enhancements to their target letter

stimuli. It seems unlikely that target letters would elicit an enhanced N1 and target digits

would not. Luck et al's (1996) results are also partly inconsistent with Koyama,

Hokama, Miyatani, Ogura, Nageishi and Shinokochi (1994) who used a semantically

related vs. unrelated vs. non-word task, very similar to the Luck et al (1996) study.

Consistent with Luck et al (1996), Koyama et al (1994) report N400 differences to

semantic mismatches, however, in addition, they also report P200 differences, as do

Gunter, Stowe and Mulder (1997) in another, similar study. It may be that different

methodological issues in the Luck et al study (1996) contributed to their findings,

however, since the study was published in <u>Nature</u> where methods sections are very brief

and the resulting ERP waveforms were not shown, it is difficult to evaluate this

speculation. In any event, replication of the Luck et al (1996) study seems prudent.

Age Differences in Auditory and Visual ABs

The third goal of this study was to investigate whether age differences exist in AB

tasks and whether the performance of older adults would elucidate the selective attention

processes governing the attentional blink. Specifically, it was predicted that if older

adults did have an inhibitory deficit, then this would be reflected in better target-probe

detection accuracy on the AB tasks. Further, if better performance was found, this in turn

would provide additional support for an early selection model of attention in the tasks

used in this experiment, according to the Shapiro et al (1992a; 1992b) models. As can be

seen in the auditory and visual AB tasks, the performance of older adults is worse, not

better, in both modalities. Further, statistical analyses indicate that older adults'

performance was significantly poorer at SOAs of 90 through 450 ms on the auditory task,

and at SOAs of 90 through 270 ms on the visual task, relative to that of younger adults.

The finding of significantly poorer performance on the part of older adults relative

to younger adults suggests two possible interpretations: either the tasks in this

experiment are not inhibitory tasks or older adults do not have an inhibitory deficit. As

discussed in the previous section, these tasks do appear to reflect inhibitory processes in

general, and attentional inhibition in particular. Given this tenable support for attentional

inhibition then, it would appear that older adults may not suffer from an inhibitory deficit.

Despite the fact that many studies have reported inhibitory deficits in older

populations (e.g. Hasher et al, 1991; McDowd & Filion, 1992; Stoltzfus et al, 1993;

Tipper, 1991), not all studies have found the inhibitory deficit effect (Kramer et al, 1994;

Kane et al, 1994; McArthur, 1996; Sullivan & Faust, 1993; Sullivan et al, 1995;). In the

current study, the lack of an inhibitory deficit is inferred from two separate

measurements. First, older adults' target-probe detection accuracy is poorer on both the

auditory and the visual AB task, relative to younger adults. Second, performance in the

visual Ignore-target control condition did not differ from the single task control

condition, suggesting that older adults did not experience any additional problems in

overtly ignoring stimuli, relative to when stimuli are not ignored, even though the older

adults' single task control condition was poorer relative to that of younger adults. With

respect to AB research and aging, McArthur (1996) did not find single-task (control)

condition differences between her younger and older adults on her visual AB task and

thus, her results and the results of this study are inconsistent. Control condition

differences, at least in the auditory task, are consistent with Slawinski and Scharf (1998)

who found baseline (control) condition differences, but did not find any evidence that

their older adults were any more "distracted" than their younger adults.

The results from the older adults' performance on the dual-task conditions are

consistent with McArthur (1996) who found poorer performance for older adults

compared to younger adults on a visual AB letters task. However, the McArthur (1996)

study also included a) a negative priming task, which showed equivalent negative

priming for older adults and b) a Stroop interference task, which showed increased

interference for the older adults. Taken together, she concluded that older adults did not

demonstrate an inhibitory deficit, but since they showed increased interference and

poorer performance on the AB, she suggested that the latter most likely reflected

increased interference on the AB task and thus supported the late-selection model of the AB.

The interference measure from the visual AB task in the present study suggests that interference is not a significant contributor to the present visual AB effect. One reason for what was presumed to be increased interference in the McArthur (1996) AB task, is that the task itself is designed to elicit a Yes/No response to the target and a typed-in letter response to the probe, where targets are present on half the trials and probes are present on all trials. Thus, participants knew that the probe was always present, and if they were not sure of its identity, they could guess. In essence, the task is set up to test for interference but not for inhibition, since there is no way to indicate an "I didn't see it" answer.

Interference aside, the problem of explaining what appears to be *stronger* inhibition, as evidence by older adults' poorer performance on the AB tasks, is problematic. The finding of stronger inhibition on the part of older adults is unprecedented in the literature and it is not clear how it can be accounted for within any existing inhibition-based theoretical framework. Inhibitory deficit models (e.g. Hasher & Zacks, 1988; McDowd & Filion, 1992) can account for weaker inhibitory mechanisms or equivalent inhibitory mechanisms but there is no allowance for "stronger" inhibitory mechanisms. It seems that it will be necessary to look outside of the inhibitory framework to account for the observed performance of older adults in this study.

