DIFFERENTIAL EFFECTS OF EVENT RATE AND TEMPORAL EXPECTANCY ON SUSTAINED ATTENTION PERFORMANCE OF ADULTS AND CHILDREN

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This study explored developmental differences in the effects of event rate and temporal expectancy on sustained attention performance. College-age adults and children (ages 7 – 8) completed visual and auditory sustained attention tasks that were equated for difficulty at an intermediate (3 sec IOI) event rate using the perceptual sensitivity index ($d'$) and then were compared at faster (1.5 sec IOI) and slower (6 sec IOI) event rates to determine whether there was an optimal presentation rate for adults and children. In order to explore temporal expectancy, 20% of the critical and neutral events occurred early or late relative to the regular rhythm of the task. The findings (a) suggest that event rate influences sustained attention differently for adults and children, (b) highlight the role of temporal expectancy in sustained attending, and (c) reveal differences in the effects of event rate and temporal expectancy on visual and auditory sustained attention.
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CHAPTER I. INTRODUCTION

Investigations of sustained attention began as early as World War II, when observers failed to detect signals, possible enemy submarines, after extended periods of uneventful monitoring (Davies & Parasuraman, 1982). Today, sustained attention remains a relevant issue in a variety of occupations, including industrial quality control, air traffic control, power plant operation, agricultural machinery operation, long distance driving, and in the medical setting (Warm, 1984). Recently, Hancock and Hart (2002) identified the role sustained attention research may play in improving airport security, including a better understanding of baggage checks. Current research on sustained attention focuses on understanding a variety of factors that affect performance in order to improve productivity and safety in many occupational settings.

Many factors have been shown to affect adult sustained attention performance. Of particular interest in the present study are the factors of event rate and temporal expectancy, both of which relate to the timing of events in a sustained attention task. These factors and many others have often been overlooked in studies with children (Laurie-Rose, Bennett-Murphy, Curtindale, Granger, and Walker, 2005). However, recently, there has been increased interest in investigating the factors that influence sustained attention performance of children. According to the NICHD Early Child Care Research Network (2003) sustained attention and inhibition of impulsive responding play a central role in the classroom and functioning in the world in general. In addition, young children with better attention skills are more likely to be prepared to cope with the demands of school than children with poorer attentional skills (Ballard, 1996; NICHD, 2003). One goal of the present study was to fill in some of the gaps in the sustained attention
literature by comparing the effects of event rate and temporal expectancy on sustained attention performance of children (ages 7 – 8) with adult performance.

Event rate refers to the rate at which events are presented during a sustained attention task. The rate of a task can be described using the number of events presented per minute or the term inter-onset-interval (IOI), which refers to the amount of time between the onset of one event and the onset of the next event. The first aim of this study was to compare the effects of event rate on sustained attention performance of adults and children in visual and auditory tasks. Specifically, how does performance change when stimuli, which have been equated in difficulty across age and modality at an intermediate event rate, are presented at faster or slower rates? Although event rate has been explored in research with adults and children, results have been conflicting. The present study sought to provide a better understanding of the effects of event rate on sustained attention, to help determine if there is a rate at which information can be presented in order to enhance attention abilities. A related aim was to consider the possibility that effects of event rate may depend on whether information is presented in the visual or auditory modality. Also of interest was the role of temporal expectancy.

Temporal expectancy refers to rhythmic expectations that develop when events are presented with no temporal uncertainty. Typically, events in a sustained attention task are presented in a temporally regular (rhythmic) manner. This temporal certainty (expectancy) allows participants to take “time-outs” in observing when an event is not being presented (Scerbo, Warm, Doettling, Parasuraman, & Fisk, 1987a). However, when events are presented irregularly (i.e., with high temporal uncertainty) participants must continually monitor the display (Scerbo, et al., 1987a). Another aim of this project was to explore the effects of violating
temporal expectancy at different event rates and modalities by adding temporally unexpected early and late events to a temporally regular (certain) task.

The remainder of the introduction is in four sections. First, I will describe basic methodology used to assess sustained attention performance. Second, I will review previous research examining the role of event rate in sustained attention performance of adults and children for visual and auditory tasks. Third, I will identify factors that affect sustained attention performance and were controlled in the present study. Finally, I will provide an overview of the present study.

**Basic Methodology**

Sustained attention performance is commonly assessed using what is referred in the literature as a continuous performance task (CPT) (Aylward, Brager, & Harper, 2002). The standard CPT is a go/no-go task where participants experience a temporally extended stream of events including both critical events and neutral (background) events. Critical events require participants to respond, while neutral events require participants to withhold a response. Studies of sustained attention have explored the decline in performance that can occur when participants sustain their attention for an extended period (referred to as a vigilance or sustained attention decrement). Another way to investigate performance, which was used in the present study, is to calculate average performance across the entire task.

Sustained attention studies typically use proportion correct detections (hits) and/or proportion false detections or errors of commission (false alarms) to assess performance. By itself, proportion of correct detections of critical events may not always be directly related to the perceptual ability of the observer (See, Warm, Dember, & Howe, 1997). Rather, an observer’s overall willingness to respond may influence their proportion of hits, as well as their proportion
of false alarms. Therefore, measurements of sustained attention performance use signal
detection theory to separate perceptual sensitivity ($d'$) from response bias ($c$) (Green & Swets,
1966; Macmillan & Creelman, 1991; See, Howe, Warm, & Dember, 1995). Perceptual
sensitivity ($d'$) refers to an observer’s ability to detect changes in stimuli, such as those between
critical and neutral events. Perceptual sensitivity ($d'$) provides an estimate of perceptual ability
that is unaffected by an observer’s willingness to respond (Green & Swets, 1966; Macmillan &
Creelman, 1991; See et al., 1997). A higher $d'$ indicates greater perceptual sensitivity to the
stimulus. Response bias ($c$) assesses a participant’s willingness to make a response. A low $c$
score indicates a willingness to accept false alarms, while a higher score reveals a more
conservative response bias (i.e., a participant’s unwillingness to commit false alarms) (See et al.,
1997). For more detailed information about how $d'$ and $c$ are calculated, refer to Appendix A. In
addition, reaction times (RT) for correct detections are used to assess sustained attention
performance.

Effects of Event Rate

Event rate is one of the most important factors, identified in the taxonomy of vigilance, to
affect adult sustained attention performance (Parasuraman & Davies, 1977). The vigilance
taxonomy is a categorization of tasks based on discrimination type and event rate that was
developed by Parasuraman and Davies (1977) to identify the type of tasks that lead to a decline
in sensitivity over time and those that do not produce a decrement in sustained attention
performance. This and related work has led to a classification of event rates greater than 24
events per minute (2.5 sec IOI) as fast and event rates less than 24 events per minute (2.5 sec
IOI) as slow (Parasuraman & Davies, 1977). Early research on sustained attention suggested that
sustained attention performance is inversely related to event rate (Parasuraman & Davies, 1977).
That is, slow event rates typically produce better overall performance, as measured by correct detections, than fast event rates. In addition, declines in perceptual sensitivity over time, as measured by $d'$, have been shown to be greater for fast event rates than for slow event rates (Davies & Parasuraman, 1982).

In the present study, I will refer to this inverse relationship as a slow event rate advantage. However, when using only two event rates questions arise about whether the inverse relationship is being driven by the slow or fast event rate. The effects of event rate may be due to superior performance at the slow event rate, poor overall performance at the fast event rate or a combination of both. Therefore, the event rate effect may actually be a fast event rate disadvantage, poor performance at the fast event rate, rather than superior performance at the slow event rate. By using an intermediate event rate, this study was able to determine whether there was a slow event rate advantage, a fast event rate disadvantage or if both effects were responsible for the inverse relationship between sustained attention and event rate.

Although the slow event rate advantage has been accepted in the sustained attention literature, this effect has not been sufficiently replicated with children. Several recent studies with adults and children have questioned the slow event rate advantage, reporting superior performance for fast event rates than for slow event rates (Laurie-Rose, Bennett-Murphy, Schickedantz, & Tucci, 2001; Laurie-Rose et al., 2005). In addition, several other studies support the view that sustained attention performance for children is best at an intermediate rate (i.e., one that is neither too fast nor too slow) (Chee, Logan, Schachar, Lindsay, & Wachsmuth, 1989; van der Meere & Stemerdingk, 1999). Studies supporting the slow-rate advantage, fast-rate advantage, and intermediate-rate advantage are reviewed below.
Slow Event Rate Advantage

Jerison and Pickett (1964) conducted one of the first studies exploring the effects of event rate on sustained attention performance. In this study, participants monitored a display continuously for 80 minutes. The stimulus was a bar of light 2 mm wide by 18 mm high. The neutral event was the movement of a bar of light 29 mm to the right, whereas the critical event occurred whenever the bar of light moved a slightly greater distance (e.g., 35 mm). Stimuli were presented at a fast event rate of 30 events per minute (2 sec IOI) and a slow event rate of 5 events per minute (12 sec IOI). Critical events were presented at an average rate of 15 per hour, leading the probability of a critical event to be different for the fast and slow event rates. The probability of a critical event was less than .01 at the fast event rate and .05 at the slow event rate. Overall, the fast event rate yielded poorer performance compared to the slow event rate, with participants detecting fewer critical events at the fast event rate (M = 0.36) than at the slow event rate (M = 0.88).

Deaton and Parasuraman (1993) investigated the effects of event rate and age on sensory and cognitive tasks. Younger, middle-aged, and older adults completed simultaneous sensory and cognitive tasks each with a duration of 32.4 minutes. In the sensory task, participants had to discriminate the physical size of letter pairs. The neutral event was the appearance of two numbers that were of the same physical size. The critical event was the presentation of a number pair in which one number was larger than the other. The same stimuli were used in the cognitive task. To make the task cognitive, participants were asked to respond when an odd and an even number were presented, which was designated the critical event. The neutral event was the appearance of two even or two odd numbers. All stimuli were presented at a one of two event rates, a fast event rate of 40 events per minute (1.5 sec IOI) and a slow event rate of 15 events
per minute (4 sec IOI). At the fast event rate the probability of a critical event was 0.04, while the slow event rate critical event probability was 0.11. In the cognitive task, participants detected fewer critical events at the fast event rate (M = 79.6) than the slow event rate (M = 96.1). However, the effects of event rate were not significant for the sensory task. Participants detected similar proportions of critical events at the fast (M = 83.6) and slow (M = 89.1) event rates. In addition, more false alarms were committed in the sensory task (M = .05) than the cognitive task (M = .006). Deaton and Parasuraman’s (1993) results suggest an interesting relationship between cognitive tasks and event rate. Using a cognitive task alone does not necessarily impose greater demands than a sensory task. However, when combined with the high resource demands of the fast event rate, the cognitive task yielded greater effects of event rate than the sensory task.