One distinct possibility arising from this line of reasoning is that rapid serial presentation tasks measure more than simple inhibition. In particular, it is reasonable to

infer that they also measure on-line processing and if this is so, then clearly speed of processing factors play an important role in accounting for performance in any speeded or rapidly presented task, including the AB. Indeed, with respect to speed of processing, it is interesting to note that Bowles (1994) when attempting to simulate the observed inhibitory deficits of older adults (e.g. Hasher & Zacks, 1988) within a computer connectionist model, had to invoke "across-the-board reductions in processing rates" (p. 427). Specifically, Bowles had to reduce the rate of activation, delay the rate of decay of activation, and delay the rate at which inhibition was overcome. Ironically, there were no reductions to the amount of inhibition *per se*. Moreover, Bowles' (1994) computer model has some support from independent ERP studies which show that evoked components (i.e. P1, N1, P2, N2, P3) are frequently of lesser amplitudes (reduced rate of activation) and have longer onset latencies (delay in the rate of activation) relative to those of younger adults (see Polich, 1996, for a review).

There is abundant literature documenting speed-of-processing decreases in older adults (see Salthouse, 1985, for a review) from simple reaction times to complex cognitive tasks such as Stroop tasks and the Digit Symbol Substitution task. The latter task is a component of the Weschler Adult Intelligence Scale and is widely accepted measure of perceptual speed. Perceptual speed slowing is important because it occurs at the initial stages of information processing and affects all stages occurring thereafter, most, if not all of which rely on transformations or end products from previous stages, resulting in additive slowing from every stage (Salthouse & Meinze, 1995).

With respect to the Digit Symbol, it may be useful to briefly describe this task since speed of perceptual processing is relevant to the present discussion. In the first part of this task, participants copy simple shapes into empty boxes and the timing of this task establishes a baseline perceptual-motor measure. In the second part of the task, numbers are located on top of the empty boxes and correspond to a key – where each number matches a particular shape – and participants again copy the shape corresponding to the number into the empty boxes (see Appendix). Both parts of the task are timed and the difference between the first and second parts of the task (difference scores) is thought to reflect "on-line" processing times. It has been found that older adults have increased baseline times (i.e., slower perceptual-motor speed) relative to younger adults, and in addition, the older adults' difference scores indicate a disproportionate slowing compared to the difference scores of younger adults (Albert, Duffy & Naeser, 1987; Flicker, Ferris & Reisberg, 1993; LaRue, O'Hara, Matsuyama & Jarvik, 1995; Pederson, Plomin, Nesselroade & McClearn, 1992; also see Salthouse, 1985; Salthouse & Meinze, 1995).

While responses in AB tasks, in general, are not timed, the results from these rapid tasks ultimately provide a measure of information-processing per unit of time, not unlike the Digit Symbol Task. In this respect, an explanation of the results from the AB tasks may have the same basis as the results from the Digit Symbol task. In particular, older adults' performance in the single-task condition is poorer than that of younger adults. Further, in the dual-task condition, the performance of older adults is differentially impaired, relative to the single-task situation and to the performance of younger adults in the dual-task condition. Although a perceptual speed measure was not

obtained in the current study, it remains plausible that slower processing of the part of older adults also contributed to the observed performance decrements. Some support, albeit indirect, for speed factors in the AB comes from a previous study conducted in the laboratory with a congenitally blind population (Goddard, Isaak & Slawinski, 1998) using the identical auditory task as was used in this study. Goddard et al. (1998) found that their blind participants had significantly better target-probe detection accuracy at 90 ms relative to the normal-vision younger adults. These authors argued that the congenitally blind had enhanced attentional allocation abilities which led to enhanced temporal processing (i.e. speed) abilities. Future studies in the area of cognitive aging might consider incorporating a number of different measures in order to assess the relative contributions of other factors to performance in general. It might also be beneficial to manipulate the presentation rates (e.g., the stimulus duration and/or the ISI) in these rapid tasks for older adults to determine at what rate of presentation AB is equal to that of younger adults. This could similarly be done in the single task situation to determine at which rate of presentation single-task performance is equivalent for younger and older adults. To the extent that speed of processing differentially affects dual task performance for older adults, presentation rates should differ for both the single-task and the dual-task condition. Further, if speed-of-processing – rather than an inhibitory deficit – is, indeed, the dominant factor responsible for producing older adults' increased AB magnitudes, then allowing more dual-task processing time for older adults (i.e. increasing the presentation rate) should mediate the AB magnitude.

Conclusions

In conclusion, this study demonstrated the existence of both an auditory and a visual attentional blink using simple stimuli. Although visual ABs are well documented with a variety of stimuli and experimental manipulations, previously demonstrated auditory ABs are ambiguous in that they may not reflect a pure auditory phenomenon. The finding of an auditory AB with pure tone frequencies establishes that the auditory modality has been successfully isolated from potential visual effects.

The second major finding of this study is that the auditory and visual ABs in this study support an early selection model of attention. Evidence for this conclusion comes from two findings. First, target-probe detection accuracy was significantly impaired in the dual-task condition in both the auditory and the visual task at all early SOAs. Second, target-probe identification measures did not differ significantly from target-probe detection measures in the visual task, suggesting that interference did not underlie target-probe impairments in the dual-task condition; rather, suppression of attention to the probe and its subsequent processing was responsible for the impairment. Of note is that this second finding also supports the dissociation between interference and inhibition, similar to what Neill (1977) and Neill and Westbury (1987) claim.

Relatedly, the differences in magnitudes between the auditory and visual ABs suggests that different attentional processes govern audition and vision, at least at the early stages of information processing. This conclusion is underscored by a lack of significant correlations between performance on the visual AB versus performance on the auditory AB.

Finally, this study revealed age differences in the magnitudes of the ABs between younger and older adults. However, because AB magnitudes were greater for older adults relative to younger adults, this study failed to find support for the Inhibitory Deficit Model of Hasher and Zacks (1988). We have speculated that speed of processing is an additional variable that may be critically important in rapid serial presentation tasks and in particular, for the dual-task condition.

REFERENCES

Ahlo, K., Sams, M., Paavilainen, P., Reinikainen, K., & Naatanen, R. (1989). Event related potentials reflecting processing of relevant and irrelevant stimuli during selective listening. Psychophysiology, 26, 514-528.

Ahlo, K. Woods, D.L. & Algazi, A. (1994). Processing of auditory stimuli and visual attention as revealed by event-related potentials. Psychophysiology, 31, 469-479.

Alain, C. & Woods, D.L. (1994). Attention modulates auditory pattern memory as indexed by event-related brain potentials. Psycholphysiology, 34, 534-546.

Albert, M.S., Duffy, F.H. & Naeser, M. (1987). Nonlinear changes in cognition with age and their neuropsychologic correlates. Special Issue: Aging and Cognition. [Abstract]. Canadian Journal of Psychology, 41, 141-157.

Banks, W.P., Roberts, D. & Ciranni, M. (1995). Negative priming in auditory attention. Journal of Experimental Psychology: Human Perception and Performance, 21, 1354-1361.

Bashinski, H.S. & Bacharach, V.R. (1980). Enhancement of perceptual sensitivity as the result of selectively attending to spatial locations. Perception and Psychophysics. 28, 241-248.

Bjorklund, D.F. & Harnishfeger, K.K. (1990). The resources construct in cognitive development: Diverse sources of evidence and a theory of inefficient inhibition. Developmental Review, 1, 48-71.

Bowles, N. L. (1994). Age and rate of activation in semantic memory. Psychology and Aging, 9, 414-429.

Broadbent, D.E. (1954). The role of auditory localization and attention in memory spans. Journal of Experimental Psychology, 47, 191-196.

Broadbent, D.E. (1962). Attention and the perception of speech. Scientific Amercian. 206, 143-151.

Broadbent, D.E. & Broadbent, M.H.P. (1987). From detection to identification: Response to multiple targets in rapid serial visual presentation. Perception and Psychophysics, 42, 105-113.

Buchtel, H.A., Butter, C.M. & Ayvasik, B. (1996). Effects of stimulus source and intensity on covert orientation to auditory stimuli. Neuropsychologia, 34, 979-985.

Cherry, C. (1953). Some experiments on the recognition with one and with two ears. Journal of the Acoustical Society of America, 25, 975-979.

Chun, M.E. & Potter, M.C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. Journal of Experimental Psychology: Human Perception and Performance, 21, 109-137.

Cohn, N.B., Dustman, R.E. & Bradford, D.C. (1984). Age-related decrements in Stroop color test performance. Journal of Clinical Psychology, 40, 1244-1250.

Corballis, M.C. (1996) Hemispheric interactions in temporal judgments about spatially separated stimuli. Neuropsychology, 10, 42-50.

Craik, F.I.M. & Salthouse, T.A. (1992). Handbook of Aging and Cognition. Hillsdale, New Jersey: Erlbaum.

Dempster, F.N. (1991). Inhibitory processes: A neglected dimension of intelligence. Intelligence, 15, 157-173.

Dempster, F.N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. Developmental Review, 12, 45-75.

Deutsch, J.A. & Deutsch, D. (1963). Attention: Some theoretical considerations. Psychological Review. 70, 80-90.

Deutsch, J.A. & Deutsch, D. (1967). Comments on selective attention: Perception or response? Quarterly Journal of Experimental Psychology, 19, 362-363.

Downing, C.J. (1988). Expectancy and visual-spatial attention: Effects on perceptual quality. Journal of Experimental Psychology: Human Perception and Performance, 14, 188-202.

Driver, J. & Baylis, G.C. (1993). Cross-modal negative priming and interference in selective attention. Bulletin of the Psychonomic Society, 31, 45-48.