In a study of the relationship between the type of task discrimination and event rate, Parasuraman (1979) had participants complete a successive and simultaneous task, each lasting 45 minutes. Stimuli were presented at 30 events per minute (2 sec IOI) or 15 (4 sec IOI) events per minute, fast and slow rates respectively. The critical event in the successive task was a 2.1 dB increase in the intensity of a 1000 Hz tone. In the simultaneous task, the critical event was a 1000 Hz tone presented in a background of noise bursts. The results indicated that the fast event rate decreased the overall detection rate (M = 0.37) compared to the slow event rate (M = 0.66), particularly when the events were presented successively. When events were presented simultaneously, participants detected a similar proportion of critical events (fast = 0.60, slow = 0.63). Similar results were reported for sensitivity scores. When events were presented consecutively, sensitivity scores were significantly lower at the fast event rate (M = 1.93), compared to the slow event rate (M = 2.57). However, when events were presented
simultaneously, sensitivity scores were comparable in the fast (M = 2.52) and slow (M = 2.47) conditions. In a second experiment, visual stimuli were presented at the fast event rate (30 events per minute) for simultaneous and successive tasks. When the results of the visual and auditory successive tasks are compared at the fast event rate, modality differences are observed. Participants detected more critical events in the visual task (M = 0.50) than the auditory task (M = 0.37). This result highlights potential modality differences in the effects of event rate.

Richter, Senter, and Warm (1981) investigated the effects of event rate and event regularity on sustained attention performance. Participants were presented with a 60-minute auditory task and were asked to respond to a 57 dB critical event and make no response to a 54 dB neutral event. Events were presented at 30 events per minute (2 sec IOI) or 5 events per minute (12 sec IOI), and had a regular or irregular event schedule. More critical events were detected in the slow event rate condition (M = 0.82) than the fast event rate condition (M = 0.67). Similarly, significantly more critical events were detected in the regular event schedule (M = 0.79) than when events were presented irregularly (M = 0.69). In addition to differences in hits, response bias scores were higher (i.e. participants were more conservative) for the fast event rate condition (M = 0.33) and the irregular event schedule (M = 0.13) than the slow event rate (M = -0.35) and regular schedule (M = -0.15).

**Fast Event Rate Advantage**

Although previous research has focused on an inverse relationship between performance and event rate, recent studies have reported the opposite result (i.e., sustained attention performance is better at fast event rates than at slow event rates). Laurie-Rose, et al., (2001) reported a fast event rate advantage in a study that explored the role of event rate and probability in sustained attention performance. Children, between the ages of 7 and 8, completed a 16-
minute CPT. The stimuli were black-outlined white squares presented on a white background. The critical event was a small square and the neutral event was a larger square. The stimuli were presented at a fast event rate of 45 events per minute (1.3 sec IOI) and a slow event rate of 10 events per minute (6 sec IOI). The probability of a critical event was either 0.10 in the low probability condition or 0.35 in the high probability condition. In general, higher perceptual sensitivity scores were reported in the fast event rate condition (M = 3.30) than the slow event rate condition (M = 2.54). Probability affected performance when event rate was slow. Children performed better when the probability of a critical event was high (M = 2.70) than when the probability was low (M = 2.37). At the fast event rate, performance was the same (M = 3.30) regardless of the probability.

Laurie-Rose et al. (2005) further investigated the role of event rate by directly comparing the sustained attention performance of adults and children. Thirty-two college age adults and thirty-two children from the second grade completed a 16-minute task. The critical and neutral events were black-outlined white squares presented on a white background. The critical event was the presentation of two equal sized smaller squares and the neutral events were two equal sized larger squares. The stimuli were presented at slow or fast event rates of 45 events per minute (1.3 sec IOI) and 10 events per minute (6 sec IOI), respectively. The probability of a critical event was 0.30 and was held constant for both events. All participants showed greater sensitivity in the fast event rate condition (M = 2.92) than the slow event rate condition (M = 2.53). Participants responded more conservatively (i.e. they produced less false alarms) in the fast event rate condition (M = .30) than the slow event rate condition (M = 0.12). The fast event rate condition also produced faster reaction times (M = 542.61) than the slow event rate condition (M = 714.28).
Intermediate Event Rate Advantage

Several studies of children have introduced the idea that an intermediate (i.e., a rate that is not too fast or too slow) rate may produce optimal sustained attention performance. In a study of event rate and stimulus display time in a sustained attention task, Chee et al. (1989) investigated the difference in performance between hyperactive and control children. The stimuli, 10 uppercase letters (A, C, D, G, L, M, N, O, T, and X), were presented visually. The critical event was designated the letter X and all the other letters were neutral events. There were three stimulus durations: 0.2, 0.4, and 0.8 seconds. The IOIs were 1, 2, 4 seconds, which produced event rates of 60 (fast), 30 (intermediate), and 15 (slow) events per minute. Each child completed tasks at all three event rates with three different stimulus durations. The probability of a critical event was set at 0.1 for all event rates. Accuracy was poorest for the shortest stimulus duration, indicating that stimulus duration had a significant effect on performance. Regarding event rate the poorest performance, specifically the lowest hit rates, occurred at the fastest and slowest event rates compared to the intermediate event rate. In addition, more false alarms were committed in the slow event rate condition. As reported in previous research, reaction times increased as event rate slowed. These findings suggest that neither fast nor slow event rates are ideal for children, but instead an intermediate event rate is most beneficial to performance.

In a similar study, Van der Meere and Stemerdink (1999) used IOIs of 1, 4, and 8 seconds to investigate sustained performance in children with ADHD. These stimulus intervals create event rates of 60 (fast), 10 (intermediate), and 7.5 (slow) events per minute. During each trial, three stars and one letter were presented on the screen. The critical event was the letter P and the presentation of the letter R was the neutral event. The participants were separated by age into
three groups: 7- to 8-year-olds, 9- to 10-year-olds, and 11- to 12-years-olds. Each participant completed a 10-minute task at all three event rates. In all the conditions, the younger age group responded more slowly and with more variability than older children. With regard to event rate, the slower the event rate, the slower and more variable the responses. This effect of event rate was most pronounced in the younger children who had the slowest responses in the intermediate and slow condition. More errors occurred in the fast and slow condition than in the intermediate condition. These findings support the suggestion that the intermediate event rate may be optimal for performance in children.

Summary

Previous investigations of event rate have produced inconsistent results. Some studies using visual and auditory tasks with adult have reported superior performance when events were presented at a slow rate compared to a fast event rate (Jerison & Picket, 1964; Parasuraman, 1979; Richter, et al., 1981; Deaton & Parasuraman, 1993). Other studies with adults and children in the visual domain, suggest better performance when events are presented at a fast event rate (Laurie-Rose, et al., 2001; Laurie-Rose et al., 2005). Other studies using more than two event rates report superior performance at an intermediate event rate for children (Chee, et al., 1989; van der Meere & Stemerdingk, 1999). Conflicting findings may be the result of several factors that have co-varied within and between studies.

Factors Influencing the Effects of Event Rate

One factor that may help explain the conflicting claims about the effects of event rate is the probability (frequency) of critical events. Typically, signal (critical event) probability is defined as the ratio of critical events to the total number of events (See et al., 1995). Research with adults and children has indicated that participants correctly identify more critical events in a
high probability condition compared to a low probability condition (Jenkins, 1958; Warm &
Alluisi, 1971; Laurie-Rose et al., 2001). Participants also make more false alarms when the
probability of a critical event is high than when it is low (Baddeley & Colquhoun, 1969; Laurie-
Rose et al., 2001). In the low probability condition participants are more conservative, whereas,
they are less cautious in the high probability condition (Baddeley & Colquhoun, 1969;
Parasuraman & Davies, 1977; Laurie-Rose et al., 2001). With regard to reaction times, adults
and children react faster when the probability of a critical event is high than when the probability
is low (Jenkins, 1958; Warm & Alluisi, 1971, Laurie-Rose et al., 2001).

Considering the numerous effects of changing signal probability, several of the previous
studies examining event rate may draw some criticism. For example, the initial investigation of
event rate by Jerison and Pickett (1964) held the number of critical events constant for both the
fast and slow event rates. As a result of this manipulation, the probability of a critical event in
the slow condition was greater than in the fast event rate condition (Davies & Parasuraman,
1982). Thus, some of the reported differences between the fast and slow event rates may be a
result of shifts in response bias rather than the effects of event rate. Varying levels of signal
probability make it difficult to make comparisons between studies and generalize the results. To
address this issue, the present study held signal probability constant across all event rate
conditions.

A second factor that may help to explain some of the inconsistent findings regarding
event rate is the difference in the performance measures reported in each study. Limiting
performance measures to proportion correct detections (hits) and proportion false detections
(false alarms) may not provide a clear understanding of task performance. Simply reporting
changes in hits or false alarms does not necessarily distinguish between an observer’s perceptual
abilities ($d'$) and response bias ($c$). For example, if two individuals have the same proportion of hits, but different percentages of false alarms they will have different perceptual abilities ($d'$ scores) and response biases ($c$ scores). Thus, poor performance during a task may be the result of decreased perceptual abilities or a change in response bias (Green & Swets, 1966; Macmillan & Creelman, 1991; See et al., 1997). Several of the event rate studies that only reported hits and/or false alarms (Jerison & Pickett, 1964; Van der Meere, et al., 1999; Chee et al., 1989), may have revealed different effects of event rate on performance if $d'$ and $c$ were also calculated. In order to accurately assess performance, the present study used the signal detection measures of $d'$ and $c$, in addition to hits, false alarms, and reaction times.

Another factor that affects performance in CPTs is type of task discrimination. Stimuli in a sustained attention task can be presented simultaneous or successively (Parasuraman, 1979). Simultaneous tasks present stimuli at the same time and allow participants to make comparative judgments of the stimuli. An example of a simultaneous task is the detection of a pure tone in a noise burst. Successive tasks present stimuli at different times, one after another. This type of task requires participants to make absolute judgments based on their memory of the critical and neutral events (Parasuraman, 1979). An example of a successive task is the discrimination between a large square and a small square, which are presented on a computer screen one at a time. In this task, participants compare the square presented on the screen to a representation of the critical and neutral event stored in memory. Successive tasks are often considered more difficult than simultaneous tasks, because they involve a memory component. The stimuli presented in a CPT can also be sensory or cognitive in nature. The critical events in a sensory task involve changes in the physical characteristics of the stimuli, while cognitive tasks use alphanumeric or symbolic stimuli (See, et al., 1995).
Combining different types of tasks and stimuli lead to important differences in sustained attention performance. For example, Parasuraman (1979) found that event rate affected performance more in a successive task than in a simultaneous task. Research on the differences between sensory and cognitive tasks suggests that sensory tasks may be more susceptible to the effects of extended time on task than cognitive stimuli. However, as discussed previously, Deaton and Parasuraman (1993) found that the effects of event rate were greater for cognitive tasks than sensory tasks. In order to control for task and stimulus type, the present study utilized successive visual and auditory tasks with sensory stimuli.

Another factor that may account for the differences in event rate results is task duration. The duration of the sustained attention tasks investigating event rate ranged from 10 minutes to 80 minutes. Task duration is important when average performance is measured, because as time on task increases, performance tends to decline. It is also important when exploring different event rates. When signal probability is held constant, more critical events will be presented in the fast event rate condition than the intermediate or slow event rate conditions. According to theories of habituation, the repeated presentation of events may lead to a decrease in neural responses to stimuli, which results in impairments in the participant’s ability to detect critical events (Davies & Parasuraman, 1982). Therefore, participants will habituate to the fast event rate condition more quickly than slower event rates. The present study explored performance of adults in two different ways. First, time on task was considered; therefore the tasks in the present study had the same task duration for each event rate condition. Results of three 20-minute tasks were compared: 200 trials for the slow rate, 400 trials for the intermediate rate, and 800 trials for the fast rate. This study also explored performance for the same total number of
events presented by only using the first 200 trials in the fast and intermediate event rate conditions and all 200 trials of the slow event rate condition.

The classification of fast, intermediate and slow event rates in each task is another factor that may account for the inconsistent findings of event rate. Although the vigilance taxonomy established a boundary between slow and fast event rates as 24 events per minute (2.5 sec IOI), this is the only guideline for choosing values in an event rate task (Parasuraman & Davies, 1977). In the studies reviewed above, the rates chosen as slow range from 5 to 15 events per minute (12 sec IOI to 4 sec IOI) and the fast rates range from 30 to 60 events per minute (2 sec IOI to 1 sec IOI). The two studies that used a moderate rate chose 10 and 30 events per minute (6 sec IOI to 2 sec IOI) for their intermediate rate. Although, the intermediate rate for both these studies produced the best performance, these rates are very different. Another potential problem is that the intermediate studies used a within subjects design, therefore the optimal rate may be relative to what they have already experienced. In the present study, event rate was a between subjects variable, in order to avoid any potential effect of participants experiencing all three event rates. In addition, the present study compared fast, intermediate, and slow event rates that were within the range of the rates used in previous studies.

Another factor that affects sustained attention performance is event uncertainty. Spatial uncertainty in a CPT requires participants to search a visual display for objects that appear in different positions (Warm & Jerison, 1984). When the spatial location of the stimuli in a task is uncertain, the result is a decline in performance efficiency. Rather than focusing attention on a specific place, participants must broaden their attention to include the entire display in order to detect critical events at all locations (Warm & Jerison, 1984). Similarly, it is not only important where objects appear during a sustained attention task, but also when events are presented.
Temporal uncertainty, often referred to as event asynchrony, is the variation in temporal structure of events (Jones, 1976; Scerbo et al., 1987a). Typically, the events in a CPT appear with temporal regularity, at expected points in time (Davies & Parasuraman, 1982). This allows participants to predict when they need to attend in order to detect critical events. When the events are predictable, observers can take breaks from monitoring the stimuli when they know events will not occur (Jones & Boltz, 1989). However, when events are temporally uncertain, participants cannot predict when the next event will occur. This results in the need to constantly monitor the display in order to detect critical events (Scerbo et al., 1987a). Several studies have reported that temporal uncertainty leads to a greater decline in performance efficiency than tasks that present events regularly (Richter, et al., 1981; Scerbo, et al., 1987a; Scerbo, Warm, & Fisk, 1987b).

In contrast to these studies of sustained attention, other research has been conducted to better understand the effects of more specific timing manipulations, such as rhythmic expectancy, on attention and timing (Jones, Moynihan, MacKenzie, & Puente, 2002; Penel & Jones, 2005). In these tasks, participants experience a sequence of events that establish a temporally regular underlying beat. According to dynamic attending theory, individuals use future-oriented attending to develop temporal predictions about events in order to anticipate when the next event will occur (Jones & Boltz, 1989). In addition, rhythmic expectancies also allow participants to notice events that are early or late compared to the rhythm of the task. The present study sought to explore the effects of rhythmic expectancy on sustained attention performance by presenting a limited number of probe events that occurred early or late relative to the expected (rhythmic) timing of the event stream rather than the manipulating the timing of the entire task.
The use of different sensory modalities is another factor that may account for differences in CPT performance (Davies & Parasuraman, 1982). Although differences between visual and auditory sustained attention tasks have been investigated, the findings remain inconsistent. Early studies in the adult literature report that the speed and accuracy of critical event detection is better for the auditory modality than the visual modality (Baker, Ware, & Sipowicz, 1962; Buckner & McGrath, 1963; Craig, Colquhoun, & Corcoran, 1976). However, a recent study found that participants detected significantly more critical events in the visual task than in the auditory task (Curtindale, Laurie-Rose, Bennett-Murphy, & Hull, in press).

Although adult literature has identified differences between visual and auditory sustained attention, there is limited research on these differences for children (Aylward et al., 2002; Brown, 1982). Research suggests that children develop attention to visual stimuli differently than auditory stimuli (Brown, 1982). In addition, the studies that do exist are primarily clinical in nature (Aylward et al., 2002; Brown, 1982). In an attempt to understand the relationship between visual and auditory sustained attention tasks and to ascertain the effectiveness of using a combination of CPTs for clinical assessments, Aylward et al. (2002) measured sustained attention performance in children referred for evaluations of problems in school performance. Participants completed cognitive CPTs, during which they responded to the presentation of a 1 was followed by a 9 and withheld responses to other combinations of numbers. They reported differences between performance in visual and auditory tasks, with clinical and non-clinical children having fewer hits in the auditory task compared to the visual task. In a similar study, Borgaro, Pogge, DeLuca, Bilginer, Stokes, and Harvey (2003) sought to correlate different versions of CPTs across modalities in adolescent psychiatric patients. Results indicated that participants performed significantly better in the visual task than in the auditory task.
As a review of the literature indicates, performance differences between visual and auditory tasks are still unclear. The results of the effects of modality on sustained attention were conflicting for adults. In some studies the auditory task produced superior performance, while others report superior performance for visual tasks (Baker, et al., 1962; Buckner & McGrath, 1963; Craig, et al., 1976; Curtindale et al., in press). The research with children reports better performance in visual tasks than in auditory tasks. It is clear that more research is necessary to determine the existence of developmental differences in visual and auditory attention for adults and children. The present study investigated whether the visual or auditory task produced superior performance and whether that effect was different for adults and children.

A final factor that may help to explain some of the conflicting findings on the effects of event rate is task difficulty. Task difficulty is an important factor, which must be considered when comparing the results of visual and auditory tasks, as well as the performance of adults and children. Regarding modality, one criticism is that the visual and auditory tasks compared in the literature were different in many ways (Buckner & McGrath, 1963; Loeb & Binford, 1968). The lack of consistency between performance in visual and auditory tasks is likely due to variability in task difficulty and the degree of coupling between the observer and the display (Hatfield & Loeb, 1968; Hatfield and Soderquist, 1970; Loeb & Binford, 1971). Visual tasks are considered loosely coupled, whereas auditory tasks are tightly coupled. In visual tasks, participants are able to move their eyes and heads away from the display, which may cause them to miss the presentation of some stimuli (Hatfield & Loeb, 1968). Auditory tasks are often presented through headphones, leading participants to be ‘tied in’ to the stimulation, making it more difficult for stimuli to be missed (Hatfield & Soderquist, 1970; Loeb & Binford, 1971).
The adult literature suggests that without matching for task difficulty or coupling, the auditory modality yields superior performance data. Tasks designed to control for task difficulty yielded visual and auditory tasks that were more comparable (See et al., 1995). Comparing visual and auditory sustained attention performance equating tasks for difficulty does provide researchers with information about the ability of participants to discriminate the specific stimuli used in the tasks. However, of interest in the present study were the effects of other variables, such as event rate, on visual and auditory performance. Therefore, the present study compared visual and auditory tasks that were equated for difficulty.

In addition to concerns about modality, previous research investigating developmental differences in sustained attention performance identified task difficulty is an important factor to consider when comparing performance of adults and children in the same study (Curtindale et al., in press; Laurie-Rose et al., 2005). In general, children are unable to successfully complete adult tasks, while adults perform at ceiling levels in tasks designed for children. These findings provide insight into adult’s superior sustained attention skills. However, age differences found when exploring other factors, such as event rate, may be due to differences in task difficulty rather than the factor itself. In order to address the issue of task difficulty, the present study created visual and auditory tasks of comparable difficulty for children and adults at an intermediate event rate.

**Overview**

Overall, a number of questions about the effects of event rate and temporal uncertainty on visual and auditory sustained attention performance remain unanswered. First, further research is necessary to determine if an optimal presentation rate exists and if this rate differs for adults and children. Results of previous studies examining event rate are conflicting. There is some
support for superior performance with slow event rates, while other studies suggest an advantage with fast event rates. These inconsistent findings may be due to differences in the task parameters, such as signal probability, incomplete performance measures, type of task discrimination, stimulus type, task duration, rate classification, stimulus uncertainty, sensory modality, or task difficulty. No previous study of event rate has controlled task parameters in a study that directly compared sustained attention performance in children and adults. Of particular interest in this thesis is whether there are modality differences in the effects of event rate on sustained attention performance and whether these differences may be mediated by age. One possibility that has not been previously considered is that effects of event rate may be different for visual and auditory tasks.

Although previous findings report a decline in performance for temporally irregular tasks, the effects of temporally unexpected probes, including critical and neutral events, have not been explored. Research examining effects of rhythmic temporal expectancy in a pitch discrimination task suggests that temporally expected events are highlighted and therefore processed more accurately than unexpected events (Jones, et al., 2002). In contrast, other studies have found temporally unexpected information to be more salient, as indicated by more responding to unexpected events (Penel & Jones, 2005). These results suggest rhythmic expectancy may play an important role in attending. Of particular interest in the present research was whether this work on rhythmic expectancy generalizes to a sustained attention task and whether effects of rhythmic expectancy on attending are mediated by sensory modality and age.

To address these questions, participants completed both visual and auditory sustained attention tasks presented at a fast, intermediate, or slow event rate. Three event rates were used in this study to help determine what happens when event presentation rate speed up and slows
down and whether the effects are different for adults and children in visual and auditory tasks. In addition, a few unexpectedly early and late events were introduced to determine the effects of temporal expectancy. For the visual task, the neutral event was a small square and the critical event was a square that was slightly larger than the neutral event. For the auditory task, the neutral event was a brief tone and the critical event was a brief tone that was slightly higher in frequency than the neutral event. Experiment 1 addressed the issue of task difficulty by creating equivalent visual and auditory sustained attention tasks for adults and children. Experiment 2 explored the developmental effects of event rate and temporal expectancy on visual and auditory sustained attention performance for adults and children.
CHAPTER II. EXPERIMENT 1

The aim of Experiment 1 was to equate (match) the level of task difficulty for adults and children in visual and auditory continuous performance tasks (CPTs) at an intermediate event rate (3 sec IOI). Task difficulty was equated using the signal detection index $d'$, which is a measure of perceptual sensitivity (see Appendix A for information on calculating of $d'$). There is precedent for using $d'$ as a means to calibrate task difficulty (e.g., Davies, Jones, & Taylor, 1984; Laurie-Rose et al., 2005; Curtindale, et al., in press). This method has been successfully used to match task difficulty across modality (e.g., Hatfield & Loeb, 1968), age (Parasuraman, Nestor, & Greenwood, 1989), and across both age and modality (Curtindale et al., in press). In Experiment 1, task difficulty was assessed by having adults and children perform 10 minutes of visual and auditory CPTs. Stimulus differences between the critical and neutral events were varied between subjects until a final sample of adults and children achieved a $d'$ value of $\approx 2.5$ for both the visual and auditory tasks.