Duncan, J., Martens, S. & Ward, R. (1997). Restricted attentional capacity within but not between sensory modalities. Nature, 379, 808-810.

Dulaney, C.L. & Rogers, W.A. (1994). Mechanisms underlying reduction in Stroop interference with practice for young and old adults. Journal of Experimental Psychology: Learning, Memory and Cognition, 20, 470-484.

Eason, R.G. (1981). Visual evoked potentials correlates of early neural filtering during selective attention. Bulletin of the Psychonomic Society, 18, 203-206.

Eimer, M. (1997). Attentional selection and attentional gradients: An alternative method for studying transient visual-spatial attention. Psychophysiology, 34, 365-376.

Eimer, M. & Schroeger, E. (1998). ERP effects of intermodal attention and cross-modal links in spatial attention. Psychophysiology, 35, 313-327.

Filion, D.L., Dawson, M.E. & Schell, A.M. (1993). Modification of the acoustic startle-reflex eyeblink: A tool for investigating early and late attentional processes. Biological Psychology, 35, 185-200.

Filion, D.L., Dawson, M.E. & Schell, A.M. (1994). Probing the orienting response with startle modification and secondary reaction time. Psychophysiology, 31, 68-78.

Flicker, C., Ferris, S. & Reisbert, B. (1993). A two-year longitudinal study of cognitive function in normal aging and Alzheimer's disease. [Abstract]. Journal of Geriatric Psychiatry, 6, 84.96

Goddard, K.M., Isaak, M.I. & Slawinski, E.B. (1998). The auditory attentional blink in a congenitally blind population. Journal of the Acoustical Society of America. Conference Proceedings, June 1998. Seattle, WA.

Graham, F.K. (1975). The more or less startling effects of weak prestimulation. Psychophysiology, 12, 238-248.

Greenwald, A.G. (1972). Evidence of both perceptual filtering and response suppression for rejected messages in selective attention. Journal of Experimental Psychology, 94, 58-67.

Grice, G.R., Nullmeyer, R. & Schnizlein, J.M. (1979). Variable criterion analysis of brightness effects in simple reaction time. Journal of Experimental Psychology: Human Perception and Performance, 5, 303-314.

Grose, J.H. & Hall, J.W. 3rd. (1996). Perceptual organization of sequential stimuli in listeners with cochlear hearing loss. Journal of Speech & Hearing Research, 39, 1149-1158.

Gunter, T.C., Stowe, L.A. & Mulder, G. (1997). When syntax meets semantics. Psychophysiology, 34, 660-676.

Harbin, T.J. & Berg, W.K. (1983). The effects of age and prestimulus duration on reflex inhibition. Psychophysiology, 20, 603-610.

Hasher, L. & Zacks, R.T. (1988). Working memory, comprehension and aging: A review and a new view. In G.H. Bower (Ed.), The Psychology of Learning and Motivation: Advances in Research and Theory (Volume 22, pp. 193-224). San Diego: Academic Press.

Hasher, L. Stoltzfus, E.R., Zacks, R.T., & Rypma, B. (1991). Age and inhibition. Journal of Experimental Psychology: Learning, Memory and Cognition. 17, 163-169.

Hillyard, S.A., Hink, R.F., Schwent, V.L. & Picton, R.W. (1973). Electrical signs of selective attention in the brain. Science, 182, 177-180.

Hoffman, H.S. & Ison, J.R. (1980). Reflex modification in the domain of startle: 1. Some empirical findings and their implications for how the nervous system processes sensory input. Psychological Review, 87, 175-189.

Houghton, G. & Tipper, S.P. (1994). Inhibitory mechanisms in selective attention. In D. Dagenbach & T.H. Carr (Eds.) Inhibitory Processes in Attention, Memory and Langauge (pp. 53 – 112). San Diego: Academic Press.

Isaak, M.I., Martin, J., & Shapiro, K.L. (1995). Probe identification errors support an interference model of the attentional blink. Poster presented at the Seventh Annual Meeting of the American Psychological Society, New York, NY. July 1995.

Isaak, M.I. & Shapiro, K.L. (1998). Visual Short Term Memory Load Effects in RSVP: The attentional blink reflects competition among probe candidates. Journal of Experimental Psychology: Human Perception and Performance. (in press)

Jennings, P.D., Schell, A.M., Filion, D.L. & Dawson, M.E. (1996). Tracking early and late states of information processing: Contributions of startle eyeblink reflex modification. Psychophysiology, 33, 148-155.

Kane, M.J., Hasher, L., Stoltzfus, E.R., Zacks, R.T. & Connelly, S.L. (1994). Inhibitory attentional mechanisms and aging. Psychology and Aging, 9, 103-112.

Kenemans, J.L., Kok, A. & Smulders, F.T.Y. (1993). Event-related potentials to conjunctions of spatial frequency and orientation as a function of stimulus parameters and response requirements. Electyroencephalography and Clinical Neurophysiology, 88, 51-63.