Method

Participants

One hundred and three undergraduate students at Bowling Green State University participated in this experiment in return for course credit. Thirty-nine children were recruited from Bowling Green and other nearby communities. They were paid ten dollars for their participation. Parents were asked to report any history of attention problems. Data for participants with either diagnoses or concerns related to attention were not included in the analyses.
Stimuli and Equipment

All aspects of stimulus generation and response collection for the visual and auditory tasks were controlled by the E-prime software package (Schneider, Eschman, & Zuccolotto, 2002). Auditory stimuli were generated on a Dell PC with a 32-bit Soundblaster Live soundcard. A variety of stimulus pairs were tested in order to match to the target $d'$ value of 2.5, a value established as moderately difficult (Craig, 1984). Average $d'$ scores were calculated and the critical stimuli were adjusted until the target value was reached. In the visual task, the neutral event for adults and children was an unfilled 1.25” x 1.25” (31.75 mm x 31.75 mm) square (S) that was held constant in size. The critical event was a larger square (S + $\Delta S$) that was adaptively varied in size across subjects. The squares were outlined by 1mm black lines and presented on a white background. In the auditory task, the neutral event was held constant at 440 Hz (F), for both adults and children. The critical event was a tone with a slightly higher frequency (F + $\Delta F$) that was adaptively varied across subjects.

Procedure

Participants were read the task instructions and were presented with examples of the visual and auditory stimuli. The duration of each task was 12-minutes, including a 2-minute practice followed by a 10-minute testing block. Prior to testing, all participants completed a practice block, consisting of 40 events. Following the practice block, participants experienced a continuous series of 200 test events (comprised of critical and neutral events). Events lasted 100 ms and were presented at an intermediate rate (3 sec IOI). The probability of a critical event was 0.30. In the visual task, participants were asked to discriminate between a small square (S) designated the neutral event and the slightly larger square (S + $\Delta S$) designated the critical event. For both children and adults, the neutral event was held constant in size 1.25” x 1.25” (31.75 mm
Several participants completed the task with critical events at the same ΔS value. Based on their performance, the difference between the critical stimulus and the neutral event (ΔS) was increased or decreased for the next group of participants. If participants produced average $d'$ scores greater than 2.5, ΔS was decreased, whereas if participants produced average scores less than 2.5, ΔS was increased. Similar adaptive procedures were used for the auditory task. In the auditory task, participants were asked to discriminate between a standard tone (F) designated the neutral event and a tone with a slightly higher frequency (F + ΔF) designated the critical event. When were asked to respond to the critical event by pressing a designated button on a response box and withhold responses to the neutral event. For both adults and children, the neutral event was held constant at 440 Hz. All tones were presented through headphones at a comfortable listening level.

Once it was determined that the stimulus differences produced average $d'$ values close to 2.5, a final group of subjects completed the tasks. The visual critical events were 1.39” x 1.39” (35.31 mm x 35.31 mm) and 1.62” x 1.62” (41.15 mm x 41.15 mm) squares, for adults and children, respectively. Thus the critical and neutral event pairs differed for adults by 0.14 in (3.56 mm) and for children by 0.37 in (9.40 mm). These stimuli are shown in Figure 1. The auditory critical events were 458.7 and 475.2 Hz tones, for adults and children, respectively. Thus the critical event and neutral event pairs differed by 18.7 Hz (4.25%) for adults and 35.2 Hz (8%) for children. The results reported below are for 22 adults, ranging in age from 18 to 21 years, with an average of 19 years and 16 children, ranging in age from 7 years, 4 months to 8 years, 10 months, who completed the visual and auditory tasks with the final stimulus values.
Results and Discussion

Perceptual sensitivity scores were calculated for the entire task, for all participants. Mean $d'$ scores were, $2.6 \pm 0.25$, $2.5 \pm 0.26$, $2.2 \pm 0.35$, and $2.5 \pm 0.33$, for the visual task for adults ($n=22$), the auditory task for adults ($n=20$), the visual task for children ($n=11$), and the auditory task for children ($n=12$), respectively. Confirming that tasks were successfully matched for difficulty across age and modality, a 2 (age: child, adult) x 2 (modality: visual, auditory) Univariate Analysis of Variance revealed no significant effect of age [$F(1,61) = 0.43$, MSE = 0.57, $p = .52$] or modality [$F(1,61) = 0.07$, MSE = 0.09, $p = .79$]. There was also no significant interaction between age and modality [$F(1,61) = 0.45$, MSE = 0.60, $p = .51$]. These findings indicate that the values obtained did not differ significantly from one another.

Overall, the results of Experiment 1 show that the final stimulus values for the visual and auditory tasks, reported in Table 1, were approximately equal in difficulty for both the adults and children for the intermediate (3 sec IOI) event rate. Using these stimulus values, four sustained attention tasks were created: 1) a visual task for adults, 2) an auditory task for adults, 3) a visual task for children, and 4) an auditory task for children. These tasks were used in Experiment 2 to assess effects of event rate and temporal expectancy on sustained attention performance of adults and children using events rates that were faster and slower than the intermediate event rate examined in Experiment 1.
CHAPTER III. EXPERIMENT 2

With the tasks equated for difficulty across age and modality at an intermediate event rate, of primary interest in Experiment 2 was the question of whether speeding up and slowing down the event rate would have the same effect on sustained attention performance of adults and children, and whether any observed effects would be same in the visual and auditory modality. Based on previous research, several predictions were generated. Regarding event rate, the first prediction was a slow event rate advantage for adults, specifically in the visual task. Second, an overall fast event rate advantage was predicted for children. For temporal expectancy, it was predicted that participants would more easily detect critical events that were on-time than those that were early or late (Jones & Boltz, 1989; Jones, et al., 2002). However, it was also possible that the participants would attend more to unexpected events than events that were on-time (Penel & Jones, 2005). It was also predicted that the effects of temporal expectancy might be different for visual and auditory tasks. Concerning the unexpected events, it was predicted that early events might be disruptive; therefore the detection of early events would be worse than the detection of late events (Jones, 2004). Using the tasks that were matched in the first experiment, the second experiment investigated these predictions.

Method

Participants

Sixty-three adults who were undergraduate students at Bowling Green State University participated in this experiment in return for course credit. Thirty-seven 7- to 8-year-old children were recruited from the local schools in Northeast and Northwest Ohio. As in Experiment 1, parents were asked to report any history of attention problems. The children were paid fifteen dollars for their participation. Data for participants with either diagnoses or concerns related to
attention were excluded from the final sample. In addition, several participants who chose not to finish both the visual and auditory tasks were also excluded from the final sample. Based on pilot data from the pitch (frequency) discrimination task, adults with extensive musical training were also excluded from the final sample. The final sample consisted of 39 adults, ranging in age from 18 to 27 years, with an average of 19 years and 33 children, ranging in age from 7 years, 1 month to 8 years, 11 months, with an average of 8 years, 2 months.

**Design**

The experiment employed a 2 (age) x 2 (modality) x 3 (event rate) x 3 (temporal expectancy) mixed factorial design. Two age groups of participants (7 – 8 years, 18 – 27 years) completed visual and auditory tasks at one of three event rates: fast (40 events-per-minute), intermediate (20 events-per-minute) or slow (10 events-per-minute). The fast, intermediate and slow event rates corresponded to fixed IOIs of 1500 ms, 3000 ms, and 6000 ms, respectively. The fast and slow event rates in this study were chosen based on the vigilance taxonomy that describes 24 events per minute (2.5 sec IOI) as the boundary between fast and slow rates (Parasuraman & Davies, 1977). In the final sample, similar numbers of adults (n = 12, 13, and 14) and children (n = 12, 10, and 11) were tested at the fast, intermediate and slow event rates, respectively. At each event rate, three levels of temporal expectancy were tested; critical and neutral events occurred early, on-time, or late relative to the regular background rhythm.

**Stimuli and Equipment**

The stimuli and equipment were identical to those developed in Experiment 1. In the visual task, the neutral event was an unfilled 1.25” x 1.25” (31.75 mm x 31.75 mm) square. The critical events were 1.39” x 1.39” (35.31 mm x 35.31 mm) and 1.62” x 1.62” (41.15 mm x 41.15mm) squares, for adults and children, respectively. In the auditory task, the neutral event
was a 440 Hz tone. The critical events were 458.7 and 475.2 Hz tones, for adults and children, respectively. The stimulus values for the visual and auditory are summarized in Table 1.

**Procedure**

All participants completed both the visual and auditory CPTs on separate occasions, at least twenty-four hours apart. Within each age group, half of the participants performed the visual task first followed by the auditory task, while the remainder of the participants performed the tasks in the reverse order. Adults were presented with 40 practice events at each rate, which correspond to durations of 1, 2, and 4 minutes for the fast, intermediate, and slow event rates, respectively. The practice was followed by a 20-minute task, consisting of 800 (fast), 400 (intermediate), or 200 (slow) critical and neutral events. Children were presented with 20 practice events, which correspond to durations of 0.5, 1, and 2 minutes for the fast, intermediate, and slow event rates, respectively. For children, the practice was followed by a 10-minute task, consisting of 400 (fast), 200 (intermediate), or 100 (slow) critical and neutral events.

In each task, 30% of the stimuli were critical events, while the remaining 70% were neutral events. In addition, during the testing sessions, the temporal expectancy of critical and neutral events was varied. For 80% of the critical and neutral events there was a fixed inter-stimulus-intervals based on the tested event rate (i.e. events were on-time with the regular rhythm established by the tested event rate). For the remaining 20% of the trials, however, events occurred 25% early or 25% late relative to the established rhythm of the event stream. A breakdown of the events can be seen in Figure 2.

**Data Analysis**

Evaluation of CPT performance focused on five dependent measures: two independent signal detection indices (perceptual sensitivity, $d'$ and response bias, $c$), proportion correct
detections (hits), proportion false detections (false alarms), and reaction time (RT). See the Appendix for a brief overview of signal detection theory and a description of the calculation of $d'$ and $c$.

**Results**

The results are presented in three sections. First, the efficacies of the matching procedures are considered. Second, effects of event rate are examined for each of the dependent measures: perceptual sensitivity ($d'$), response bias ($c$), hits, false alarms, and RTs for the on-time events only. Third, effects of temporal expectancy are considered. Of primary interest with respect to the temporal expectancy manipulation was whether participants attended to on-time events more efficiently than unexpectedly early and late events.

**Matching**

Perceptual sensitivity $d'$ scores were calculated for the auditory and visual tasks, for all participants at the intermediate event rate. Mean $d'$ scores were and $2.2 \pm 0.25$, $2.2 \pm 0.42$, $2.2 \pm 0.28$, and $1.9 \pm 0.48$, for the visual task for adults, the auditory task for adults, the visual task for children, and the auditory task for children, respectively. All values were slightly less than the target $d'$ value of 2.5. However, of primary interest was whether the tasks were of equal difficulty. To verify that the tasks were equated for difficulty, a 2 (age) x 2 (modality) mixed measures ANOVA was performed on $d'$ for adults and children at the intermediate event rate. The results of the ANOVA support the efficacy of the $d'$ matching procedures used in Experiment 1. There was no significant effect of age [$F(1,21) = 0.22, \text{MSE} = 0.42, p = .64$] or modality [$F(1,21) = 0.15, \text{MSE} = 0.19, p = .70$] at the intermediate event rate. There was also no significant interaction between age and modality [$F(1,21) = 0.31, \text{MSE} = 0.38, p = .58$].
To investigate the effects of matching $d'$ on other performance measures, separate 2 (age) x 2 (modality) mixed measures ANOVA were performed on $c$, hits, false alarms, and RTs. The results of this analysis indicated that tasks matched for $d'$ also produced equivalent scores for most of the other performance measures, but not all. For $c$, hits, and false alarms, there were no significant main effects of age or modality and there was no significant age x modality interaction (all p’s > .05). The one performance measure that was not equated when the tasks were matched for $d'$ was reaction time. RT results showed significant effects of age [$F(1,20) = 9.40, \text{MSE} = 222,161.33, p < .01$] and modality [$F(1,21) = 43.11, \text{MSE} = 430,833.27, p < .01$] at the intermediate event rate, as well as a significant interaction between age and modality [$F(1,21) = 7.27, \text{MSE} = 72,664.51, p = .01$]. Overall, children responded more slowly than adults even when the tasks were matched across the other four dependent measures. In addition, participants responded more slowly in the auditory task than the visual task. In general, adults responded more quickly than did children. This difference was most pronounced in the auditory task. Means and standard errors for $d'$, $c$, hits, false alarms, and RT for the intermediate event rate are presented in Table 2.

Effects of Event Rate

Separate 3 (Event Rate) x 2 (Age) x 2 (Modality) mixed ANOVAs were performed on each of the five dependent measures. The means and standard errors for $d'$, $c$, hits, false alarms and RTs for children and adults in the auditory and visual tasks for fast, intermediate, and slow event rates are reported in Table 2.

Perceptual Sensitivity. Figure 3a and 3b compare adults and children CPT performance for the visual and auditory tasks, respectively. Overall, the ANOVA on $d'$ showed no significant main effects of event rate, age or modality (all p’s > 0.05), but did reveal a significant two-way
interaction between age and modality \[F(1,66) = 9.10, \text{MSE} = 10.57, p < .01\] and a significant three-way interaction between age, modality and event rate \[F(2,66) = 3.54, \text{MSE} = 4.11, p = .04\]. For the visual task (Figure 3a), adults and children performed similarly at the intermediate and slow event rates. However, adult visual perceptual sensitivity scores were lower for the fast event rate than intermediate and slow event rates, while children’s scores were superior at the fast event rate compared to the intermediate and slow event rates.

For the auditory task (Figure 3b), adults and children performed similarly at intermediate and slow event rates, but they again showed a different pattern at the fast event rate. For adults, unlike the lower perceptual sensitivity scores observed in the visual task for the fast event rate, perceptual sensitivity in the auditory task at the fast event rate was better than at the intermediate and slow event rates. For the children, performance at the fast event rate appeared similar on average to their performance at the intermediate and slow event rates. However, closer inspection of the data showed substantial individual differences. At the fast event rate, children’s performance in the auditory task was greatly affected by their ability to complete the task. As can be seen in Figure 3b (good performers), when children were able to do the task, they performed at adult levels. However, some children were unable to discriminate between the high and low pitched tones at the fast event rate, as can be seen in the figure 3b (poor performers). This bimodal distribution for the children did not occur for the intermediate or slow event rates.

**Response Bias.** Figure 4a and 4b compare adult and children CPT performance for the visual and auditory tasks, respectively. Overall, the ANOVA on \(c\) showed no significant main effects of event rate, age or modality (all \(p\)’s > 0.05), but did reveal a significant three-way interaction between age, modality and event rate \[F(2,66) = 3.35, \text{MSE} = 0.65, p = .04\].
Figure 4a reveals that in the visual task, adults were more conservative at the fast event rate than the intermediate or slow event rates. This decrease in responding at the fast event rate is supported by a significant linear trend \[ F(1,38) = 6.36, \text{MSE} = 1.63, p = .02 \]. Although, children responded less (were more conservative) when events were presented at the fast and intermediate event rates than the slow event rate, there was no significant linear trend \( p > .05 \). In addition, at the fast event rate, adults responded less overall than did children. Figure 4b shows that in the auditory task adults and children were both more conservative at the fast event rate than the intermediate and slow event rates. A significant linear trend was found for both adults \( F(1,38) = 4.02, \text{MSE} = 0.43, p = .05 \) and children \( F(1,32) = 10.11, \text{MSE} = 2.52, p < .01 \). In summary, at the fastest event rate, the visual task yielded more conservative responding by adults, while the auditory task produced more conservative responding for children.

**Hits and False Alarms.** The ANOVA on hits showed significant main effects of event rate \( F(2,66) = 3.15, \text{MSE} = 0.11, p = .05 \), age \( F(1,66) = 4.33, \text{MSE} = 0.146, p = .04 \) and modality \( F(1,66) = 6.22, \text{MSE} = 0.23, p = .02 \). The ANOVA also revealed a significant two-way interaction between age and modality \( F(1,66) = 13.15, \text{MSE} = 0.48, p < .01 \) and a significant three-way interaction between age, modality and event rate \( F(2,66) = 6.25, \text{MSE} = 0.23, p < .01 \). Regarding false alarms, the ANOVA revealed a significant main effect of event rate \( F(2,66) = 5.49, \text{MSE} = 0.20, p < .01 \). There were no other main effects or significant interactions (all \( p \)’s > 0.05).

Based on Signal Detection Theory (Macmillan & Creelman, 1991), changes in hits and false alarms determine perceptual sensitivity \( d' \) scores. For example, in the visual task at the fast event rate, the decline in \( d' \) for adults is the result of a decline in correct detections. As can be seen in Table 2, in the visual task, adults correctly detected fewer critical events and produced
lower $d'$ scores at the fast event rate than the intermediate or slow event rates. These changes in correct detections are supported by a significant linear trend $[F (1,38) = 10.32, \text{MSE} = 0.22, p < .01]$. For children, in the visual task, the increase in $d'$ at the fast event rate was driven primarily by changes in false alarms. Table 2 reveals that while children detected a similar number of critical events at all three event rates in the visual task, they committed fewer false alarms at the fast event rate. This decline in false alarms was supported by a significant linear trend $[F (1,32) = 5.95, \text{MSE} = 0.08, p = .02]$. This supports the influence of false alarms on the increase in $d'$ at the fast event rate. Similarly, false alarms affected $d'$ scores for adults in the auditory task. As can be seen in Table 2, adults committed fewer false alarms at the fast event rate compared to the intermediate and slow event rates. This decline in false alarms led to an increase in $d'$ scores, for the fast event rate and is supported by a significant linear trend $[F (1,38) = 4.48, \text{MSE} = 0.15, p = .04]$. 

In addition to producing changes in $d'$, hits and false alarms also influence response bias ($c$). As can be seen in Table 2, in the visual task, adults detected fewer critical events and committed fewer false alarms at the fast event rate than the intermediate and slow event rates. As discussed above, adults’ detections of fewer critical events are supported by a significant linear trend $[F (1,38) = 10.32, \text{MSE} = 0.22, p < .01]$. This conservative response pattern is reflected in greater response bias ($c$) scores at the fast event rate than the intermediate or slow event rates. Table 2 reveals that in the visual task, children detected more critical events at the intermediate and slow event rates than the fast event rate. In addition, children committed the most false alarms at the slow event rate. The differences in false alarms are supported by a significant linear trend $[F (1,32) = 5.95, \text{MSE} = 0.08, p = .02]$. This increase in overall responding at the slow event rate is seen in low response bias ($c$) scores, which reflect less
conservative responding. In the auditory task children and adults were both more conservative at the fast event rate than the intermediate and slow event rates. However, these increases in response bias \((c)\) at the fast event rate were achieved in different ways. As can be seen in Table 2, adults correctly detected a similar percentage of critical events, regardless of event rate. Therefore, the increase in conservatism at the fast event rate was driven by a dramatic decrease in the false alarms. This decline in false alarms is supported by a significant linear trend \([F(1,38) = 4.48, \text{MSE} = 0.15, p = .04]\). Children, however, correctly detected fewer critical events at the fast event rate than intermediate and slow event rates in the auditory task. In addition, although the decline in false alarms was not significant, there was a significant linear trend \([F(1,32) = 5.08, \text{MSE} = 0.16, p = .03]\), which contributed to the increase in response bias \((c)\) at the fast event rate.

Reaction Times. Figure 5a and 5b compare CPT performance of adults and children for the auditory and visual tasks, respectively. Overall, the ANOVA on RT showed a significant main effect of event rate \([F(2,65) = 34.12, \text{MSE} = 1,590,721.55, p = .001]\), age \([F(1,65) = 5.97, \text{MSE} = 278,324.91, p = .017]\), and modality \([F(1,65) = 83.88, \text{MSE} = 1,595,947.70, p = .001]\).

In general, adults responded more quickly overall \((M = 589.63 \text{ ms})\) than children \((M = 678.73 \text{ ms})\), participants responded more quickly to visual critical events \((M = 527.49 \text{ ms})\) than auditory critical events \((M = 740.87 \text{ ms})\), and as event rate slowed reaction times lengthened (i.e. participants responded more slowly). Mean RTs for the fast, intermediate, and slow event rates were \(451 \pm 31.87, 633.13 \pm 32.11, \text{ and } 817.58 \pm 30.76 \text{ ms}\), for the fast, intermediate, and slow event rates, respectively. The ANOVA also revealed a significant two-way interaction between rate and modality \([F(2,65) = 22.31, \text{MSE} = 424,419.55, p < .01]\) and significant two-way interaction between age and modality \([F(1,65) = 5.41, \text{MSE} = 102,946.24, p = .02]\). In the
visual task (Figure 5a), reaction times for adults and children were similar, with the fastest responses to critical events at the fast event rate compared to the intermediate and slow event rates. This finding is supported by significant linear trends for adults \(F(1,38) = 18.24, \text{MSE} = 309,190.46, p < .01\) and children \(F(1,32) = 6.71, \text{MSE} = 96,125.11, p = .02\). As can be seen in the figure, reaction times slowed slightly as event rate slowed. However, the pattern was more dramatic in the auditory task than in the visual task. In the auditory task (Figure 5b), reaction times for adults and children also increased (slowed) as event rate slowed. This finding is supported by significant linear trends for adults \(F(1,38) = 24.34, \text{MSE} = 1,529,896.17, p < .01\) and children \(F(1,38) = 60.80, \text{MSE} = 2,024,579.42, p < .01\). In addition, the slowing of reaction times as event rate slowed in the auditory task was more pronounced for children. There were no other significant interactions (all \(p\)’s > 0.05).

Effects of Temporal Expectancy

Finally, effects of temporal expectancy were examined. For this analysis, separate 2 (Modality) x 3 (Temporal Expectancy) repeated measures ANOVAs were performed on each of the five dependent measures for adults and children.

Adults. Overall, there were no significant main effects of temporal uncertainty for any of the dependent measures (all \(p\)’s > .05). However, Figure 6 shows a significant two-way interaction between modality and expectancy. Adult participants were significantly more conservative when responding to early events in the visual task than in the auditory task, whereas on-time and late events produced similar levels of responding for both visual and auditory tasks. These findings are supported by a significant two-way interaction between modality and expectancy \(F(2,72) = 4.59, \text{MSE} = 0.47, p = .01\). The effects of temporal expectancy on response bias are also supported by participants’ proportion of hits and false alarms.
Examination of Figure 7 reveals that participants correctly detected fewer early events in the visual task than in the auditory task. For the visual task, this result is supported by a significant linear trend \[ F(1,36) = 4.41, \text{MSE} = 0.13, p = .04 \]. In addition, there was a significant quadratic trend of expectancy for the visual task \[ F(1,36) = 9.87, \text{MSE} = 0.06, p < .01 \]. Similar to response bias, correct detections of on-time and late events were comparable in the visual and auditory tasks. In addition, Figure 8 shows that participants committed fewer false alarms for early events in the visual task than in the auditory task. When events occurred on-time or late, proportions of false alarms in the visual and auditory tasks were similar. These results are supported by significant two-way interaction between modality and expectancy for hits \[ F(2,72) = 4.39, \text{MSE} = 0.06, p = .016 \] and false alarms \[ F(2,72) = 4.16, \text{MSE} = 0.03, p = .02 \].