Klein, S.K., Kurtzberg, D., Brattson, A., Kreuzer, J.A., Stapells, D.R., Dunn, M.A., Rapin, I. & Vaughan, Jr., J.G. (1995). Electrophysiologic manifestations of impaired temporal lobe auditory processing in verbal auditory agnosia. Brain and Language, 51, 383-405.

Klein, R.M. & Taylor, T.L. (1994). Categories of attentional inhibition. In D. Dagenbach and T.H. Carr (Eds.) Inhibitory Processes in Attention, Memory and Langauge. San Diego: Academic Press.

Koyama, S., Hokama, H., Miyatani, M., Ogura, C., Nageishi, Y., & Shimokochi, M. (1994). ERPs in schizophrenic patients during word recognition task and reaction times. Electroencephalography and Clinical Neurophysiology, 92, 546-554.

Kramer, A.F., Humphrey, D.G., Larish, J.F., Logan, G.D. & Strayer, D.L. (1994). Aging and Inhibition: Beyond a unitary view of inhibitory processing in attention. Psychology and Aging, 10, 458-468.

LaRue, A., O'Hara, R., Matsuyama, S. & Jarvik, L. (1995). Cognitive changes in young-old adults: Effects of family history dementia. [Abstract]. Journal of Clinical and Experimental Neuropsychology, 17, 63-70.

Lipp, O.V., Arnold, S.L., Siddle, D.T., & Dawson, M.E. (1994). The effect of repeated prepulse-blink reflex trials on blink reflex modulation at short lead intervals. Biological Psychology, 38, 19-36.

Lowe, D.G. (1985). Further investigations of inhibitory mechanisms in attention. Memory and Cognition, 13, 74-80.

Luck, S.J., Heinze, H.J., Mangun, G.R. & Hillyard, S.A. (1990). Visual event-related potentials index focused attention within bilateral stimulus arrays. II. Functional dissociation of P1 and N1 components. Electroencephalography and Clinical Neurophysiology, 75, 528-542.

Luck, S.J., Hillyard, S.A., Mouloua, M. Woldorff, M.G., Clark, V.P., & Hawkins, H.L. (1994). Effects of spatial cueing on luminance detectability: Psychlophysical and electrophysiological evidence for early selection. Journal of Experimental Psychology: Human Perception and Performance. 20, 887-904,

Luck, S.A., Vogel, E.K., & Shapiro, K.L. Word Meanings can be accessed but not reported during the attentional blink. Nature. 383, 616-618.

MacLeod, C.M. (1991). Half a century of research on the Stroop effect: An integrative review. Psychological Bulletin, 109, 169-203.

Maki, W.S., Frigen, K. & Paulson, K. (1995). Effects of semantic relations on the attentional blink [Abstract] *Proceedings of the 34th Annual Meeting of the Psychonomic Society*, p.1.

Maki, W.S., Frigen, K. & Paulson, K. (1997). Associative priming by targets and distractors during rapid serial visual presentation: does word meaning survive the attentional blink? Journal of Experimental Psychology: Human Perception and Peformance, 23, 1014-1034.

McArthur, A.D. (1996). Inhibitory mechanisms, interference and the attentional blink in younger and older adults. Unpublished Master's Thesis University of Calgary, Calgary, AB.

McDowd, J.M. (1997). Inhibition in attention and aging. Journal of Gerontology: Psychological Sciences. 52B, P265-P274.

McDowd, J.M., Filion, D.L., Harris, M.J. & Braff, D.L. (1993). Sensory gating and inhibitory function in late-life schizophrenia. Schizophrenia Bulletin, 19, 733-746.

McDowd, J.M. & Oseas-Kreger, D.M. (1991). Aging, inhibitory processes and negative priming. Journal of Gerontology, 46, 340-345.

McEvoy, L., Levanen, S. & Loveless, N. (1997). Temporal characteristics of auditory sensory memory: Neuromagnetic evidence. Psychophysiology, 34, 308-316.

McGurk, H. & MacDonald, J. (1976). Hearing lips and seeing voices. Nature, 264, 746-748.

Muller, H.J. & Findlay, J.F. (1987). Sensitivity and criterion effects in the spatial cueing of visual attention. Perception and Psychophysics, 42, 383-399.

Naatanen, R. (1990). The role of attention in auditory information processing as revealed by event-related potentials and other brain measures of cognitive function. Behavioral and Brain Sciences, 13, 201-233.

Naatanen, R. (1995). The Mismatch Negativity: A Powerful Tool for Cognitive Neuroscience. Ear and Hearing, 16, 1-18.

Naatanen, R., Paavilainen, P., Tiitinen, J., Jiang, D. &Alho, K. (1993a). Attention and mismatch negativity. Psychophysiology, 30, 436-450.

Neill, W.T. (1977). Inhibitory and facilitory processes in selective attention. Journal of Experimental Psychology: Human Perception and Performance, 3, 444-450.