**Children.** Overall, there were no significant main effects of or interactions between event rate, modality, or temporal uncertainty for hits, false alarms, \( d' \), or \( c \) (all \( p \)'s > .05). However, Figure 9 shows a significant two-way interaction between modality and expectancy. In the visual task, the early events produced the slowest reaction times. However, in the auditory task, reaction times were fastest for the early events. These results are supported by a significant two-way interaction between modality and expectancy \[ F(2,56) = 4.42, \text{MSE} = 249,405.87, p = .016 \] for reaction time. The findings in the visual task are supported by a significant linear trend of reaction time \[ F(1,30) = 13.33, \text{MSE} = 169,409.51, p < .01 \].

**Discussion**

In general, the results of Experiment 2 reveal differential effects of event rate for adults and children, in the visual and auditory tasks. The results of the visual task for adults support the previously established inverse relationship between performance and event rate. However, the auditory task did not support this relationship. Instead, when the rate of the auditory task
increased adult performance improved, revealing a fast event rate advantage. The picture for children is a little more complicated, given the large individual differences observed in the auditory task. In the visual task, children revealed a fast event rate advantage; that is, performance was best when event rate was fast. In the auditory task, performance of children who were able to complete the task at the fast event rate was at adult levels and was better than children who completed the task at the intermediate and slow event rates. However, performance of children who were unable to differentiate the high and low pitch tones at the fast event rate was at chance levels and was worse than children who completed the task at the intermediate and slow event rates. In general, children who were able to complete the visual and auditory tasks at the fast event rate performed better than children who complete the tasks at intermediate and slow event rates.

Regarding expectancy, results differed for the visual and auditory tasks. For adults, early events in the visual task yielded more conservative responding than on-time or late events. This result is consistent with Jones et al. (2002), which reported less accurate responding to unexpected events compared to events that are on-time. However, the results of the auditory task suggest that early events were more salient than on-time or late events. Participants responded more (were less conservative) to early events than on-time and late events. The pattern of results was similar for children in the visual and auditory task. In the visual task reaction times were the slowest for early events, supporting the results of Jones et al. (2002). In the auditory task, reaction times were faster to early events than on-time and late events.
CHAPTER IV. GENERAL DISCUSSION

The present study sought to create comparable visual and auditory sustained attention tasks in order to make developmental comparisons concerning the effects of event rate, expectancy, and modality on sustained attention performance. To achieve that goal, an initial experiment was conducted in which the signal detection index $d'$ was used to equate tasks across modality and age at an intermediate event rate. Once comparable tasks were established, a second experiment explored the effects of speeding up and slowing down the task by adding a fast and slow event rate to the previously established intermediate event rate. Further, the study explored how variations in temporal expectancy might differentially affect performance of adults and children in both the visual and auditory sustained attention tasks. It was predicted that performance would be best when events occurred on-time compared to early and late events. To assess potential effects of temporal expectancy, relatively rare events were introduced that occurred, early or late with respect to the regular background rhythm established by the tested event rate.

The first section of the discussion highlights the efficacy and implications of using perceptual sensitivity $d'$ to equate task difficulty. The second section of the discussion explores the differential effects of event rate on sustained attention performance of adults and children in visual and auditory tasks. The next section discusses the effects of temporal expectancy on sustained attention performance. Finally, the theoretical implications of this research will be discussed.

**Matching Task Difficulty Across Modality and Age**

The present study provides further support for equating task difficulty using the perceptual sensitivity index of $d'$. In the first experiment, I created visual and auditory tasks of
equal difficulty for adults and children, as indicated by the average $d'$ scores, which were similar to the criterion $d'$ value of 2.5. In the second experiment, it was verified that the tasks were of similar difficulty by looking at the results of the intermediate event. Although the average $d'$ scores were slightly lower than the criterion value, they were not significantly different from each other. To further explore the equivalence of the tasks, the other performance measures were compared. The results of this analysis indicated that tasks matched for $d'$ across age and modality produced equivalent scores for $c$, hits, and false alarms. However, there were significant differences in RT for age and modality. Adults responded more quickly than children and all participants responded more quickly in the visual task than in auditory task. The implication of matching performance measures at the intermediate event rate is that it permits an examination of the effects of event rate (speeding up and slowing down the task) and expectancy in the second experiment without the concerns of differences in task difficulty.

Effects of Event Rate

The results are partially consistent with the previous research on the effects of event rate. In general, performance differences for adults and children in the visual and auditory tasks were observed when events were presented at the fast event rate rather than at the intermediate and slow event rates, which yielded similar levels performance. Therefore, this discussion focuses primarily on performance when events were presented at the fast event rate. In order to compare the results of this study to previous work, the effects of event rate are discussed in three separate sections. The first section, perceptual sensitivity, considers $d'$ scores, as well as hits and false alarms, which are the two performance measures signal detection theory utilizes to calculate sensitivity. The second section, response bias, includes participants’ willingness to respond to
stimuli or their levels of conservative responding. The final section explores consistency of the effects of event rate on reaction times in the present study compared to previous findings.

Perceptual Sensitivity

Results of the visual task for adults indicate an inverse relationship between sustained attention performance and event rate. These results are consistent with previous findings on the effects of event rate on sustained attention performance (Jerison & Pickett, 1964). However, the results of the auditory task do not support previous findings of Parasuraman (1979) and Richter et al. (1981), which found that the slow event rate produced better performance than the fast event rate in an auditory task. These studies differ from the present study in many of the factors that were identified in the introduction as influencing performance sustained attention performance including differences in performance measures, task discrimination, task duration, rate classification, stimulus uncertainty, and task difficulty.

A factor that was not addressed in the introduction, but may have led this study to be inconsistent with previous work was the use of a pitch discrimination task. Clément, Demany, and Semel (1999) conducted a study of auditory memory by comparing pitch (frequency) and intensity (loudness) discriminations. Participants completed both pitch and intensity discrimination tasks with IOIs of 0.5, 2, 5, and 10 seconds that varied throughout the trial. Although the shortest IOI yielded the best performance for both types of discrimination, the pitch and intensity discriminations yielded very different patterns of perceptual sensitivity scores across all the IOIs. In the pitch (frequency) judgment task, sensitivity scores increased slightly as the IOI’s were shortened from 10 to 0.5 sec. In the intensity discrimination task, perceptual sensitivity scores were similar for IOIs of 10, 5, and 2 sec and then increased dramatically when the IOI was shortened from 2 to 0.5 sec.
Clément et al.’s (1999) results revealed performance differences between pitch and intensity discriminations that should be taken into account when surveying the auditory event rate literature. Previous studies of the effects of event rate in auditory tasks used discriminations in intensity, requiring participants to discriminate between two tones that differed in loudness (Parasuraman, 1979; Richter et al., 1981). In addition, both studies used a 2 sec IOI as the fast event rate. The fast event rate advantage found in the auditory task of the present study supports Clément et al.’s (1999) finding that sensitivity scores increased steadily as IOI was shortened for pitch discrimination tasks. Previous studies that used intensity discrimination tasks may not have found a fast event rate advantage because their fast event rate was 2 sec IOI, which Clément et al. (1999) found was not fast enough to produce improvements in perceptual sensitivity for intensity discriminations. Perhaps if these studies had introduced a fast rate shorter than a 2 sec IOI, their results would have been more similar to those of Clément et al. (1999) and the present study.

In the present study, children’s performance in the visual task supports a fast event rate advantage. This finding is not consistent with the intermediate event rate advantage, which was reported in previous research done with children using more than two events (Chee et al., 1989; van der Meere & Stemerdink, 1999). However, the results of the visual task are consistent with other previous research using visual tasks with children that report a fast event rate advantage. In the present study, children (if good and poor performers are included) in the auditory task performed similarly regardless of event rate. The results of the auditory task are not consistent with the results of one of the only children’s studies to investigate event rate in an auditory task (Leung, Leung, & Tang, 2000).
Leung, et al. (2000) investigated of event rate and extra-task stimulation in an auditory task for children with ADHD and found a slow event rate advantage. In this study, children committed more false alarms for the fast (M = .05) than for the slow (M = .02) event rate. The omission errors (misses), which are the reverse of hits, were not significantly different for the fast (M = .02) and slow (M = .01) event rates. Although $d'$ was not calculated, the false alarms and misses reported by Leung et al. (2000) can be used to calculate approximate perceptual sensitivity scores. When calculated, $d'$ was in general greater for the slow event rate (M = 4.21) than the fast event rate (M = 3.67). This provides further support for a slow event rate advantage. However, these results must be considered carefully and may differ from the results of the present study for two potential reasons. First, Leung et al. (2000) used a cognitive task, which when combined with a fast event rate has been found to produce poorer performance than a sensory task presented at the same event rate (Deaton & Parasuraman, 1993). Second, Leung et al. (2000) used a 1 sec IOI for the fast event rate, which is faster than the 1.5 sec IOI used in this study. These results may have been closer to those of the present study if an event rate of 1.5 sec IOI was used. It is difficult to compare performance at these two event rates. For example, it is possible that event rates of 1 sec IOI or faster lead to a breakdown in performance regardless of task type. Further research comparing a variety of IOIs is necessary in order to pinpoint the IOI at which performance begins to decline.

Comparing children’s performance to that of adults in the auditory task, there are interesting differences. Adults showed improvement at the fast event rate, while children’s $d'$ scores were similar at all event rates. However, the results begin to look more similar when the bimodal distribution found in the child data is considered. As discussed in the results, children who were able to complete the task above chance levels produced perceptual sensitivity scores
that were comparable to adult scores. Children’s performance improved when events were presented at a fast rate as opposed to the intermediate and slow rates. The bimodal distribution of $d'$ scores for children in the auditory task reflects large individual differences in children’s ability to discriminate pitch. Considering these large individual differences, it is possible that the results of the auditory task for all children in this study are specific to pitch (frequency) discrimination. Using another type of auditory discrimination task, such as duration, might yield similar performance for more of the children.

Response Bias

Considering participants’ willingness to respond to stimuli in the visual task, adults were more conservative at the fast event rate than at the intermediate and slow event rates. This result is consistent with a previous investigation of event rate in the visual modality for adults and children that have reported response bias scores (Laurie-Rose, et al., 2005). The results for children in the present study were not consistent with previous findings. In the visual task, children were less conservative (responded to more events) at the slow event rate than at the fast and intermediate event rates. In the auditory task, response bias scores for adults and children at the fast event rate were different. The results for adults are consistent with previous work done by Richter, et al. (1981) using an auditory task. Although no previous studies that explored the effects of event rate on auditory sustained attention reported response bias scores, the results for the auditory task are similar to those reported previously for children in a visual task (Laurie-Rose et al., 2005).

Reaction Times

In the visual and auditory tasks, participants responded more quickly to critical events in the fast event rate condition than to events that were presented at the intermediate and slow event
rates. This finding is consistent with the results of previous studies of adults and children that have utilized the measurement of reaction time (Chee et al., 1989; Laurie-Rose et al., 2001; Laurie-Rose et al., 2005; Leung, et al., 2000). The effects of event rate were mediated by age and modality. Effects of event rate on reaction time were, however, similar for adults and children. However, in the auditory task, the effect of event rate (as event rate slowed, reaction times also slowed) was more pronounced for children than it was for adults. In addition, adults responded almost 100 ms faster than children across all event rates in the auditory task. These age differences in the auditory task are consistent with previous research that reported more variable and slower responding for younger participants than older participants (Laurie-Rose et al., 2005; Van der Meere and Stemerdingk, 1999). Regarding modality, the effect of event rate on reaction times was more pronounced in the auditory task than the visual task. This result has not been reported previously, because studies of event rate and sustained attention have not reported reactions times for visual and auditory tasks that are compared in the same study. These differential effects of event rate on reaction times may be the result of entrainment in the auditory task. That is, in the auditory task, participants may respond at a regular rhythm, which corresponds to the rate of the task. However, in the visual task, participant responses may rely less on the rate of the task.

Effects of Temporal Expectancy

The present study was the first in the sustained attention literature to explore the effects of temporal expectancy by introducing events that were early or late relative to the regular rhythm of a sustained attention task. As predicted, the effects of temporal expectancy were different for the visual and auditory tasks. In the visual task, the unexpected events yielded more responses than on-time events, while the opposite occurred in the auditory task. In addition, the
early events were more disruptive than the on-time and late events. It is difficult to compare these results with previous investigations of temporal uncertainty in sustained attention, because those tasks manipulated the timing of the entire task by making the appearance of all events uncertain. For example, Scerbo et al. (1987a) investigated the effects of event regularity on sustained attention performance by comparing three levels of synchrony in a visual task. During a 40-minute task, participants were asked to detect an increase in the height of two lines. The presentation of events could be one of three levels of event asynchrony: synchronous, low asynchrony, and high asynchrony. The low asynchrony and high asynchrony conditions produced poorer performance than the synchronous condition. Based on the result it is clear that temporal uncertainty results in poorer performance than tasks in which events are presented regularly. Richter et al. (1981) reported similar results for an auditory task, which explored the effects of event rate and event regularity on performance in an auditory task. In general, participants detected more critical events when events were presented at a regular rhythm compared to the temporally irregular task. In contrast to these studies, the present study explored the effects of a few temporally unexpected events presented in a background of rhythmically expected events.

Although, the differences between the timing manipulations in the present study and previous studies of event rate make the results difficult to compare, there is the large body of work examining temporal expectancy in different types of auditory tasks. In one recent study investigating effect of rhythmic expectancy on pitch identification, Jones, et al., (2002) had participants listen to a standard tone, followed by a series of distractor pitches and a final comparison tone. They were asked to judge whether the pitch of the final comparison tone was higher, lower or the same pitch as the standard. The IOI preceding the comparison tone was
varied in order to create expected and unexpected comparison tones relative to the rhythm of the preceding context. Judgments were most accurate when tones occurred at expected points in time and lowest when tones were unexpected (i.e., they occurred early or late). In a similar study, Penel & Jones (2005) investigated the role of temporal irregularity in a speeded detection task. Participants were presented with sequences of tones and asked to respond when they heard a lower pitched tone in a sequence of high-pitched tones. When events occurred early or late participants committed more false alarms compared to events that were presented on-time relative to the rhythm of the task. Penel and Jones (2005) recognize this difference in false alarms as an increase in overall responding to unexpected events.

The results of the present study were partially consistent with previous findings (Jones et al., 2002; Penel & Jones, 2005). The results of the present study are different from previous studies in two ways. First, this study found that early events were significantly different than on-time and late events, which produced similar levels of performance. Therefore, all expectancy effects are discussed as differences between responses to early events compared to on-time and late events. This asymmetry in responding may be due to the disruptive nature of early events. However, if an event is late, participants may be waiting for it to occur. Second, previous studies investigating the effects of temporal expectancy used only auditory tasks. The present study used a visual and auditory task and found different expectancy effects in each modality. In the visual task, participants detected more critical events when they were on-time and late compared to events that were early. This general decrease in responding to early events is also seen as an increase in response bias scores indicating more conservative responding to early events compared to on-time and late events. In the auditory task, participants responded more to early events compared to the on-time and late events. Specifically, participants committed more false
alarms when events were early compared when they were on-time or late. In addition, participants’ response bias scores were lower, indicating less conservative responding to early events compared to on-time and late events. Regarding children, in the visual task, reaction times were slightly slower to early events than to on-time or late events. In the auditory task, children responded more slowly to on-time events than to events that were early or late. These modality differences in the effects of temporal expectancy on sustained attention are discussed later with regard to theoretical implications.

*Theoretical Implications*

When determining the appropriate theory to explain the effects of event rate, it must be able to account for the differential effects of event rate in the visual and auditory tasks for adults and children. The results of the present study are considered with regard to several theories that have been proposed to explain the various effects of event rate, modality and temporal expectancy on performance.

*Slow Event Rate Advantage*

Researchers have offered several theories to account for the inverse relationship between event rate and sustained attention performance. The first explanation, habituation theory, states that repeated stimulation may reduce or eliminate behaviors (Davies & Parasuraman, 1982). Therefore, in the fast event rate more events occur per minute leading to poorer performance due to greater habituation (Davies & Parasuraman, 1982). Although, there was no significant slow event rate advantage in the current study, performance was poorer at the fast event rate, suggesting a fast event rate disadvantage. In the visual task, adults performed best at the slow rate and worst at the fast rate. Therefore, the results of the visual task were explored in two different ways in order to determine if habituation partially responsible for the inverse
relationship between performance and event rate in the present study. In order to explore the role of habituation in visual task, the entire 20-minute visual task (800 trials for the fast rate, 400 trials for the intermediate rate, and 200 trials for the slow rate) was compared to the first 200 trials of the each task at each event rate. Through this comparison it was possible to determine if the poor performance reported at the fast event rate is consistent with habituation theory. That is, did the overall presentation of more events lead to a decline in performance?

Looking at hits and perceptual sensitivity (\(d'\)), minor performance differences for adults exist between the entire 20-minute task and first 200 events. When the entire task is considered, the hit rates are 0.621, .826, and .833 for the fast, intermediate, and slow event rates respectively. There is clearly an increase in hits when the task slows down. When only the first 200 events are considered, proportions of hits were more similar at 0.768, .833, and .833 for fast, intermediate, and slow event rates, respectively. Although similar proportions of hits were detected across event rate when only 200 events were considered, the pattern of fewer hits at the fast event rate compared to the intermediate and slow event rates remained. Perceptual sensitivity scores reveal a similar pattern. For the entire task, the fast, intermediate, and slow event rates yielded \(d'\) scores of 1.818, 2.18, and 2.2, while the first 200 trials yielded more similar values of 2.169, 2.161, and 2.2 for the fast, intermediate, and slow event rates, respectively. It is possible that habituation is partially responsible for the decrease hits at the fast event rate during the entire 20-minute task. However, this is not conclusive and other theories exist that may better explain the effects of event rate found in the present study.

An alternative explanation to the habituation hypothesis is a fast event rate increases the necessary rate of responding and increases task demands (Jerison, 1970). Therefore, lower hits at the fast event rate may be due to an increase in conservatism, which is an unwillingness to
attend and respond (Richter et al., 1981). According to Richter et al. (1981), the change in responding may reflect a cognitive strategy developed to deal with the increased demands of the fast event rate condition. In order to reduce the demanding pace of attending necessary for detecting critical events, participants set a high criterion for making a response, which decreases the amount of responding. Previous research on the effects of event rate on sustained attention performance has reported fewer correct detections and a greater response bias in the fast event rate condition (Richter, 1981; Laurie-Rose et al., 2005). In the present study, only the visual task for adults supported a slow event rate advantage (fast event rate disadvantage). Therefore, this theory would not be used to address the results of the auditory task for adults, the visual task for children, and the auditory task for children. In the present study, adults were more conservative and had fewer hits at the fast event rate than at the intermediate or slow event rates for the visual task. This increase in conservatism led to a decline in performance and may have been the result of increased task demands. The results for the visual adult task in the present study are consistent with this hypothesis. However, in the auditory task, which revealed a fast event rate advantage, participants were also more conservative at the fast rate than the intermediate and slow rates. Therefore, a mere increase in conservatism does not account for the decline in performance at the fast event rate and this theory is insufficient in fully explaining the effects of event rate.

Fast Event Rate Advantage

To explain the fast event rate advantage for children Laurie-Rose et al. (2005) posit an arousal based account of optimal stimulation theory. According to this theory, children have lower levels of arousal than adults. It has been suggested that the state of an individual may be affected by the presentation rate of stimuli (Sanders, 1983). When combined with less
experience in modulating arousal, these lower levels of arousal may cause the fast event rates to optimize stimulation and lead to improved performance (Zentall & Zentall, 1983). Children also may be more dependent on task variables to regulate attention (Laurie-Rose, et al., 2005), because they are less able to modulate stimuli inwardly (Zentall & Zentall, 1983). Therefore, children may be more affected by the rhythm of a fast event rate task than adults. Further, the fast event rate may be more likely to increase arousal than the slow event rate, leading children to perform better when their arousal is increased. In general, the results of the present study support the idea that a faster event rate may lead to optimal arousal and better performance for children. As stated previously, adults have more experience modulating their arousal, so the rate of presentation may not have influenced their performance to the extent it did for children. Therefore, an interesting question remains about the differences in performance between the visual and auditory task at the fast event rate: why do adults in the present study perform better at the fast event rate compared to the intermediate and slow event rates? It is possible that when other factors (i.e. inappropriate observing) are combined with a fast event rate, they result in a decline in performance in the visual task for adults.

*Differential Effects of Event Rate and Modality*

Inappropriate observing, which is related to coupling or the degree to which participants are connected to the task display, is another explanation for the event rate effect (Warm & Jerison, 1984). In the fast event rate, if participants observe inappropriately, they may miss events. However, the effect of inappropriate observing can depend on whether the task is loosely or tightly coupled. When observers in a visual task, were put in head restraints to make the task more tightly coupled, the effects of event rate decreased (Warm, Wait, & Loeb, 1976). Correct detections in the fast condition increased, however, for the slow event rate, the level of coupling
did not have an effect. In the slow condition, participants detected similar proportions of critical events when the task was closely coupled compared to when it was loosely coupled. These findings indicate that observing might become easier when tasks are closely coupled (Warm & Jerison, 1984). These suggestions indicate that an auditory task, which is typically considered more tightly coupled than a visual task, should not reveal the decline in performance at the fast event rate that has been found in visual tasks. According to this theory, when the loosely coupled visual task is used an increase in inappropriate observing and an overall lower level of responding are possible. Inappropriate observing in this context might be seen as fewer hits and a higher level of conservatism at the fast rate than the intermediate or slow event rates. The increase in inappropriate observing at the fast event rate should be reduced by the tightly coupled nature of the auditory tasks. Therefore, less disparity in between the fast event rate and the intermediate and slow event rates in the auditory task than the visual task would be expected. The results of the present study support this hypothesis. In the visual task, there is a decline hits and false alarms, and an increase in response bias ($c$) as event rate increases. In the auditory task, the hit rate remains very similar across event rates and actually increases slightly at the fast rate. Although there is an increase in conservatism at the fast event rate, in the auditory task, it is much less than the difference between the fast event rate and intermediate and slow event rate in the visual task.