Neill, W.T. (1991). Journal of Experimental Psychology: Human Perception and Performance, 3, 444-450.

Neill, W.T., Lissner, L.S. & Beck, J.L. (1990). Negative priming in same-different matching: Further evidence for a central locus of inhibition. Perception and Psychophysics, 48, 398-400.

Neill, W.T., Valdes, L.A. & Terry, K.M. (1995). Selective attention and the inhibitory control of cognition. In Dempster & Brainerd (Eds.) Interference and Inhibition in Cognition. San Diego: Academic Press

Neill, W.T. & Westbury, R.L. (1987). Selective attention and the suppression of cognitive noise. Journal of Experimental Psychology: Learning, Memory and Cognition, 13, 327-334.

Neumann, E. & DeSchepper, B.G. (1991). Costs and benefits of target activation and distractor inhibition in selective attention. Journal of Experimental Psychology: Learning, Memory and Cognition, 17, 1136-1145.

Neumann, E. & DeSchepper, B.G. (1992). An inhibition-based fan effect: Evidence for an active suppression mechanism in selective attention. Canadian Journal of Experimental Psychology, 33, 33-48.

Olson, S.L. (1989). Assessment of impulsivity in preschoolers: Cross-measure convergencies, longitudinal stability, and relevance to social competence. Journal of Clinical Child Psychology, 18, 176-183.

Paavilainen, P., Tiitinen, H. Alho, K. & Naatanen, R. (1993). Mismatch negaitvity to slight pitch changes outside strong attentional focus. Biological Psychology, 37, 23-41.

Pederson, N., Plomin, R., Nesselroade, J. & McClearn. G. (1992). A quantitative genetic analysis of cognitive abilities during the second half of the lifespan. [Abstract]. Pscyhological Science, 3, 346-353.

Plude, D.J. & Doussard-Roosevelt, J.A. (1989). Aging, selective attention and feature integration. Psychology and Aging, 4, 98-105.

Polich, J. (1996). Meta-analyses of P300 normative aging studies. Psychophysiology, 33, 334-353.

Polich, J., Eischen, S.E. & Collins, G.E. (1994). P300 from a single auditory stimulus. Electroencephalography and Clinical Neurophysiology, 92, 253-251.

Posner, M.I. (1980). Orienting of attention. Quarterly Journal of Experimental Psychology. 32, 3-25.

Posner, M.I., Snyder, C.R.R. & Davidson, B.J. (1980). Attention and the detection of signals. Journal of Experimental Psychology: General. 109, 160-174.

Potter, M.C., & Chun, M.M. (1995). Auditory attention does not blink. Poster presented at the 36th Annual Meeting of the Psychonomic Society, Los Angeles, CA. November 1995.

Rafal, R. & Henyk, A. (1994). Neurology of inhibition. In D. Dagenbach and T.H. Carr (Eds.) Inhibitory Processes in Attention, Memory and Language (pp.1 - 52). San Diego: Academic Press.

Raymond, J.E., Shapiro, K.L. & Arnell, K.M. (1992a). Temporary suppression of visual processing in an RSVP task: An attentional blink? Journal of Experimental Psychology: Human Perception and Performance, 18, 849-860.

Raymond, J.E., Shapiro, K.L. & Arnell, K.M. (1992b). The role of post-target stimulation in producing "attentional blinks: in RSVP. International Journal of Psychology, 27 (3 & 4), 44.

Salthouse, T.A. (1985). Speed of behavior and its implication for cognition. In J.E. Birren & K.W. Schaie (Eds.), Handbook of Psychology and Aging (2nd Ed., pp. 400-426). New York: Van Nostrand Reinhold.

Salthouse, T.A. & Meinze, E.J. (1995). Aging, inhibition, working memory and speed. Journal of Gerontology: Psychological Sciences, 50B, P297-P306.

Scheiber, F. & Kline, D.W. (1982). Age and the discrimination of visual successiveness. Experimental Aging Research, 8, 159-161.

Schooler, C., Neumann, E., Caplan, L.J. & Roberts, R.R. (1997). A time course analysis of Stroop interference and facilitation: Comparing normal individuals and individuals with Schizophrenia. Journal of Experimental Psychology: General, 126, 19-36.

Schroger, E. (1997). On the detection of auditory deviations: A pre-attentive activation model. Psychophysiology, 34, 245-257.

Shapiro, K.L., Driver, J., Ward, R., & Sorenson, R.E. (1995). Priming and the attentional blink: A failure to extract visual tokens, but not visual types. Psychological Science, 8, 95-100.

Shapiro, K.L. & Raymond, J.E. (1994). Temporal allocation of visual attention: Inhibition of interference? In D.Dagenbach & T.H. Carr (Eds), Inhibitory mechanisms in attention memory, and language. New York: Academic Press.

Shulman, H. & Hsieh, V. The attention blink in mixed modality streams. Paper presented at 36th Annual Meeting of the Psychonomic Society. Los Angeles, CA. November 1995.