**Effects of Temporal Expectancy**

The differential effects of temporal expectancy on visual and auditory performance may be the result of coupling differences and inappropriate observing. As discussed previously, visual and auditory tasks differ in their degree of coupling. In visual tasks, which are considered loosely coupled, participants may miss stimuli when they move their eyes and heads away from
the display (Hatfield & Loeb, 1968). Auditory tasks, which are often presented through headphones, may make it more difficult for participants to miss stimuli (Hatfield & Soderquist, 1970; Loeb & Binford, 1971). Based on these modality differences it is possible that the differential effects of temporal expectancy are due to coupling differences.

When participants become familiar with the rhythm of the events presented during a task, they develop expectancies. In the visual task participants may use the temporal expectancies they have developed throughout the tasks to predict when they need to attend in order to detect critical events. This allows them to take breaks from monitoring the stimuli when they know events will not occur (Jones & Boltz, 1989). However, participants may miss events if they are unexpectedly early. For example, in the present study participants were conservative in their responses to early critical and neutral events in the visual task. It is possible that participants were looking away from the screen when the early events occurred. The nature of the auditory task makes it difficult for participants to miss the presentation of stimuli. Therefore, events that occur early may be surprising, because they are unexpected. An unexpected tone may result in disruptions participants’ attention in the auditory task. This is evident in the less conservative responding to early events in the auditory task. Participants responded more to early events regardless of whether they were critical or neutral events. Although coupling differences mediate the effects of temporal expectancy on visual and auditory sustained attention tasks, further research is necessary to determine what other factors may also contribute to these differences.

According to dynamic attending theory, individuals can use future-oriented attending to develop expectancies and anticipate the occurrence of events (Jones & Boltz, 1989). This anticipatory attending focuses on the occurrence of future events. When anticipatory attending is
used, participants are able to predict the occurrence of events that are on-time. These expectancy effects highlight expected events rather than events that occur unexpectedly. In addition to future-oriented (anticipatory) attending, individuals can also use reactive attending (Penel & Jones, 2005). Reactive attending occurs when individuals shift their attention toward an unexpected event after it has occurred. This highlighting of unexpected events compared to on-time and predictable events is known as a capture effect (Penel & Jones, 2005).

Results of accuracy (hits) and reaction times have been used to determine the presence of expectancy or capture effects (Penel & Jones, 2005). Expectancy effects produce the highest accuracy for on-time events compared to early and late events. In addition, expectancy effects in studies using speech are reported as faster reaction times for on-time (undistorted) vowel sounds compared to early (shortened) and late (lengthened) vowel sounds (Martin, 1979). Conversely, capture effects yield more false alarms and fewer misses (more hits) to early and late events than on-time events. The increase in false alarms and hits for early and late events, which indicates a capture effect, can also be seen as a decrease in response bias. Capture effects can also be seen in reaction time differences, with slower reaction times to expected events compared to early or late events. The results of Penel and Jones (2005) indicated capture effects based on errors. In their study, participants committed more false alarms to the early and late events than the on-time events.

The results of the present study indicate the presence of capture and expectancy effects. The results of the visual task indicate expectancy effects, while the auditory task supports capture effects. In the visual task, adults responded more to on-time and late events compared to events that were unexpectedly early. This expectancy effect is seen most clearly in decreased response bias scores for on-time and late events compared to early events, indicating more
willingness to respond. In the auditory task, adults committed more false alarms when events were early compared to on-time and late events. In addition, adult responding was less conservative (lower c scores) to early events compared to on-time and late events. The results for children suggest similar differences in the effects of expectancy between the visual and auditory task. In the visual task, children’s reaction times were slightly slower to early events compared to on-time or late events. These faster reaction times to on-time events support an expectancy effect. The auditory task, in contrast, revealed a trend toward capture effects. Although the difference was not significant, children responded more quickly to early and late events compared to events that were on-time.

**Conclusion**

This study investigated the developmental effects of event rate and temporal expectancy on visual and auditory sustained attention performance. The first experiment provides further support for the method of $d'$ matching as a tool for making developmental comparisons of sustained attention performance in auditory and visual tasks. The second experiment revealed differential effects of event rate for adults and children, in the visual and auditory tasks. The results for adults revealed interesting modality differences. The results of the visual task were consistent with the inverse relationship between event rate and performance. However, the auditory task produced a fast event rate advantage; that is, when the event rate increased (became faster) adult performance improved. This result had not been found previously in an auditory sustained attention study. In general for children who were able to complete the tasks above chance levels, the fast event rate lead to improvements in performance in the visual and auditory task. Although habituation theory, inappropriate observing, and arousal theory explain some of the effects of event rate, these theories cannot account for the age and modality differences found
in the present study. Future research should focus on developing a theory that will better explain the differential effects of event rate, age, and modality on sustained attention performance. Regarding expectancy effects, this study attempted to generalize the results of temporal expectancy research to sustained attention. The results were somewhat consistent with previous results and generally supported dynamic attending theory. However, differential effects of temporal expectancy on modality were found. The visual task produced expectancy effects, while the auditory task yielded capture effects. Gaining a better understanding of the effects of sensory modality on sustained attention and temporal expectancy in future research will help identify important developmental differences in auditory and visual attention.
REFERENCES


Table 1
Stimulus Values of Neutral and Critical Events for Adults and Children in the Visual and Auditory Tasks.

<table>
<thead>
<tr>
<th></th>
<th>VISUAL</th>
<th>AUDITORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Event</td>
<td>1.25 in square</td>
<td>440.0 Hz tone</td>
</tr>
<tr>
<td>Critical Event- Adults</td>
<td>1.39 in square</td>
<td>458.7 Hz tone</td>
</tr>
<tr>
<td>Critical Event- Children</td>
<td>1.62 in square</td>
<td>475.2 Hz tone</td>
</tr>
</tbody>
</table>
### Table 2
Performance Measures as a Function of Modality, Event Rate, and Age.

<table>
<thead>
<tr>
<th>Age</th>
<th>Modality</th>
<th>Event Rate</th>
<th>Performance Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean $d'$</td>
</tr>
<tr>
<td>Adults</td>
<td>Visual</td>
<td>Fast (1.5 sec)</td>
<td>1.82 (0.23)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intermediate (3 sec)</td>
<td>2.18 (0.22)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow (6 sec)</td>
<td>2.20 (0.21)</td>
</tr>
<tr>
<td></td>
<td>Auditory</td>
<td>Fast (1.5 sec)</td>
<td>3.09 (0.45)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intermediate (3 sec)</td>
<td>2.23 (0.43)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow (6 sec)</td>
<td>2.09 (0.41)</td>
</tr>
<tr>
<td>Children</td>
<td>Visual</td>
<td>Fast (1.5 sec)</td>
<td>2.53 (0.23)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intermediate (3 sec)</td>
<td>2.17 (0.25)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow (6 sec)</td>
<td>2.05 (0.24)</td>
</tr>
<tr>
<td></td>
<td>Auditory</td>
<td>*Fast (1.5 sec)-G.P.</td>
<td>3.07 (0.67)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fast (1.5 sec)</td>
<td>3.07 (0.45)</td>
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<td></td>
<td></td>
<td>Intermediate (3 sec)</td>
<td>1.86 (0.49)</td>
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<tr>
<td></td>
<td></td>
<td>Slow (6 sec)</td>
<td>1.48 (0.47)</td>
</tr>
<tr>
<td>Mean</td>
<td>Visual</td>
<td>Fast (1.5 sec)</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intermediate (3 sec)</td>
<td>2.18</td>
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<td></td>
<td></td>
<td>Slow (6 sec)</td>
<td>2.13</td>
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<tr>
<td></td>
<td>Auditory</td>
<td>*Fast (1.5 sec)-G.P.</td>
<td>3.08</td>
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<td>Fast (1.5 sec)</td>
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<td></td>
<td></td>
<td>Intermediate (3 sec)</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Slow (6 sec)</td>
<td>1.79</td>
</tr>
</tbody>
</table>
FIGURE CAPTIONS

Figure 1. Critical and neutral events for a) adults and b) children.

Figure 2. Diagram of the proportion of early, on-time, and late critical and neutral events.

Figure 3. Mean Perceptual Sensitivity ($d'$) with standard error bars as a function of age and event rate in the a) visual and b) auditory tasks. In the auditory task, children were separated into good performers (*) and poor performers (+).

Figure 4. Mean Response bias ($c$) with standard error bars as a function of age and event rate in the a) visual and b) auditory tasks.

Figure 5. Mean reaction times (RTs) with standard error bars as a function of age and event rate in the a) visual and b) auditory tasks.

Figure 6. Mean Response bias ($c$) with standard error bars as a function of modality and timing of events for adults.

Figure 7. Proportion of hits with standard error bars as a function of modality and timing of events for adults.

Figure 8. Proportion of false alarms with standard error bars as a function of modality and event timing for adults.

Figure 9. Mean Reaction time (RT) with standard error bars as a function of modality and timing of events for children.
A)

Adult Neutral Event  
Adult Critical Signal

B)

Child Neutral Event  
Child Critical Signal
Event Rate (seconds)

Response Bias (c)

- □ Adults
- ● Children

[Graph showing the relationship between Event Rate (seconds) and Response Bias (c) for adults and children.]
Event Rate (seconds)

Mean RT (ms)

- Adults
- Children
Early On-time Late

Response Bias (c)

Timing of Events

Visual
Auditory
Early On-time Late

Timing of Events

Proportion of Hits

- Visual
- Auditory
Timing of Events

Proportion of False Alarms

- Early
- On time
- Late

Visual
Auditory
Timing of Events

Mean RT (ms)

Early

On time

Late

Visual

Auditory
Signal Detection Theory: Yes-No Experiment (Macmillan & Creelman, 1991)

The present study used Signal Detection Theory as described by Macmillan and Creelman (1991) to determine:

1) Proportion of Hits  
2) Proportion of False Alarms  
3) Participants’ perceptual sensitivity to a stimulus \( d' \)  
4) Participants’ response bias \( c \) or willingness to respond to a stimulus (indicating that it is a critical event)

<table>
<thead>
<tr>
<th>Response</th>
<th>“Yes”</th>
<th>“No”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Event (C)</td>
<td>Hits</td>
<td>Misses</td>
</tr>
<tr>
<td>Neutral Event (N)</td>
<td>False Alarms</td>
<td>Correct Rejections</td>
</tr>
</tbody>
</table>

Conditional Probabilities of Hits and False Alarms:

\[ H = p(“Yes”/C) \quad \text{Hit Rate} \]
\[ F = p(“Yes”/N) \quad \text{False Alarm Rate} \]

Hit rate \( H \) is the proportion of “Large Square” responses when the large square is presented. False alarm rate \( F \) is the proportion of “Large Square” responses when the small square is presented.

\[ d' = z(H) - z(F) \quad \text{Perceptual Sensitivity} \]
\[ c = -\frac{1}{2} [z(H) + z(F)] \quad \text{Response Bias} \]

Where \( z(H) \) and \( z(F) \) are the normalized values of \( H \) and \( F \) and can be obtained from tables of standard normal curve areas.

Higher \( d' \) values indicate greater perceptual sensitivity. If \( d' \) is equal to zero, participants are performing at chance levels.

When \( c \) is equal to zero, the observer is not biased. When \( c \) is less than zero, participants are biased to say that the event is a critical event (less conservative responding). When \( c \) is greater than zero, participants are biased to without a response, indicating that the event neutral (conservative responding).