Slawinski, E.B. & Scharf, B. (1998). Effects of tonal masker uncertainty on detection. Journal of the Acoustical Society of America. Conference Proceedings, June 1998. Seattle, WA.

Smid, H.O., Jakob, A. & Heinze, H.J. (1997). The organization of multidimensional selection on the basis of color and shape: An event-related brain potential study. Perception and Psychophysics, 59, 693-713.

Stoltzfus, E.R., Hasher, L., Zacks, R.T., Ulivi, M.S. and Goldstein, D. (1993). Investigatons of inhibition and interferce in younger and older adults. Journal of Gerontology: Psychological Sciences, 48B, P179-P188.

Sugg, M.J. & McDonald, J.E. (1994). Time course of inhibition in color-response and word-response versions of the Stroop task. Journal of Exprimental Psychology, 20, 647-675.

Sullivan , M.P. & Faust, M.E. (1993). Evidence for identity inhibition during selective attention in old adults. Psychology and Aging, 8, 589-598.

Sullivan, M..P., Faust, M.E. & Balota, D. (1995). Identity negative priming in old adults and individuals with dementia of the Alzheimer's type. Neuropsychology, 9, 537-555.

Swerdlow, N.R., Lipska, B.K., Weinberger , D.R., Jaskiw, G.E. & Geyer, M.A. (1995). Increased sensitivity to the sensorimotor gating-disruptive effects of apomorphine after lesions of medial prefontal cortex or ventral hippocampus in adult rats. Psychopharmacology, 122, 27-34.

Tipper, S.P. (1985). The negative priming effect: Inhibitory effects of ignored primes. Quarterly Journal of Experimental Psychology, 37A, 571-590.

Tipper, S.P. (1991). Less attentional selectivity as a results of declining inhibition. Bulletin of the Psychonomic Society, 29, 45-47.

Tipper, S.P. & Baylis, G.C. (1987). Individual differences in selective attention: The relation of priming and interference to cognitive failure. Personality and Individual Differences, 8, 667-675.

Tipper, S.P., Brehaut, J.C. & Driver, J. (1990). Selection of moving and static objects for the control of spatially directed action. Journal of Experimental Psychology: Human Perception and Performance, 18, 891-905.

Tipper, S.P., Bourke, T.A., Anderson, S.H. & Brehaut, J. (1989). Mechanisms of attention: A developmental study. Journal of Experimental Child Psychology, 47, 353-378.

Tipper, S.P. & Cranston, M. (1985). Selective attention and priming: Inhibitory and facilitory effects of ignored primes. Quarterly Journal of Experimental Psychology, 37A, 591-611.

Treisman, A.M. & Gelade, G. (1980). A feature-integration theory of attention. Cognitive Psychology, 12, 97-136.

Treisman, A.M. & DeSchepper, B. (1994) Object tokens, attention and visual memory. Paper presented at Attention and Performance Conference, Kyoto, Japan. July 1994.

Trejo, L.J., Ryan-Jones, D.L. & Kramer, A.F. (1995). Attentional modulation of the mismatch negativity elicited by frequency differences between binaurally presented tone bursts. Psychophysiology, 32, 319-328.

Tsotsos, J.K. (1997). Limited capacity of any realizable perceptual system is a sufficient reason for attentive behavior. [Abstract]. Consciousness and Cognition, 6, 429-436.

Vander, A.J., Sherman, J.H. & Luciano, D.S. (1994). Human Physiology. New York: McGraw-Hill.

Van der Stelt, O., Kok, A., Smulders, F.T., Snel, J. & Boudewijn-Gunning, W. Cerebral event-related potentials associated with selective attention to color: developmental changes from childhood to adulthood. Psychophysiology, 35, 227-239.

Van Selst, M. & Jolicouer, P. (1997). Decision and response in dual-task interference. Cognitive Psychology, 33, 266-307.

Viemeister, N.F. & Plack, C.J. (1993). Time analysis. In W.A. Yost, A.N. Popper and R.R. Fay (Eds) Human Psychophysics. New York, Springer-Verlag.

Ward, R., Duncan, J. & Shapiro, K. (1997). Effects of similarity, difficulty and nontarget presentation on the time course of visual attention. Perception and Psychophysics, 59, 593-600.

Watson, C.S., Lehman, J.R. & Kelly, W.J. (1981). Detection between sensation level and frequency discrimination under conditions of informational masking. Journal of the Acoustical Society of America. Supplement 1, 69, S.64.

Watson, C.S., Wroton, H.W., Kelly, W.J. & Benbosset, C.A. (1975). Factors in the discrimination of tonal differences. 1. Component frequency, temporal position and silent intervals. Journal of the Acoustical Society of America, 57, 1175-1185.

Wijers, A.A., Lange, J.J. Mulder, G. & Mulder, L.J.M. (1997). An ERP study of visual spatial attention and letter target detection for isoluminant and nonisoluminant stimuli. Psychophysiology. 34, 553-565.

Wijers, A.A., Mulder, G., Okita, T. & Mulder, L.J.M. (1989). Event-related potentials during memory search and selective attention to letter size and conjunctions of letter size and color. Psychophysiology, 26, 529-547.

Woldorff, M. & Hillyard, S.A. (1991). Modulation of early auditory processing during selective listening to rapidly presented tones. Electroencephalography and Clinical Neurophysiology, 79, 170-191.

Woldorff, M.G., Hackley, S.A. & Hillyard, S.A. (1991). The effect of channel selective listening on the mismatch negativity wave elicited by deviant tones. Psychophysiology, 28, 30-42.

Woldorff, M.G., Gallen, C.C., Hampson, S.R., Hillyard, S.A., Pantev, C., Sobel, D. & Bloom, F.E. (1993). Modulation of early sensory processing in human auditory cortex during auditory selective attention. Proceedings of the National Academy of Sciences. U.S.A., 90, 8722-8726.

Woods, D.L., Ahlo, K., & Algazi, A. (1994). Stages of auditory feature conjunction: An event-related brain potential study. Journal of Experimental Psychology: Human Perception and Performance, 20, 81-94.

Yee, P.L. (1991). Semantic inhibition of ignored words during a figure classification task. Quarterly Journal of Experimental Psychology, 43A, 127-153.

Zacks, R.T. & Hasher, L. (1994). Directed ignoring: Inhibitory regulation of working memory. In D.Dagenbach and T.H. Carr (Eds), Inhibitory processes in attention, memory and language. San Diego, CA: Academic Press.

Zacks. R.T. & Hasher, L. (1997). Inhibitory function and aging. Journal of Gerontology: Psychological Sciences. 52B,

Zacks, R.T., Henderson, J.M., Stewart Mangum, r., & Hasher, L. (1994). The attentional blink: Comparison of older and younger adults. Poster presented at the Psychonomics Meeting, St. Louis, MO.

APPENDIX

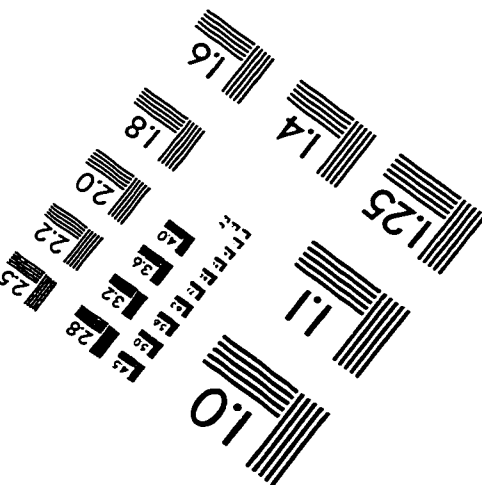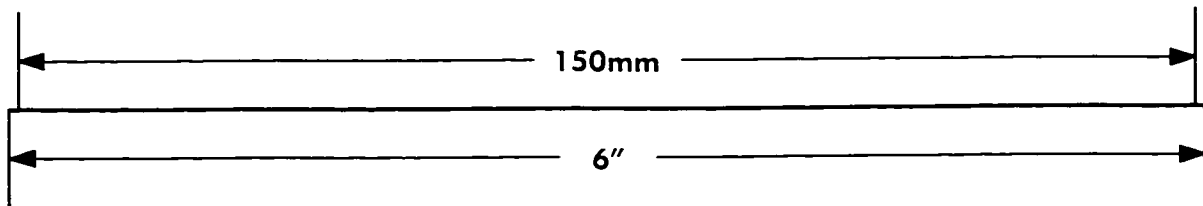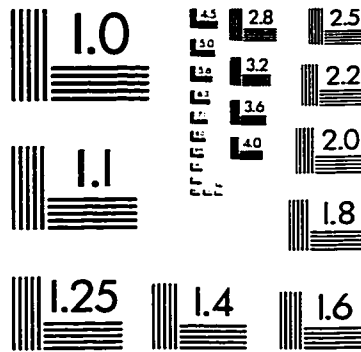**10. DIGIT SYMBOL**

1	2	3	4	5	6	7	8	9	SCORE
—	⊥	⊐	L	⊔	O	∧	X	=	

SAMPLES

2	1	3	7	2	4	8	2	1	3	2	1	4	2	3	5	2	3	1	4	5	6	3	1	4

1	5	4	2	7	6	3	5	7	2	8	5	4	6	3	7	2	8	1	9	5	8	4	7	3

6	2	5	1	9	2	8	3	7	4	6	5	9	4	8	3	7	2	6	1	5	4	6	3	7

9	2	8	1	7	9	4	6	8	5	9	7	1	8	5	2	9	4	8	6	3	7	9	8	6

IMAGE EVALUATION
TEST TARGET (QA-3)

150mm

6"